OPERATION OF WASTEWATER TREATMENT PLANTS

A Field Study Training Program

• ENVIRONMENTAL PROTECTION AGENCY •
• OFFICE OF WATER PROGRAMS •
• DIVISON OF MANPOWER AND TRAINING •

OPERATION OF WASTEWATER TREATMENT PLANTS

A Field Study Training Program

prepared by

Sacramento State College
Department of Civil Engineering

in cooperation with the

California Water Pollution Control Association

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for the

Environmental Protection Agency
Water Quality Office
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1970

PREFACE

The purposes of this home study program are:

a. to develop new qualified treatment plant operators;

b. to expand the abilities of existing operators, permitting better service to both their employers and the public; and

c. to prepare operators for certification examinations.[1]

To provide you with information needed to operate a wastewater treatment plant as efficiently as possible, experienced plant operators prepared the material on treatment plant processes; each chapter begins with an introduction and then discusses start-up, daily operation, interpretation of lab results and possible approaches to solving operational problems. This order of topics was determined during the testing program on the basis of operators' comments indicating the information they needed most urgently. Additional chapters discuss maintenance, safety, sampling, laboratory procedures, hydraulics, records, analysis and presentation of data, and report writing.

Plant influents (raw wastewater) and the efficiencies of treatment processes vary from plant to plant and from location to location. The material contained in this program is presented to provide you with an understanding of the basic operational aspects of your plant and with information to help you analyze and solve operational problems. This information will help you operate your plant as efficiently as possible.

Wastewater treatment is a rapidly advancing field. To keep pace with scientific advances, the material in this program must be periodically revised and updated. This means that you, the operator, must recognize the need to be aware of new advances and the need for continuous training beyond this program.

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[1] Certification examination. An examination administered by a state or professional association that operators take to indicate a level of professional competence. In many states the Chief Operator of a plant must be "certified" (successfully pass a certification examination), and in other states certification is voluntary. Current trends indicate that more states and employers will require operators to be "certified" in the future.

Originally the concepts for this manual evolved from Mr. Larry Trumbull, 1967 Chairman of the Operator Training Committee of the California Water Pollution Control Association. Messrs. Bill Dendy and Kenneth Kerri, Project Directors, investigated possible means of financial support to develop and test the manual and prepared a successful application to the Federal Water Pollution Control Administration (5TT1-WP-16-03). The chapters were written, tested by pilot groups of operators and potential operators, reviewed by consultants and the Federal Water Quality Administration, and rewritten in accordance with the suggestions from these sources.

The project directors are indebted to the many operators and other men who contributed to the manual. Every effort was made to acknowledge material from the many excellent references in the wastewater treatment field. Special thanks are due Messrs. John Brady and William Crooks who both contributed immensely to the manual. Mr. F. J. Ludzack, Chemist, National Training Center, Environmental Protection Agency, Water Quality Office, offered many technical improvements. A note of thanks is also due our typists, Miss Linda Smith, Mrs. Gloria Uri, Mrs. Daryl Rasmussen, Mrs. Vicki Sadlem, Mrs. Peggy Courtney, and Mrs. Pris Jernigan. Illustrations were drawn by Mr. Martin Garrity.

Kenneth D. Kerri

Bill Dendy

1971

INSTRUCTIONS TO PARTICIPANTS

Procedures for reading the lessons and answering the questions are contained in this section.

To progress steadily through this program, you should establish a regular study schedule. For example, many operators in the past have set aside two hours during two evenings a week for study.

The study material is contained in seventeen chapters. Some are longer and more difficult than others. For this reason, many of the chapters are divided into two or more lessons. The time required to complete a lesson will depend on your background and experience. It might take some people an hour to complete a lesson, and some might require three hours, but that is perfectly all right. The important thing is that you understand the material in the lesson!

Each lesson is arranged for you to read a short section, write the answers to the questions at the end of the section, check your answers against suggested answers; and then you decide if you understand the material sufficiently to continue or whether you should read the section again. You will find that this procedure is slower than reading a normal textbook, but you will remember much more when you have finished the lesson.

At the end of the first three chapters, you will find an "objective test." Mark your answers on the IBM answer sheet. In the later chapters you will be asked to answer questions before ("pre-test") you read the chapter. The pre-test indicates to you the important concepts you will find in the lessons. Some discussion and review questions are provided following each lesson in the later chapters. These questions review the important points you have covered in the lesson.

The objective test at the end of each lesson contains true or false, multiple choice, fill in the blank, or match the answers types of questions. The purposes of this exam are to review the chapter and to give experience in taking different types of exams. Mail to the program director only your answers to pre-tests and objective tests on IBM answer sheets.

You are your own teacher in this program. You could merely look up the suggested answers from the answer sheet or copy them from someone else, but you would not understand the material. Consequently, you would not be able to apply the material to the operation of your plant nor recall it during an examination for certification or a civil service position.

You will get out of this program what you put into it.

SUMMARY OF PROCEDURE

A. OPERATOR

1. Marks answers to pre-test on IBM answer sheet (Chapters 4-16).

2. Reads sections in lesson.

3. Writes answers to questions at end of sections in his notebook. You should write the answers to the questions just like you would if these were questions on a test.

4. Checks his answers with suggested answers.

5. Decides whether to reread section or to continue with the next section.

6. Writes answers to discussion and review questions at the end of lessons in his notebook

7. Marks answers to objective test on IBM answer sheet.

8. Mails material to program director.

Professor Kenneth Kerri
Department of Civil Engineering
Sacramento State College
6000 Jay Street
Sacramento, California 95819

B. PROGRAM DIRECTOR

1. Mails lessons in advance to keep operators studying.

2. Corrects tests, answers any questions, and returns results to operator.

C. ORDER OF WORKING LESSONS

To complete this program you will have to work all of the chapters. You may proceed in numerical order, or you may wish to work some lessons sooner. Chapter 15, Basic Mathematics and Treatment Plant Problems, will be mailed to you with Chapter 4 because Chapter 4 requires the use of simple mathematics. If you have trouble with the math in Chapter 4 or some of the following chapters, you may find it helpful to refer to the math chapter, or you may decide to work the math chapter first.

Chapter 14, Laboratory Procedures and Chemistry, will be mailed to you with Chapter 5 because the operation of sedimentation and flotation treatment processes requires some laboratory tests. Again, you may wish to refer to the lab chapter while working on Chapter 5 and the other chapters, or you may wish to work the lab chapter first.

Safety is a very important chapter. Everyone working in a treatment plant must always be safety conscious. You must take extreme care with your personal hygiene to prevent the spread of disease to yourself and your family. Operators in treatment plants daily encounter situations and equipment that can cause a serious disabling injury if the operator is not aware of the potential danger and does not exercise adequate precautions. For these reasons, if you decide to work on the chapter on Plant Safety and Good Housekeeping early, please notify the Project Director and he will be happy to comply with your wish.

COURSE OUTLINE

Chapter	Topic
1	INTRODUCTION, by Larry Trumbull and William Crooks
2	WHY TREAT WASTES? by William Crooks
3	WASTEWATER FACILITIES, by John Brady and William Crooks
4	RACKS, SCREENS, COMMINUTERS, AND GRIT REMOVAL, by Larry Bristow
5	SEDIMENTATION AND FLOTATION, by Elmer Herr
6	TRICKLING FILTERS, by Larry Bristow
7	ACTIVATED SLUDGE, by John Brady
8	SLUDGE DIGESTION AND HANDLING, by John Brady
9	WASTE TREATMENT PONDS, by A. L. Hiatt
10	DISINFECTION AND CHLORINATION, by Leonard Hom
11	MAINTENANCE, by Norman Farnum, Stan Walton, and Roger Peterson
12	PLANT SAFETY AND GOOD HOUSEKEEPING, by Robert Reed
13	SAMPLING RECEIVING WATERS, by Bill Dendy
14	LABORATORY PROCEDURES AND CHEMISTRY, by James Paterson
15	BASIC MATHEMATICS AND TREATMENT PLANT PROBLEMS, by William Crooks
16	ANALYSIS AND PRESENTATION OF DATA, by Kenneth Kerri
17	RECORDS AND REPORT WRITING, by George Gribkoff and John Brady

TECHNICAL CONSULTANTS

William Garber
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Ralph Stowell

CHAPTER 1

INTRODUCTION

by

Larry Trumbull

and

William Crooks

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

CHAPTER 1. INTRODUCTION

This portion of Chapter 1 was prepared especially for the new or the potential wastewater[1] treatment plant operator. If you are an experienced operator, you may find some new viewpoints.

1.0 WHAT IS A TREATMENT PLANT OPERATOR?

Before modern man entered the scene, water was purified in a natural cycle as shown below:

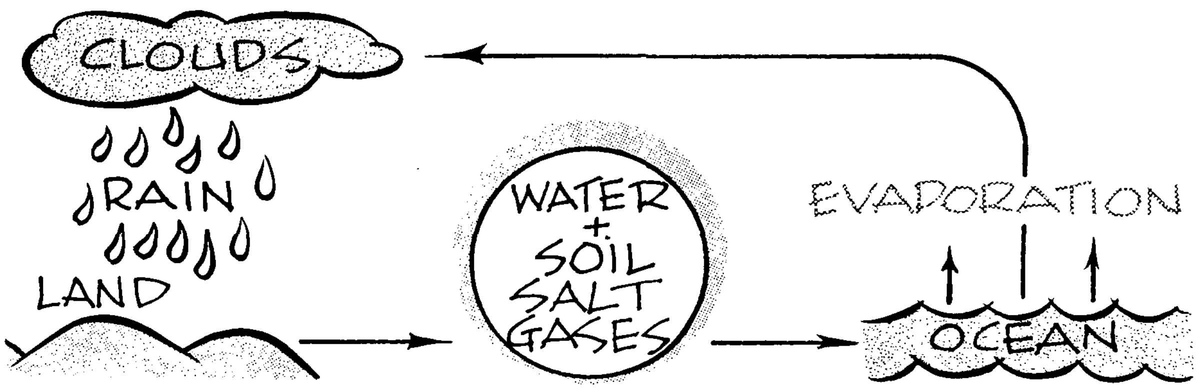

Fig. 1.1 Natural purification cycle

But modern man and his intensive use of the water resource could not wait for sun, wind, and time to accomplish the purification of soiled water; consequently treatment plants were built. Thus, nature was given an assist by a team consisting of designer, builders, and treatment plant operators. Designers and builders occupy the scene only for an interval, but operators go on forever. They are the final and essential link in maintaining and protecting the aquatic environment upon which all life depends.

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[1] Wastewater. The used water and solids from a community that flow to a treatment plant. Storm water, surface water, and groundwater infiltration also may be included in the wastewater that enters a plant. The term sewage usually refers to household wastes, but this word is being replaced by the term wastewater.

1.01 What does a Treatment Plant Operator do?

Simply described, he keeps a wastewater (sewage) treatment plant working. Physically he turns valves, pushes switches, collects samples, lubricates equipment, reads gauges and records data.

Fig. 1.2 The operator's duties

He may also maintain equipment and plant area by painting, weeding, gardening, repairing and replacing. Mentally he inspects records, observes conditions, makes calculations to determine that his plant is working effectively, and predicts necessary maintenance and facility needs to assure continued effective operation of his plant. He also has an obligation to explain to supervisors, councilmen, civic bodies, and the general public what his plant does, and most importantly, why its continued and expanded financial support is vital to the welfare of the community.

1.02 Who does the Treatment Plant Operator work for?

His paycheck usually comes from a city, sanitation district, or other public agency. He may, however, be employed by one of the many large industries which operate their own treatment plants. The operator is responsible to his employer for maintaining an economic and efficiently operating facility. An even greater obligation rests with the operator because the great numbers of people who rely upon downstream water supplies are totally dependent upon the operator's competence and trustworthiness for their welfare. It is these vitally affected people for whom, in the final analysis, the operator is really working.

1.03 Where does the Treatment Plant Operator work?

Obviously he works in a wastewater treatment plant. But the different types and locations of treatment plants offer a wide range of working conditions. From the mountains to the sea, wherever people congregate into communities, will be found wastewater treatment plants. From a unit process operator at a complex municipal facility to a one-man manager of a small town plant, each man can select his own special place in treatment plant operation.

1.04 What pay can a Treatment Plant Operator expect?

In dollars? Prestige? Job satisfaction? Community service? In opportunities for advancement? By whatever scale you use, returns are what you make them. If you choose a large municipality, the pay is good and advancement prospects are tops. Choose a small town and pay may not be as good; but job satisfaction, freedom from time-clock hours, community service, and prestige may well add up to outstanding personal achievement. Total reward depends on you.

1.05 What does it take to be a Treatment Plant Operator?

Desire. First you must choose to enter this profession. You can do it with a grammar school, a high school, or a college degree. While some jobs will always exist for manual labor, the real and expanding need is for trained operators. New techniques, advanced equipment, and increasing instrumentation require a new breed of operator, one who is willing to learn today, and gain tomorrow, for surely his plant will move towards newer and more effective operating procedures and treatment processes. Indeed, the truely service-minded operator assists in adding to and improving his plant performance on a continuing basis.

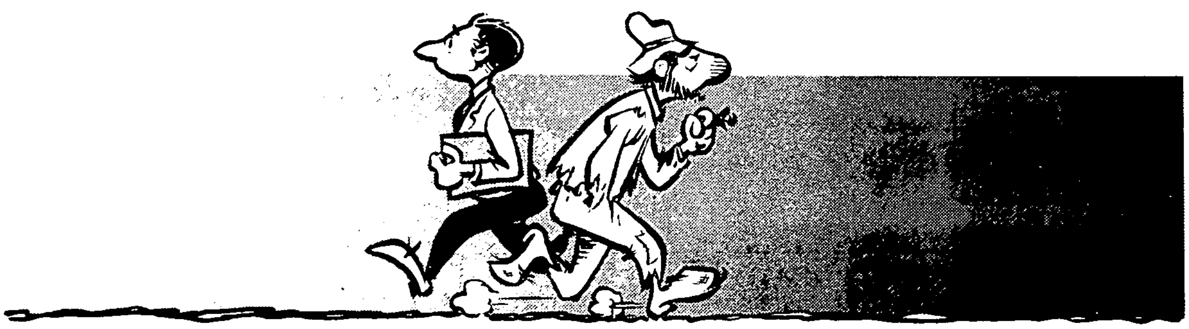

Fig. 1.3 Tomorrow's forgotten man stopped learning yesterday

You can be an operator tomorrow by beginning your learning today; or you can be a better operator, ready for advancement, by accelerating your learning today.

This training course, then, is your start towards a better tomorrow, both for you and for the public who will receive better water from your efforts.

QUESTIONS

Place an X by the correct answer or answers. After you have answered all the questions, check your answers with those given at the end of the chapter on page 1-17. Reread any sections you did not understand and then proceed to the next section. You are your own teacher in this training program, and you should decide when you understand the material and are ready to continue with new material.

EXAMPLE

This is a training course on:

_____ A. Accounting

_____ B. Engineering

__X__ C. Wastewater Treatment Plant Operation

_____ D. Salesmanship

1.0A. Wastewater is the same thing as:

_____ A. Steam

_____ B. Soil

_____ C. Sewage

_____ D. Asphalt

1.0B. What does an operator do?

_____ A. Collect Samples

_____ B. Lubricate Equipment

_____ C. Record Data

1.0C. Who may a Treatment Plant Operator work for?

_____ A. City

_____ B. Sanitation District

_____ C. Industry

Check your answers on Page 1-17.

1.1 YOUR PERSONAL TRAINING COURSE

Beginning on this page you are embarking on a training course which has been carefully prepared to allow you to improve your knowledge and ability to operate a wastewater treatment plant. You will be able to proceed at your own pace; you will have an opportunity to learn a little or a lot about each topic. The course has been prepared this way to fit the various needs of operators, depending on what kind of plant you have or how much you need to learn about it. To study for certification examinations you will have to cover all the material. You will never know everything about your plant or about the wastewater which flows through it, but you can begin to answer some very important questions about how and when certain things happen in the plant. You can also learn to manipulate your plant so that it operates at maximum efficiency.

1.2 WHAT DO YOU ALREADY KNOW?

If you already have some experience operating a wastewater treatment plant, you may use the first three chapters for a review. If you are relatively new to the wastewater treatment field, these chapters will provide you with the background information necessary to understand the later chapters. The remainder of this introductory chapter describes your role as a <u>protector of water quality</u>, your <u>qualifications</u> to do your job, a little about <u>manpower</u> needs in the wastewater treatment field, and some information on other <u>training opportunities</u>.

1.3 THE WATER QUALITY PROTECTOR: YOU

Historically Americans have shown a great lack of interest in the protection of their water resources. We have been content to think that "the solution to pollution is dilution." For years we were able to dump our wastes with little or no treatment back into the nearest receiving water.[2] As long as there was enough dilution water to absorb the waste material, nature took care of our disposal problems for us. As more and more towns and

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[2] Receiving Water. A stream, river, lake, or ocean into which treated or untreated wastewater is discharged.

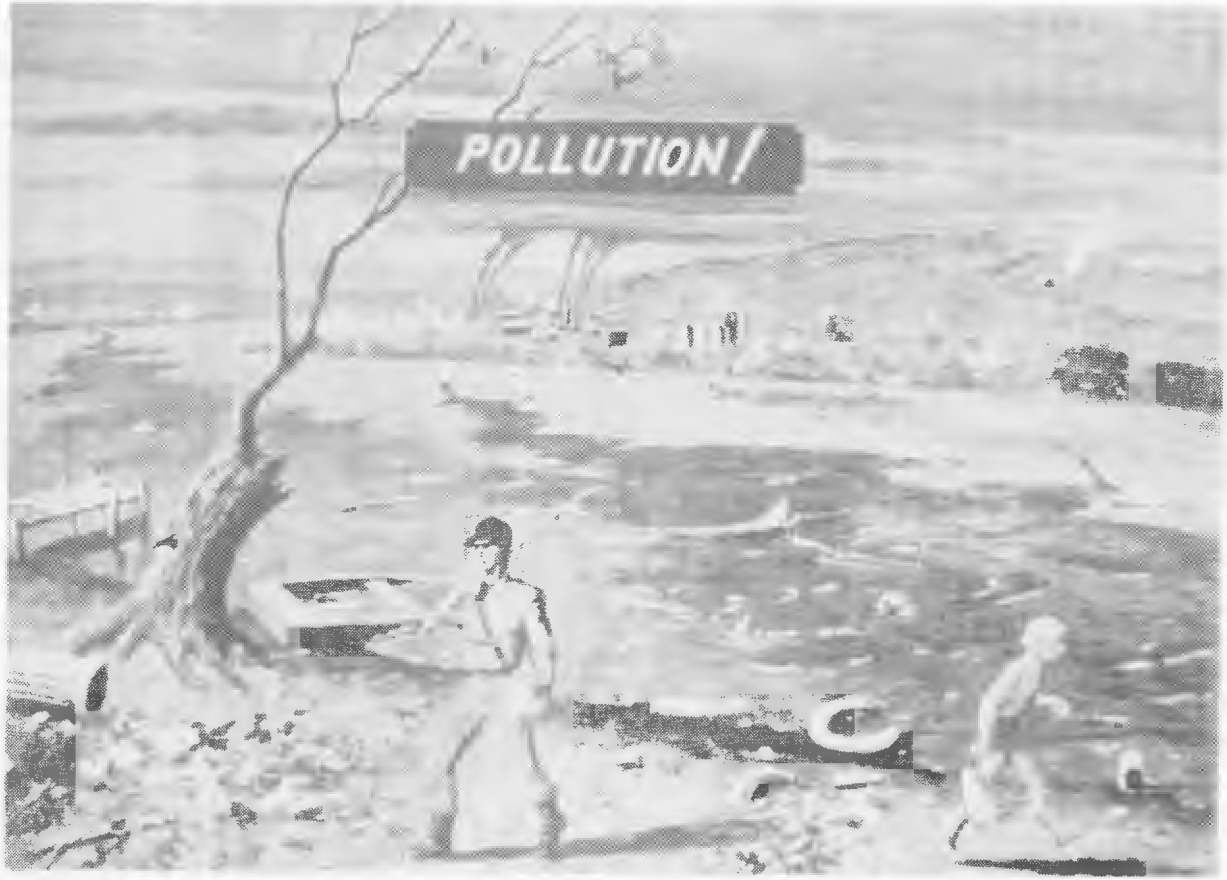

Fig. 1.4 Pollution

Courtesy Water Pollution Control Federation industry sprang up, waste loads increased until the natural purification processes could no longer do the job. Many waterways were converted into open sewers. Unfortunately, for many areas this did not signal the beginning of a clean-up campaign. It merely increased the frequency of the cry: "We don't have the money for a treatment plant," or the ever-popular, "If we make industries treat their wastes they will move to another state". Thus, the pollution of our waters increased (Fig. 1.4).

Within the last few years we have seen many changes in this depressing picture. We now realize that we must give nature a hand by treating wastes before they are discharged. Adequate treatment of wastes will not only protect our health and that of our downstream neighbors, it can also increase property values, allow game fishing and various recreational uses to be enjoyed, and attract water-using industries to the area. Today we are seeing massive efforts being undertaken to control water pollution and improve water quality throughout the nation. This includes the efforts not only of your own community, county and state, but also the federal government.

Great sums of public and private funds are now being invested in large, complex municipal and industrial wastewater treatment facilities to overcome this pollution; and you, the treatment plant operator, will play a key role in the battle. Without efficient operation of your plant, much of the research, planning, and building that has been done and will be done to accomplish the goals of water quality control in your area will be wasted. You are the difference between a facility and a performing unit. You are, in fact, a water quality protector on the front line of the water pollution battle.

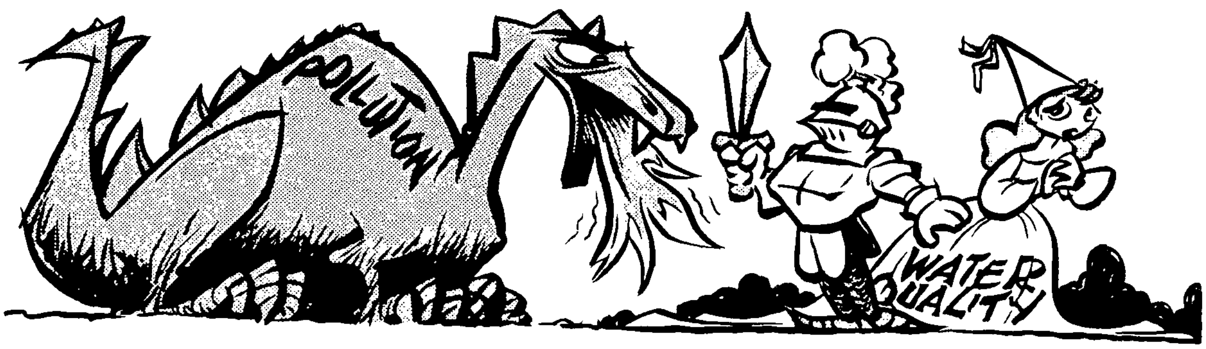

Fig. 1.5 Water quality protector

The receiving water quality standards and waste discharge requirements that your plant has been built to meet have been formulated to protect the water users downstream from your plant. These uses may include domestic water supply, industrial water supply, agricultural water supply, stock and wildlife watering, propagation of fish and other aquatic and marine life, shellfish culture, swimming and other water contact sports, boating, esthetic enjoyment, hydroelectric power, navigation, and others.

Therefore, you have an obligation to the users of the water downstream, as well as to the people of your district or municipality. You are the key water quality protector and must realize that you are in a responsible position.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 1-17.

1.3A Why must municipal and industrial wastewaters receive adequate treatment?

1.3B How did many receiving waters become polluted?

1.4 YOUR QUALIFICATIONS

The skill and ability required for your job depend to a large degree on the size and type treatment plant where you are employed. You may work at a large modern treatment plant serving several hundred thousand persons and employing a hundred or more operators. In this case you are probably a specialist in one or more phases of the treatment process.

On the other hand, you may operate a small plant serving only a thousand people or fewer. You may be the only operator at the plant or, at best have only one or two additional employees. If this is the case you must be a "jack-of-all-trades" because of the diversity of your tasks.

1.41 Your Job

To describe the operator's duties, let us start at the beginning. Let us say that the need for a new or improved wastewater treatment plant has long been recognized by the community. The community has voted to issue the necessary bonds to finance the project, and the consulting engineers have submitted plans and specifications. It is to the best interests of the community and the consulting engineer that you be in on the ground floor planning. If it is a new plant you should be present, or at least available, during the construction period in order to become completely familiar with the entire plant, including the equipment and machinery and its operation. This will provide you with the opportunity to relate your plant drawings to actual facilities.

You and the engineer should discuss how the treatment plant should best be run and the means of operation he had in mind when he designed the plant. If it is an old plant being remodeled, you are in a position to offer excellent advice to the consulting engineer. Your experience provides valuable technical knowledge concerning the characteristics of wastewater, its sources, and the limitations of the present facilities. Together with the consultant, you are a member of an expert team to advise the district or city.

Once the plant is operating, you become an administrator. In a small plant your duties may not include supervision of personnel, but you are still in charge of records. You are responsible for operating the plant as efficiently as possible, keeping in mind that the primary objective is to protect the receiving water quality by continuous and efficient plant performance. Without adequate, reliable records of every phase of operation, the effectiveness of your operation has not been documented (recorded).

You may also be the budget administrator. Most certainly you are in the best position to give advice on budget requirements, management problems, and future planning. You should be aware of the necessity for additional expenditures, including funds for plant enlargement, equipment replacement, and laboratory requirements. You should recognize and define such needs in sufficient time to inform the proper officials to enable them to accomplish early planning and budgeting.

You are in the field of public relations and must be able to explain the purpose and operation of your plant to visitors (Fig. 1.6), civic organizations, school classes, representatives of news media, even to city council or directors of your district. Public interest in water quality is increasing, and you should be

Fig. 1.6 Visitors

prepared to conduct plant tours that will contribute to public acceptance and support. A well-guided tour for officials of regulatory agencies or other operators may provide these people with sufficient understanding of your plant to allow them to suggest helpful solutions to operational problems.

The appearance of your plant indicates to the visitor the type of operation you maintain. If the plant is dirty and rundown with flies and other insects swarming about, you will be unable to convince your visitors that the plant is doing a good job. <u>Your records showing a high-quality effluent will mean nothing to these visiting citizens unless your plant appears clean and well maintained and the effluent looks good.</u>

Fig. 1.7 Special care and safety must be practiced when visitors are taken through your treatment plant. An accident could spoil all of your public relation efforts.

Another aspect of your public relations duties is your dealings with the downstream water user. Unfortunately, the operator is often considered by the downstream user as a polluter rather than a water quality protector. Through a good public information program, backed by facts supported by reliable data, you can correct the impression held by the downstream user and establish "good neighbor" relations (Fig. 1.8). This is indeed a challenge. Again, you must understand that you hold a very responsible position and be aware that the sole purpose of the operation of your plant is to protect the downstream user, be that user a private property owner, another city or district, an industry, or a fisherman.

You are required to understand certain laboratory procedures in order to conduct various tests on samples of wastewater and receiving waters. On the basis of the data obtained from these tests, you may have to adjust the operation of the treatment plant to meet stream standards or discharge requirements.

Fig. 1.8 Clean Water

Courtesy Water Pollution Control Federation

As an operator you must have a knowledge of the complicated mechanical principles involved in many treatment mechanisms. In order to measure and control the wastewater flowing through the plant you must have some understanding of hydraulics. Practical knowledge of electrical motors, circuitry, and controls is essential also.

All operators must be aware of the safety hazards in and around treatment plants. You should plan or be a part of an active safety program. Chief operators frequently have the responsibility of training new operators and should encourage all operators to become certified.

Clearly then, the modern day wastewater treatment plant operator must possess a broad range of qualifications.

QUESTIONS

1.4A Why is it important that the operator be present during the construction of a new plant?

1.4B How does the operator become involved in public relations?

1.5 MANPOWER NEEDS AND FUTURE JOB OPPORTUNITIES

The wastewater treatment field, like so many others, is changing rapidly. New plants are being constructed, and old plants are being modified and enlarged to handle the wastewater from our growing population and to treat the new chemicals being produced by our space age technology. Operators, maintenance personnel, foremen, managers, instrument men, and laboratory technicians are sorely needed.

A look at past records and future predictions indicates that wastewater treatment is a rapidly growing field. In 1967 it was estimated that over $1 billion was spent in the previous year for industrial and municipal waste treatment facilities, and $9 billion in the previous 14 years. Municipalities employed approximately 20,000 operators in 1967, and it was estimated that 30,000 trained operators will be needed by 1972 to operate existing, expanded, and planned new plants.

Fig. 1.9 Trained operators are needed

Industry employed approximately 3500 operators in 1967 and will probably need around 12,000 plant operators by 1972. The need for trained operators is increasing rapidly and is expected to continue in the future.[3]

1.6 TRAINING YOURSELF TO MEET THE NEEDS

This training course is not the only one available to help you improve your abilities. The states have offered various types of both long- and short-term operator training through their health departments or water pollution control agencies. Both local and state water pollution control associations have provided training classes, conducted by members of the associations, largely on a volunteer basis. The Water Pollution Control Federation has developed two visual aid training courses to complement its Manual of Practice No. 11. State and local colleges have provided valuable training under their own sponsorship or in partnership with others. Many state, local and private agencies have conducted both long- and short-term training as well as interesting and informative seminars. The California Water Pollution Control Association has prepared two textbooks, one on laboratory procedures

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[3] Data contained in this paragraph were obtained from "Manpower and Training Needs in Water Pollution Control", Report of the Department of the Interior, Federal Water Pollution Control Administration to the Congress of the United States, Senate Document No. 49, 90th Congress, First Session, Washington, D.C., 1967.

and one on mathematics. Excellent textbooks have been written by many state agencies. Those of the New York State Health Department and the Texas Water Utilities Association deserve special attention.

Listed below are several very good references in the field of wastewater treatment plant operation that are frequently referred to throughout this course. The name in quotes represents the term usually used by operators when they mention the reference.

1. "MOP 11". Operation of Wastewater Treatment Plants, WPCF Manual of Practice No. 11, Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016. Price $2.00 to members; $4.00 to others.

2. "New York Manual". Manual of Instruction for Sewage Treatment Plant Operators, distributed in New York by the New York State Department of Health, Office of Public Health Education, Water Pollution Control Board. Distributed outside of New York State by Health Education Service, P.O. Box 7283, Albany, New York 12224. Price $1.50.

3. "Texas Manual". Manual of Wastewater Operations, prepared by Texas Water Utilities Association. Obtainable from Texas Water Utilities Association, c/o Mrs. Earl H. Goodwin, 2202 Indian Trail, Austin, Texas 78703. Price $10.00.

4. Sewage Treatment Practices, by Don E. Bloodgood, obtainable from Water and Sewage Works Magazine, Scranton Publishing Company, Inc., 35 East Wacker Drive, Chicago, Illinois 60601. Price $1.25.

5. Operator Short Course, by Gerson Chanin, Water and Wastewater Work Book Series/1, Water and Wastes Engineering, Magazine Publishing Division, The Reuben H. Donnelley Corporation, 466 Lexington Avenue, New York, New York 10017. Price $3.00.

These publications cover the entire field of treatment plant operation. At the end of many of the chapters yet to come, lists of other references will be provided.

SUGGESTED ANSWERS

CHAPTER 1. INTRODUCTION

You are not expected to have the exact answer suggested for questions requiring written answers, but you should have the correct idea.

1.0A. C

1.0B. A, B, C

1.0C. A, B, C

1.3A. Municipal and industrial wastewaters must receive adequate treatment to protect receiving water uses.

1.3B. Receiving waters become polluted by a lack of public concern and by discharging wastewater into a receiving water beyond its natural purification capacity.

1.4A. The operator should be present during the construction of a new plant in order to become familiar with the plant before he begins operating it.

1.4B. The operator becomes involved in public relations by explaining the purpose and operation of his plant to visitors, civic organizations, newspaper people, and his supervisors.

DIRECTIONS FOR WORKING OBJECTIVE TEST

CHAPTER 1. INTRODUCTION

1. Complete the answer sheet as shown in the example on the next page.

   Name Doakes, John D.

   Date September 28, 1970

   City Clearwater, California

   1. Time: 1 hour, 10 minutes (include time working tests)

   Instructor Your Program Director

   Name of Test Chapter 1, Objective

2. Mark your answers on the answer sheet.

   For example, Question 1.1 has two correct answers (2 and 3). Therefore, you should place a mark under both Columns 2 and 3 on the answer sheet.

   Questions 1.3 through 1.6 are true or false questions. If a question is true, then mark Column 1, and if false mark Column 2. The correct answer to Question 1.3 is true; therefore, place a mark in Column 1.

3. Be sure to write the time you worked on the lesson, including your time working the tests.

4. Mail IBM answer sheet to your program director.

NAME DOAKES (LAST) JOHN (FIRST) D (MIDDLE) DATE SEPT. 28, 1970 AGE ____ SEX ____ (M OR F)

SCHOOL ____ CITY CLEARWATER, CALIF DATE OF BIRTH ____ GRADE OR CLASS ____ INSTRUCTOR YOUR PROG. DIRECT.

TIME: 1 HOUR, 20 MIN, SOC. SEC. NO. 484-54-1915 NAME OF TEST CHAPTER 1, OBJECTIVE PART

SCORES 1 ____ 2 ____ 3 ____ 4 ____ 5 ____ 6 ____ 7 ____ 8 ____

1	1 2 3 4 5	31	1 2 3 4 5	61	1 2 3 4 5	91	1 2 3 4 5
2	1 2 3 4 5	32	1 2 3 4 5	62	1 2 3 4 5	92	1 2 3 4 5
3	1 2 3 4 5	33	1 2 3 4 5	63	1 2 3 4 5	93	1 2 3 4 5
4	1 2 3 4 5	34	1 2 3 4 5	64	1 2 3 4 5	94	1 2 3 4 5
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13	1 2 3 4 5	43	1 2 3 4 5	73	1 2 3 4 5	103	1 2 3 4 5
14	1 2 3 4 5	44	1 2 3 4 5	74	1 2 3 4 5	104	1 2 3 4 5
15	1 2 3 4 5	45	1 2 3 4 5	75	1 2 3 4 5	105	1 2 3 4 5

BE SURE YOUR MARKS ARE HEAVY AND BLACK.
ERASE COMPLETELY ANY ANSWER YOU WISH TO CHANGE.

16	1 2 3 4 5	46	1 2 3 4 5	76	1 2 3 4 5	106	1 2 3 4 5
17	1 2 3 4 5	47	1 2 3 4 5	77	1 2 3 4 5	107	1 2 3 4 5
18	1 2 3 4 5	48	1 2 3 4 5	78	1 2 3 4 5	108	1 2 3 4 5
19	1 2 3 4 5	49	1 2 3 4 5	79	1 2 3 4 5	109	1 2 3 4 5
20	1 2 3 4 5	50	1 2 3 4 5	80	1 2 3 4 5	110	1 2 3 4 5
21	1 2 3 4 5	51	1 2 3 4 5	81	1 2 3 4 5	111	1 2 3 4 5
22	1 2 3 4 5	52	1 2 3 4 5	82	1 2 3 4 5	112	1 2 3 4 5
23	1 2 3 4 5	53	1 2 3 4 5	83	1 2 3 4 5	113	1 2 3 4 5
24	1 2 3 4 5	54	1 2 3 4 5	84	1 2 3 4 5	114	1 2 3 4 5
25	1 2 3 4 5	55	1 2 3 4 5	85	1 2 3 4 5	115	1 2 3 4 5
26	1 2 3 4 5	56	1 2 3 4 5	86	1 2 3 4 5	116	1 2 3 4 5
27	1 2 3 4 5	57	1 2 3 4 5	87	1 2 3 4 5	117	1 2 3 4 5
28	1 2 3 4 5	58	1 2 3 4 5	88	1 2 3 4 5	118	1 2 3 4 5
29	1 2 3 4 5	59	1 2 3 4 5	89	1 2 3 4 5	119	1 2 3 4 5
30	1 2 3 4 5	60	1 2 3 4 5	90	1 2 3 4 5	120	1 2 3 4 5

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OBJECTIVE TEST

CHAPTER 1. INTRODUCTION

Please mark correct answers on IBM answer sheet.

1.1 The used water and solids from a community that flow to a treatment plant are called ___________?

1. Effluent
2. Wastewater
3. Sewage
4. Mixed Liquor

1.2 Receiving water uses protected by an operator include:

1. Fishing
2. Boating
3. Drinking Water Supply
4. None of These

TRUE OR FALSE:

1.3 In many treatment plants the operator must be a "jack-of-all-trades".

1.4 A treatment plant operator is a water quality protector.

1.5 Plant visitors are impressed by records showing efficient plant operation, and their opinions are never influenced by the appearance of the plant and grounds.

1.6 After finishing this program, an operator will need to continue to study if he is to keep pace with changes occurring in the field.

Please write how long you worked on this chapter on your answer sheet.

CHAPTER 2

WHY TREAT WASTES?

by

William Crooks

TABLE OF CONTENTS

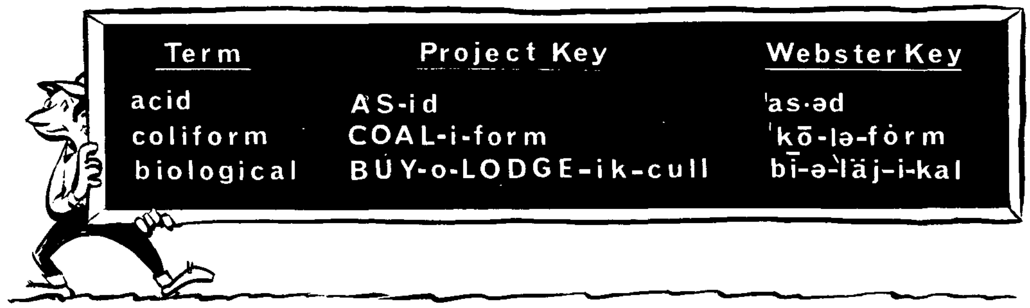
Chapter 2. Why Treat Wastes?

Project Pronunciation Key

by Warren L. Prentice

The project Pronunciation Key is designed to aid you in the pronunciation of new words. While this Key is based primarily of familiar sounds, it does not attempt to follow any particular pronunciation guide. This Key is designed solely to aid operators in this program.

You may find it helpful to refer to other available sources for pronunciation help. Each current standard dictionary contains a guide to its own pronunciation Key. Each Key will be different from each other and from this Key. Examples of the differences between the Key used in this program and the Webster's New World Dictionary Key, College Edition, 1968[1] are shown below:



Term	Project Key	Webster Key
acid	AS-id	'as·əd
coliform	COAL-i-form	'kō-lə-fȯrm
biological	BUY-o-LODGE-ik-cull	bī-ə-'läj-i-kal

In using this Key, you should accent (say louder) the syllable which appears in capital letters. The following chart is presented to give examples of how to pronounce words using the Project Key.

	Syllable				
Word	1st	2nd	3rd	4th	5th
acid	AS	id			
coagulant	co	AGG	you	lent	
biological	BUY	o	LODGE	ik	cull

The first word acid has its first syllable acdented. The second word, coagulant, has its second syllable accented. The third word, biological, has its first and third syllables accented.

We hope you will find the Key useful in unlocking the pronunciation of any new word.

---

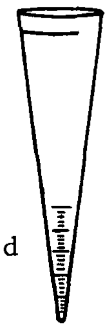
[1] The Webster's New World Dictionary, College Edition, 1968, was chosen rather than an unabridged dictionary because of its availability to the operator.

GLOSSARY

Aerobic Bacteria (AIR-O-bick back-TEAR-e-ah): Bacteria which will live and reproduce only in an environment containing oxygen which is available for their respiration (breathing), such as atmospheric oxygen or oxygen dissolved in water. Oxygen combined chemically, such as in water molecules, H_2O, cannot be used for respiration by aerobic bacteria.

Anaerobic Bacteria (AN-air-O-bick back-TEAR-e-ah): Bacteria that live and reproduce in an environment containing no "free" or dissolved oxygen. Anaerobic bacteria obtain their oxygen supply by breaking down chemical compounds which contain oxygen, such as sulfate (SO_4).

Disinfection (DIS-in-feck-shun): The process by which pathogenic organisms are killed. There are several ways to disinfect, but chlorination is the most frequently used method in water and wastewater treatment.



Imhoff Cone: A clear cone-shaped container marked with graduations used to measure the volumetric concentration of settleable solids in wastewater.

Inorganic Waste (IN-or-GAN-nick): Waste material such as sand, salt, iron, calcium, and other materials which are not converted in large quanitites by organism action. Inorganic wastes are chemical substances of mineral origin and may contain carbon and oxygen, whereas organic wastes are chemical substances of animal or vegetable origin and contain carbon and hydrogen along with other elements.

Milligrams per liter, mg/1 (MILL-i-GRAMS per LEET-er): A measure of the concentration by weight of a substance per unit volume. For practical purposes, one mg/1 is equal to one part per million parts (ppm). Thus, a liter of water with a specific gravity of 1.0 weighs one million milligrams; and if it contains 10 milligrams of dissolved oxygen, the concentration is 10 milligrams per million milligrams, or 10 parts per million (10 ppm).

Nutrients: Substances which are required to support living plants and organisms. Major nutrients are carbon, hydrogen, oxygen, sulfur, nitrogen, and phosphorus. Nitrogen and phosphorus are difficult to remove from wastewater by conventional treatment processes because they are water soluble and tend to recycle.

Organic Waste (or-GAN-nick): Waste material which comes from animal or vegetable origin. Organic waste generally can be consumed by bacteria and other small organisms. Inorganic wastes are chemical substances of mineral origin and may contain carbon and oxygen, whereas organic wastes contain mainly carbon and hydrogen along with other elements.

Pathogenic Organisms (path-o-JEN-nick OR-gan-iz-ums): Bacteria or viruses which can cause disease (typhoid, cholera, dysentery). There are many types of bacteria which do not cause disease and which are not called pathogenic. Many beneficial bacteria are found in wastewater treatment processes actively cleaning up organic wastes.

pH: Technically, this is the logarithm of the reciprocal of the hydrogen-ion concentration, which will be explained in Chapter 14, Laboratory Procedures and Chemistry. For now, it is sufficient to understand that pH may range from 0 to 14, where 0 is most acid and 14 is most alkaline, and 7 is neutral. Most natural waters have a pH between 6.5 and 8.5.

Pollution: Any interference with beneficial reuse of water or failure to meet water quality requirements.

Primary Treatment: A wastewater treatment process consisting of a rectangular or circular tank which allows those substances in wastewater that readily settle or float to be separated from the water being treated.

Secondary Treatment: A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated.

Stabilize: To convert to a form that resists change. Organic material is stabilized by bacteria which convert the material to gases and other relatively inert substances. Stabilized organic material generally will not give off obnoxious odors.

CHAPTER 2. WHY TREAT WASTES?

2.0 PREVENTION OF POLLUTION

The operator's main job is to protect the many users of receiving waters. He must do the best he can to remove any substances which will unreasonably affect these users.

Many people think any discharge of waste to a body of water is pollution. However, with our present system of using water to carry away the waste products of home and industry, it would be impossible and perhaps unwise to prohibit the discharge of all wastewater to oceans, streams, and groundwater basins. It is possible under present day technology to treat wastes in such a manner that existing or potential receiving water uses are not unreasonably affected. Definitions of pollution include any interference with beneficial reuse of water or failure to meet water quality requirements. Any questions or comments regarding this definition must be settled by the appropriate enforcement agency.

2.1 WHAT IS PURE WATER?

Water is a combination of two parts hydrogen and one part oxygen, or H_2O. This is true, however, only for "pure" water such as might be manufactured in a laboratory. Water as we know it is not "pure" hydrogen and oxygen. Even the distilled water we purchase in the store has measurable quantities of various substances in addition to hydrogen and oxygen. Rain water, even before it reaches the earth, contains many substances. These substances, since they are not found in "pure" water, may be considered "impurities". When rain falls through the atmosphere, it gains nitrogen and other gases. As soon as the rain flows overland it begins to

Fig. 2.1 Water + Impurities

dissolve from the earth and rocks such substances as calcium, magnesium, sodium, chlorides, sulfates, iron, nitrogen, phosphorus, and many other materials. Organic matter (matter derived from plants and animals) is also dissolved by water from contact with decaying leaves, twigs, grass, or small insects and animals. Thus it should be realized that a fresh flowing mountain stream may pick up many natural "impurities", some possibly in harmful amounts, before it ever reaches civilization or is affected by the waste discharges of man. Many of these substances, however, are needed in small amounts to support life and be useful to man. Concentrations of impurities must be controlled or regulated to prevent harmful levels in receiving waters.

<u>QUESTIONS</u>

2.1A What are some of the dissolved substances in water?

2.1B How does water pick up dissolved substances?

2.2 TYPES OF WASTE DISCHARGES

The waste discharge that first comes to mind in any discussion of stream pollution is the discharge of domestic wastewater. Wastewater contains a large amount of organic waste.[1] Industry also contributes substantial amounts of organic waste. Some of these organic industrial wastes come from vegetable and fruit packing; dairy processing; meat packing; tanning; and processing of poultry, oil, paper and fiber (wood), and many more.

---

[1] Organic waste (or-GAN-nick). Waste material which comes from animal or vegetable origin. Organic waste generally will be consumed by bacteria and other small organisms. Inorganic wastes are chemical substances of mineral origin and may contain carbon and oxygen, whereas organic wastes contain mainly carbon and hydrogen along with other elements.

Another classification of wastes is inorganic wastes.[2] Domestic wastewater contains inorganic material as well as organic, and many industries discharge inorganic wastes which add to the mineral content of receiving waters. For instance, a discharge of salt brine (sodium chloride) for water softening will increase the amount of sodium and chloride in the receiving waters. Some industrial wastes may introduce inorganic substances such as chromium or copper, which are very toxic to aquatic life. Other industries (such as gravel washing plants) discharge appreciable amounts of soil, sand or grit, which also may be classified as inorganic waste.

There are two other major types of wastes that do not fit either the organic or inorganic classification. These are heated (thermal) wastes and radioactive wastes. Waters with temperatures exceeding the requirements of the enforcing agency may come from cooling processes used by industry and from thermal power stations generating electricity. Radioactive wastes are usually controlled at their source, but could come from hospitals, research laboratories, and nuclear power plants.

QUESTIONS

2.2A Several of the following contain significant quantities of organic material. Which are they?

a. Domestic Wastewater
b. Cooling Water from Thermal Power Stations
c. Paper Mill Wastes
d. Metal Plating Wastes
e. Tanning Wastes

2.2B List four types of pollution.

2.3 EFFECTS OF WASTE DISCHARGES

Certain substances not removed by wastewater treatment processes can cause problems in receiving waters. This section reviews some of these substances and discusses why they should be treated.

---

[2] Inorganic waste (IN-or-GAN-nick). Waste material such as sand, salt, iron, calcium, and other mineral materials which are not converted in large quantities by organism action. Inorganic wastes are chemical substances of mineral origin and may contain carbon and oxygen, whereas organic wastes are chemical substances of animal or vegetable origin and contain mainly carbon and hydrogen along with other elements.

2.30 Sludge and Scum

If certain wastes (including domestic wastewater) do not receive adequate treatment, large amounts of solids may accumulate on the banks of the receiving waters, or they may settle to the bottom to form sludge deposits or float to the surface and form rafts of scum. Sludge deposits and scum are not only unsightly; but if they contain organic material, they may also cause oxygen depletion and be a source of odors. Primary treatment[3] units in the wastewater treatment plant are designed and operated to remove the sludge and scum before they reach the receiving waters.

2.31 Oxygen Depletion

Most living creatures need oxygen to survive, including fish and other aquatic life. Although most streams and other surface waters contain less than 0.001% dissolved oxygen (10 milligrams of oxygen per liter of water, or 10 mg/l),[4] most fish can thrive if there are at least 5 mg/l and other conditions are favorable. When oxidizable wastes are discharged to a stream, bacteria begin to feed on the waste and decompose or break down the complex substances in the waste into simple chemical compounds. These bacteria also use dissolved oxygen (similar to human respiration or breathing) from the water and are called aerobic bacteria.[5] As more organic waste is added, the bacteria reproduce

---

[3] Primary treatment. A wastewater treatment process consisting of a rectangular or circular tank which allows those substances in wastewater that readily settle or float to be separated from the water being treated.

[4] Milligrams per liter, mg/l (MILL-i-GRAMS per LEET-er). A measure of the concentration, by weight of a substance per unit volume. For practical purposes, one mg/l is equal to one part per million parts (ppm). Thus, a liter of water with a specific gravity of 1.0 weighs one million milligrams; and if it contains 10 milligrams of dissolved oxygen, the concentration is 10 milligrams per million milligrams, or 10 milligrams per liter (10 mg/l), or 10 parts of oxygen per million parts of water, or 10 parts per million (10 ppm).

[5] Aerobic bacteria (AIR-O-bick back-TEAR-e-ah). Bacteria which will live and reproduce only in an environment containing oxygen which is available for their respiration, such as atmospheric oxygen or oxygen dissolved in water. Oxygen combined chemically, such as in water molecules, H_2O, cannot be used for respiration by aerobic bacteria.

rapidly; and as their population increases, so does their use of oxygen. Where waste flows are high the population of bacteria may grow large enough to use the entire supply of oxygen from the stream faster than it can be replenished by natural diffusion from the atmosphere. When this happens fish and most other living things in the stream which require dissolved oxygen die.

Fig. 2.2 Oxygen depletion

Therefore, one of the principal objectives of wastewater treatment is to prevent as much of this "oxygen-demanding" organic material as possible from entering the receiving water. The treatment plant actually removes the organic material the same way a stream does, but it accomplishes the task much more efficiently by removing the wastes from the wastewater. Secondary treatment[6] units are designed and operated to use natural organisms such as bacteria in the plant to stabilize[7] and remove organic material.

Another effect of oxygen depletion, in addition to the killing of fish and other aquatic life, is the problem of odors. When

---

[6] Secondary treatment. A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated.

[7] Stabilize. To convert to a form that resists change. Organic material is stabilized by bacteria which convert the material to gases and other relatively inert substances. Stabilized organic material generally will not give off obnoxious odors.

all the dissolved oxygen has been removed, anaerobic bacteria[8] begin to use the oxygen which is combined chemically with other elements in the form of chemical compounds, such as sulfate (sulfur and oxygen), which are also dissolved in the water. When anaerobic bacteria remove the oxygen from sulfur compounds, hydrogen sulfide (H_2S) is released which has a "rotten egg" odor. This gas is not only very odorous, but it also erodes concrete and can discolor and remove paint from homes and structures. Hydrogen sulfide also may form explosive mixtures with air and is capable of paralyzing your respiratory center. Other products of anaerobic decomposition (putrefaction: PU-tree-fack-SHUN) also can be objectionable.

2.32 Other Effects

Some wastes adversely affect the clarity and color of the receiving waters, making them unsightly and unpopular for recreation.

Many industrial wastes are highly acid or alkaline, and either condition can interfere with aquatic life, domestic use, and other uses. An accepted measurement of a waste's acidity or alkalinity is its pH.[9] Before wastes are discharged they should have a pH similar to that of the receiving water.

Waste discharges may contain toxic substances, such as heavy metals or cyanide, which may affect the use of the receiving water for domestic purposes or for aquatic life.

---

[8] Anaerobic bacteria (AN-air-O-bick back-TEAR-e-ah). Bacteria that live and reproduce in an environment containing no "free" or dissolved oxygen. Anaerobic bacteria obtain their oxygen supply by breaking down chemical compounds which contain oxygen, such as sulfate (SO_4) and nitrate (NO_3).

[9] pH. Technically, this is the logarithm of the reciprocal of the hydrogen-ion concentration, which will be explained in Chapter 14, Laboratory Procedures and Chemistry. For now, it is sufficient to understand that pH may range from 0 to 14, where 0 is most acid and 14 is most alkaline, and 7 is neutral. Most natural waters have a pH between 6.5 and 8.5.

Taste- and odor-producing substances may reach levels in the receiving water which are readily detectable in drinking water or in the flesh of fish.

Treated wastewaters contain nutrients[10] capable of encouraging excess algae and plant growth in receiving waters. These growths hamper domestic, industrial, and recreational uses. Conventional wastewater treatment plants do not remove a major portion of the nitrogen and phosphorus nutrients.

QUESTIONS

2.3A What causes oxygen depletion when organic wastes are discharged to the water?

2.3B What kind of bacteria cause hydrogen sulfide gas to be released?

2.33 Human Health

Up to now we have discussed the physical or chemical effects that a waste discharge may have on the uses of water. More important, however, may be the effect on human health through the spread of disease-producing bacteria and viruses. Initial efforts to control human wastes evolved from the need to prevent the spread of diseases. Although untreated wastewater contains many billions of bacteria per gallon, most of these are not harmful to humans, and some are even helpful in wastewater treatment processes. However, humans who have a disease which is caused by bacteria or viruses may discharge some of these harmful organisms in their body wastes. Many serious outbreaks of communicable diseases have been traced to direct contamination of drinking water or food supplies by the body wastes from a human disease carrier.

---

[10] Nutrients. Substances which are required to support living plants and organisms. Major nutrients are carbon, hydrogen, oxygen, sulfur, nitrogen and phosphorus. Nitrogen and phosphorus are difficult to remove from wastewater by conventional treatment processes because they are water soluble and tend to recycle.

Some known examples of diseases which may be spread through wastewater discharges are:

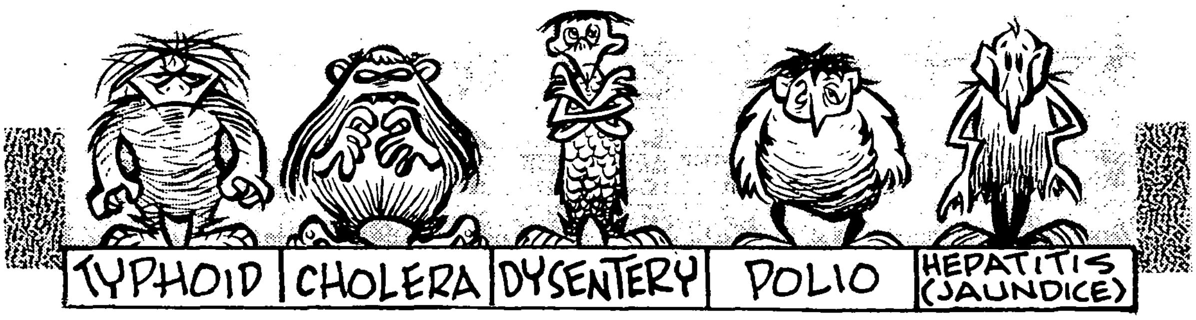


Fig. 2.3 Diseases

Fortunately these organisms that grow in the intestinal tract of diseased humans are not likely to find the environment in the wastewater treatment plant or receiving waters favorable for their growth and reproduction. Although many of these pathogenic organisms[11] are removed by natural die-off during the normal treatment processes, sufficient numbers can remain to cause a threat to any downstream use involving human contact or consumption. If these uses exist downstream, the treatment plant must also include a disinfection[12] process.

The disinfection process historically employed is the addition of chlorine. Proper chlorination of a well-treated waste will usually result in essentially a complete kill of these pathogenic organisms. The operator must realize, however, that

---

[11] Pathogenic organisms (path-o-JEN-nick OR-gan-iz-ums). Bacteria or viruses which can cause disease. There are many types of bacteria which do not cause disease and which are not called pathogenic.

[12] Disinfection (DIS-in-feck-shun). The process by which pathogenic organisms are killed. There are several ways to disinfect, but chlorination is the most frequently used method in water and wastewater treatment.

breakdown or malfunction of equipment could result in the discharge at any time of an effluent which contains pathogenic organisms.

QUESTIONS

2.3C Where do the disease-causing organisms in wastewater come from?

2.3D What is the term which means "disease-causing"?

2.3E What is the most frequent means of disinfecting treated wastewater?

2.4 SOLIDS IN WASTEWATER

One of the primary functions of a treatment plant is the removal of solids from wastewater.

2.40 Types of Solids

In Section 2.2 you read about the different types of pollution: organic, inorganic, thermal, and radioactive. For a normal municipal wastewater which contains domestic wastewater as well as some industrial and commercial wastes, the concern of the treatment plant designer and operator usually is to remove the organic and inorganic suspended solids, to remove the dissolved organic solids (the treatment plant does little to remove dissolved inorganic solids), and to kill the pathogenic organisms by disinfection. Thermal and radioactive wastes require special treatment.

Since the main purpose of the treatment plant is removal of solids from the wastewater, a detailed discussion of the types of solids is in order. Figure 2.4 will help you understand the different terms.

2.41 Total Solids

For discussion purposes assume that you obtain a one-liter sample of raw wastewater entering the treatment plant. Heat this sample enough to evaporate all the water and weigh all the solid material left (residue); it weighs 1000 milligrams. Thus, the total solids concentration in the sample is 1000 milligrams per liter (mg/l). This weight includes both dissolved and suspended solids.

2.42 Dissolved Solids

How much is dissolved and how much is suspended? To determine this you could take an identical sample and filter it through a very fine-mesh filter such as a membrane filter or fiberglass. The suspended solids will be caught on the filter, and the dissolved solids will pass through with the water. You can now evaporate the water and weigh the residue to determine the weight of dissolved solids. In Fig. 2.4 the amount is shown as 800 mg/l. The remaining 200 mg/l is suspended solids. Dissolved solids are also called filterable residue.

2.43 Suspended Solids

Suspended solids are composed of two parts: settleable and nonsettleable. The difference between settleable and nonsettleable solids depends on the size, shape, and weight per unit volume of the solid particles; larger-sized particles tend to settle more rapidly than smaller particles. It is important to know the amount of settleable solids in the raw wastewater for design of settling basins (primary units), sludge pumps, and sludge handling facilities. Also, measuring the amount of settleable solids entering and leaving the settling basin allows you to calculate the efficiency of the basin for removing the settleable solids. A device called an Imhoff Cone[13] is used to measure settleable solids in milliliters per liter, ml/l. (The example in Fig. 2.4 shows a settleable solids concentration of 130 mg/l. The settled solids in the Imhoff Cone had to be dried and weighed by proper procedures to determine their weight.

It is possible to calculate the weight of nonsettleable solids by subtracting the weight of dissolved and settleable solids from the weight of total solids. In Fig. 2.4 the nonsettleable solids concentration is shown as 70 mg/l. Suspended solids are also called nonfilterable residue.

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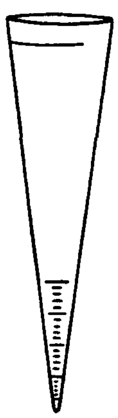
[13] Imhoff Cone. A clear cone-shaped container marked with graduations used to measure the volumetric concentration of settleable solids in wastewater.



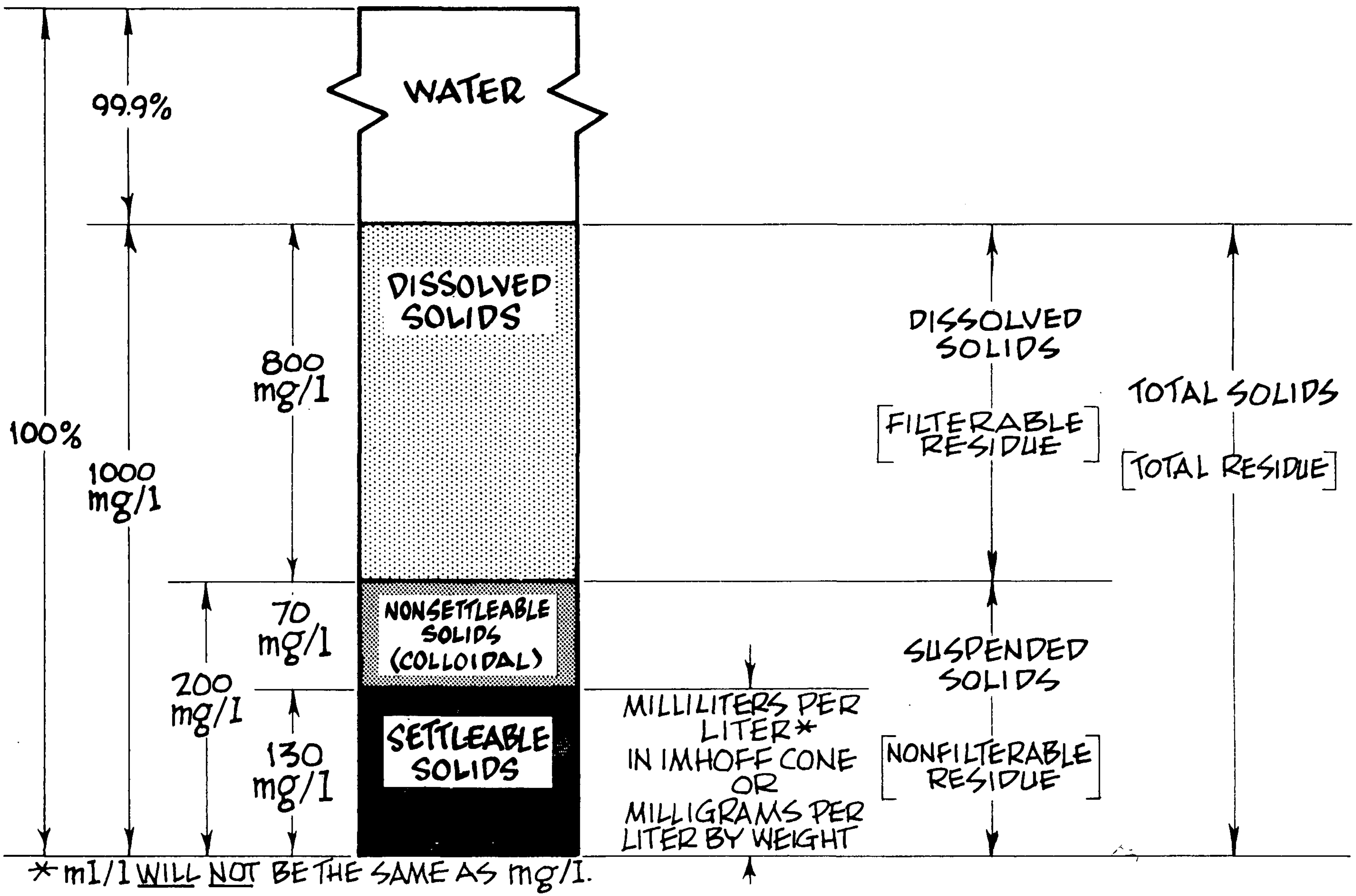


Fig. 2.4 Composition of solids in raw wastewater

2.44 Organic and Inorganic Solids

For total solids or for any separate type of solids, such as dissolved, settleable, or nonsettleable, the relative amounts of organic and inorganic matter can be determined. This information is important for estimating solids handling capacities and for designing treatment processes for removing the organic portion in waste. The organic portion can be very harmful to receiving waters.

2.45 Floatable Solids

There is no standard method for the measurement and evaluation of floatable solids. Since treatment units are designed to remove these solids, it is important for you to be aware of floatable solids in raw wastewater and treated effluent. Floatable solids are undesirable in the plant effluent from an aesthetic viewpoint because the sight of floatables in receiving waters indicates the presence of inadequately treated wastewater.

2.5 ADDITIONAL READING

For a detailed discussion of the physical and chemical composition of wastewater you may wish to refer to:

1. MOP 11, pp 4-7
2. New York Manual, pp 1-10
3. Texas Manual, pp 1-18

QUESTIONS

2.4A An Imhoff Cone is used to measure ______________ solids.

2.4B Why is it necessary to measure settleable solids?

2.4C Total solids are made up of ________________ and __________________ solids, both of which contain organic and inorganic matter.

2.6 REVIEW

In this chapter you have read why it is necessary to treat wastewater, something about the types of waste discharges and their effects, and a brief description of the different kinds of solids in wastewater. This is intended to be only a general discussion of these subjects; you will find more detail in later chapters.

You are now ready to go on to Chapter 3 which deals with a description of the basic elements of the wastewater collection and treatment systems. Chapter 3 actually begins the discussion of how to treat wastewater. Chapter 2 has told you why you need to do so.

Fig. 2.5 "GO"

SUGGESTED ANSWERS

Chapter 2. Why Treat Wastes?

2.1A Some of the dissolved substances in water include oxygen, calcium, carbon, magnesium, chlorides, sodium, sulfates, iron, nitrogen, phosphorus, and organic material.

You should have listed at least three of the items in the answer.

2.1B Water picks up dissolved substances as it falls as rain, flows over land and is used for domestic, industrial, agricultural, and recreational purposes.

2.2A a, c, and e.

2.2B Organic, inorganic, thermal, radioactive.

2.3A Organic wastes in a water provide food for the bacteria. These bacteria require oxygen to survive and consequently deplete the oxygen in the water in a way similar to people breathing.

2.3B Hydrogen sulfide gas is released by anaerobic bacteria.

2.3C Disease-causing organisms in wastewater come from the body wastes of humans who have a disease.

2.3D Pathogenic.

2.3E Chlorination is the most frequent means of disinfecting treated wastewater.

2.4A Settleable.

2.4B Settleable solids must be measured to determine the efficiency of settling basins. This amount must also be known to calculate loads on settling basins, sludge pumps, and sludge handling facilities for design and operational purposes. You should have recognized the need to know the efficiency of settling basins.

2.4C Dissolved and suspended.

OBJECTIVE TEST

Chapter 2. Why Treat Wastes?

Please write your name, date, city, time, instructor, and name of test on your answer sheet, then mark correct answers on answer sheet.

2.1 Wastes are treated to:

1. Prevent Pollution
2. Protect Human Health
3. Remove Harmful Wastes from Wastewater
4. Prevent Receiving Waters from Stinking

2.2 Diseases possibly spread by wastewater discharges include:

1. Typhoid
2. Cholera
3. Q Fever
4. Dysentery
5. Hepatitis (Jaundice)

2.3 Pathogenic bacteria are:

1. Inorganic
2. Disease Producing
3. Easy to See
4. Dissolved Gases
5. None of These

2.4 What does an Imhoff Cone measure?

1. Total Solids
2. Dissolved Solids
3. Settleable Solids
4. Organic Solids
5. Colloidal Solids

Match the definitions on the following page by placing the correct number from the column on the right in the proper space in front of the definition.

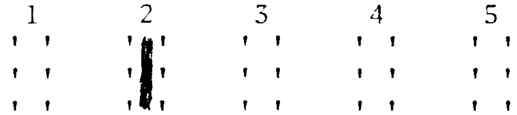
EXAMPLE

__2__ Milligrams per liter.

1. MPL
2. mg/l
3. MPN

Mark Column 2 on your answer sheet:

1 2 3 4 5



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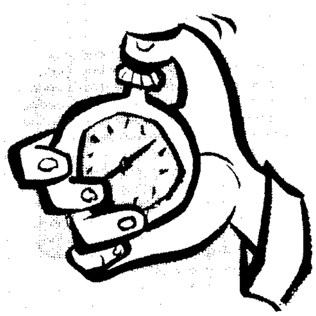
continue test on next page

2.5	________	Waste material which comes from animal or vegetable sources.		
2.6	________	Bacteria which will live and reproduce only in an environment containing dissolved oxygen.	1.	Organic Waste
			2.	Inorganic Waste
			3.	Radioactive Waste
			4.	Aerobic Bacteria
2.7	________	Bacteria which obtain their oxygen by breaking down chemical compounds which contain oxygen, such as sulfates (SO_4).	5.	Anaerobic Bacteri

2.8	________	Bacteria which can cause disease.	1.	Pollution
2.9	________	A process which kills disease-causing bacteria.	2.	Disinfection
			3.	Nutrients
			4.	pH
2.10	________	Any discharge of waste that reduces receiving water quality indicators below the established water quality standards.	5.	Pathogenic Organisms

Please write how long you worked on this chapter on your answer sheet.



CHAPTER 3

WASTEWATER FACILITIES

by

John Brady

and

William Crooks

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Chapter 3. Wastewater Facilities

GLOSSARY

Chapter 3. Wastewater Facilities

Biochemical Oxygen Demand or BOD (BUY-o-KEM-ik-cull OX-zi-gen de-MAND): The BOD indicates the rate of oxygen utilized by wastewater under controlled conditions of temperature and time.

Combined Sewer: A sewer designed to carry both sanitary wastewaters and storm or surface water runoff.

Comminution (com-min-OO-shun): A mechanical treatment process which cuts large pieces of wastes into smaller pieces so they won't plug pipes or damage equipment (shredding).

Detention Time: The time required to fill a tank at a given flow or the theoretical time required for a given flow of wastewater to pass through a tank.

Grit: The heavy mineral material present in wastewater, such as sand, gravel, cinders, and eggshells.

Infiltration (IN-fill-TRAY-shun): Groundwater that seeps into pipes through cracks, joints, or breaks.

Media: The material in a trickling filter over which settled wastewater is sprinkled and then flows over and around during treatment. Slime organisms grow on the surface of the media and treat the wastewater.

Photosynthesis (foto-SIN-tha-sis): A process in which chlorophyll (green plant tissue) converts carbon dioxide and inorganic substances to oxygen and additional plant material, utilizing sunlight for energy. Land plants grow by the same process.

Primary Treatment: A wastewater treatment process consisting of a rectangular or circular tank which allows those substances in wastewater that readily settle or float to be separated from the water being treated.

Sanitary Sewer (SAN-eh-tar-ee SUE-er): A sewer intended to carry wastewater from homes, businesses, and industries. Storm water runoff is sometimes collected and transported in a separate system of pipes.

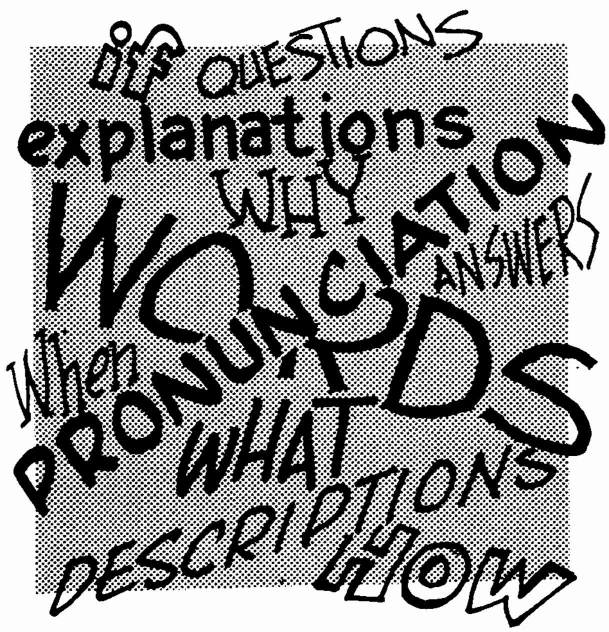
Secondary Treatment: A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated.

Shredding: A mechanical treatment process which cuts large pieces of wastes into smaller pieces so they won't plug pipes or damage equipment (comminution).

Sludge (sluj): The settleable solids separated from liquids during processing or deposits on bottoms of streams or other bodies of water.

Storm Sewer: A separate sewer that carries runoff from storms, surface drainage, and street wash, but that excludes domestic and industrial wastes.

Weir (weer): A vertical obstruction, such as a wall or plate, placed in an open channel and calibrated in order that a depth of flow over the weir can easily be converted to a flow rate in MGD (million gallons per day).



CHAPTER 3. WASTEWATER FACILITIES

3.0 COLLECTION, TREATMENT, DISPOSAL

Facilities for handling wastewater are usually considered to have three major components or parts: collection, treatment, and disposal. For a municipality, these components make up the "sewerage" system or wastewater facilities; but for an individual industry which handles its own wastewater, the same three components are necessary. This training course is directed primarily to plant operators for municipalities, so the discussion in this and later chapters will be in terms of municipal wastewater facilities.

3.1 COLLECTION OF WASTEWATER

Collection and transportation of wastewater to the treatment plant is accomplished through a complex network of pipes and pumps of many sizes.

Major water using industries which contribute waste to the collection system may affect the efficiency of a wastewater treatment plant, especially if there are periods during the day or during the year when these industrial waste flows are a major load on the plant. For instance, canneries are highly seasonal in their operations; therefore, it is possible to predict the time of year to expect large flows from them. A knowledge of the location of commercial and industrial dischargers in the collection system may enable an operator to locate the source of a problem in the plant influent, such as oil from a refinery or a gas station.

The length of time required for wastes to reach your plant can also affect treatment plant efficiency. Hydrogen sulfide gas (rotten egg gas) may be released by anaerobic bacteria feeding on the wastes if the flow time is quite long and the weather is hot; this can cause odor problems, damage concrete in your plant, and make the wastes more difficult to treat. (Solids won't settle easily, for instance.) Wastes from isolated subdivisions located far away from the main collection network often have this "aging" problem.

3.10 Sanitary, Storm, and Combined Sewers

For most sewerage systems the sewer coming into the treatment plant carries wastes from households and commercial establishments in the city or district, and possibly some industrial waste. This type of sewer is called a sanitary sewer.[1] All storm runoff from streets, land, and roofs of buildings is collected separately in a storm sewer,[2] which normally discharges to a water course without treatment. In some areas only one network of sewers has been laid out beneath the city to pick up both sanitary wastes and storm water in a combined sewer.[3] Treatment plants that are designed to handle the sanitary portion of the wastes sometimes must be bypassed during storms due to inadequate capacity, allowing untreated wastes to be discharged into receiving waters. Separation of combined sewers into sanitary and storm sewers is very costly and difficult to accomplish.

Even in areas where the sanitary and storm sewers are separate, infiltration[4] of groundwater or storm water into sanitary sewers through breaks or open joints can cause high flow problems at the treatment plant. Replacement or sealing of leaky sections of sewer pipe is called for in these cases. The treatment plant operator is generally the first to know about infiltration problems because of the unusually high flows he observes at the plant during periods of storm water runoff.

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[1] Sanitary Sewer (SAN-eh-tar-ee SUE-er). A sewer intended to carry wastewater from homes, businesses, and industries.

[2] Storm Sewer. A separate sewer that carries runoff from storms, surface drainage, and street wash, but that excludes domestic and industrial wastes.

[3] Combined sewer. A sewer designed to carry both sanitary wastewaters and storm or surface water runoff.

[4] Infiltration (IN-fill-TRAY-shun). Groundwater that seeps into pipes through cracks, joints, or breaks.

Sanitary sewers are normally placed at a slope sufficient to produce a velocity of approximately two feet per second. This velocity will usually prevent the deposition of solids that may clog the pipe or cause odors. Manholes are placed every 300 to 500 feet to allow for inspection (Fig. 3.1) and cleaning of the sewer.

Fig. 3.1 Manholes allow inspection of the collection system

When low areas of land must be sewered or where pipe depth under the ground surface becomes excessive, pump stations (Fig. 3.2) are normally installed. These pump stations lift the wastewater to a higher point from which it may again flow by gravity, or the wastewater may be pumped under pressure directly to the treatment plant. A large pump station located just ahead of the treatment plant can create problems by periodically sending large volumes of flow to the plant one minute, and virtually nothing the next minute.

QUESTIONS

3.1A Why should the operator be familiar with the wastewater collection and transportation network?

3.1B List three types of sewers.

3.1C What problem may occur when it takes a long time for wastewater to flow through the collection sewers to the treatment plant?

3.1D Why are combined sewers a problem?

3.2 TREATMENT PLANTS

Upon reaching a wastewater treatment plant, the wastewater flows through a series of treatment processes (Fig. 3.3) which remove the wastes from the water and reduce its threat to the public health before it is discharged from the plant. The number of treatment processes and the degree of treatment usually depend on the uses of the receiving waters. Treated wastewaters discharged into a small stream used for a domestic water supply and swimming will require considerably more treatment than wastewater discharged into water used solely for navigation.

To provide you with a general picture of treatment plants, the remainder of this chapter will follow the paths a drop of wastewater might travel as it passes through a plant. You will be introduced to the names of the treatment processes, the kinds of wastes the processes treat or remove, and the location of the processes in the flow path. Not all treatment plants are alike; however, there are certain typical flow patterns that are similar from one plant to another.

When wastewater enters a treatment plant, it usually flows through a series of pretreatment processes--screening, shredding, and grit removal. These processes remove the coarse material from the wastewater. Flow-measuring devices are usually installed after pretreatment processes to record the flow rates and volumes of wastewater treated by the plant.

Next the wastewater will generally receive primary treatment. During primary treatment some of the solid matter carried by the wastewater will settle out or float to the water surface where it can be separated from the wastewater being treated.

Secondary treatment processes usually follow primary treatment and commonly consist of biological processes. This means that organisms living in the controlled environment of the process are used to partially stabilized (oxidize) organic matter not removed by previous treatment processes and to convert it into a form which is easier to remove from the wastewater.

Waste material removed by the treatment processes goes to solids handling facilities and then to ultimate disposal.

Waste treatment ponds may be used after pretreatment, primary treatment, or secondary treatment. Ponds are frequently constructed in rural areas where there is sufficient available land.

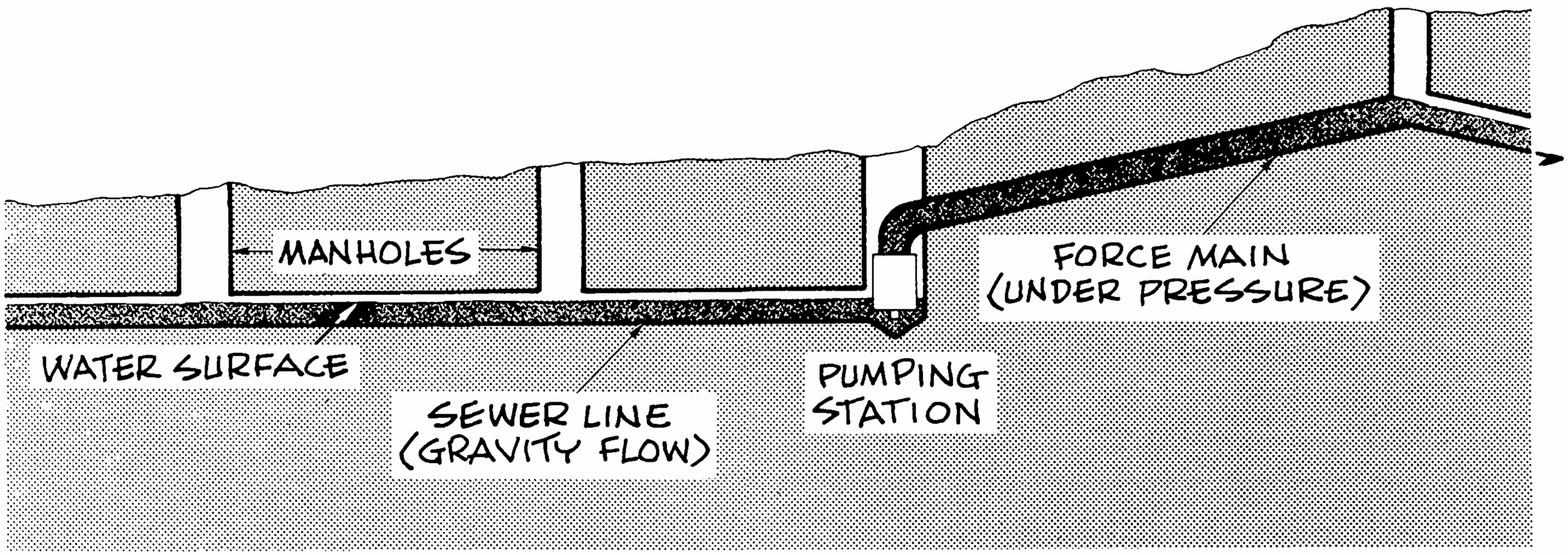


Fig. 3.2 Collection sewer profile

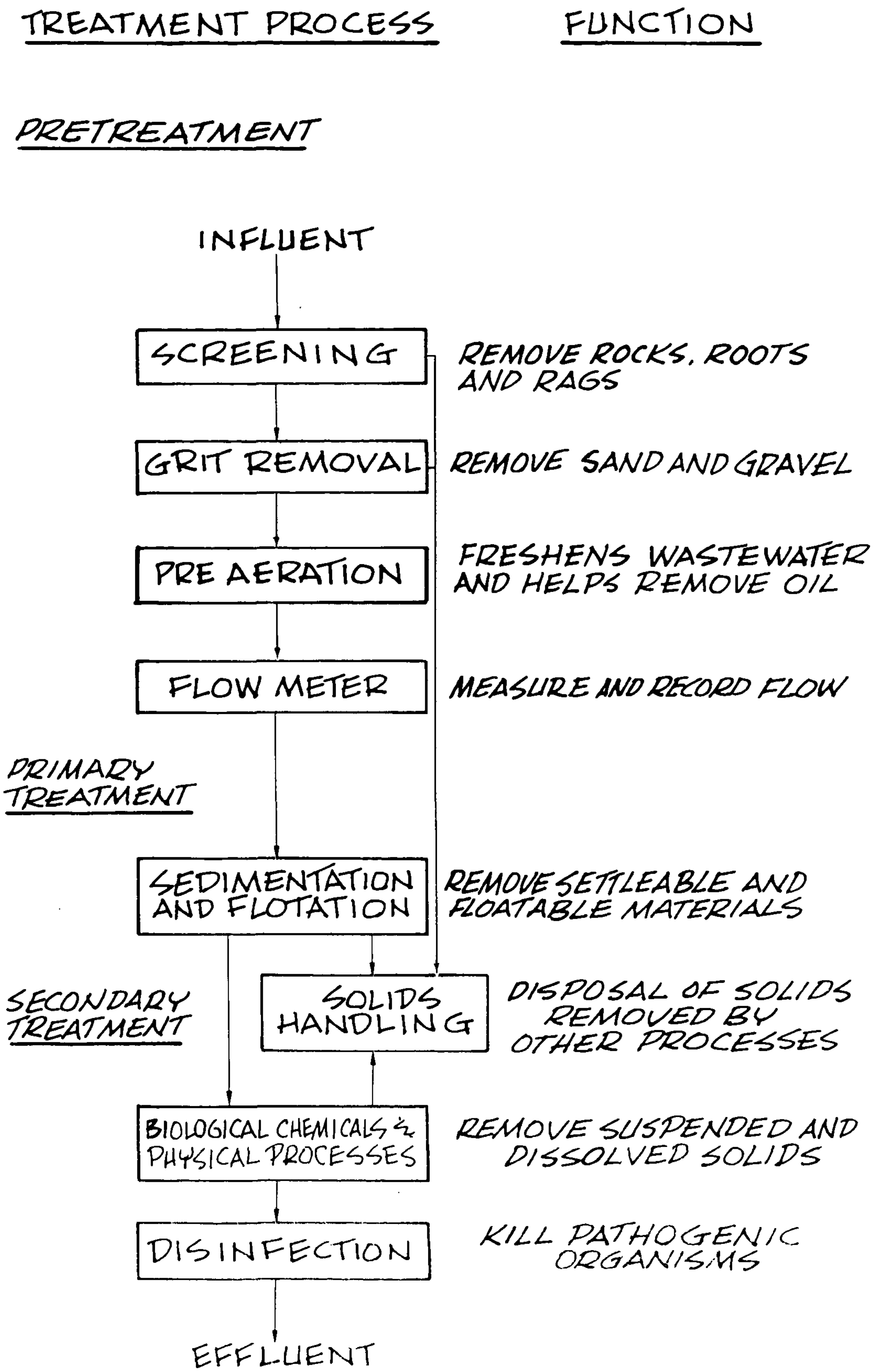
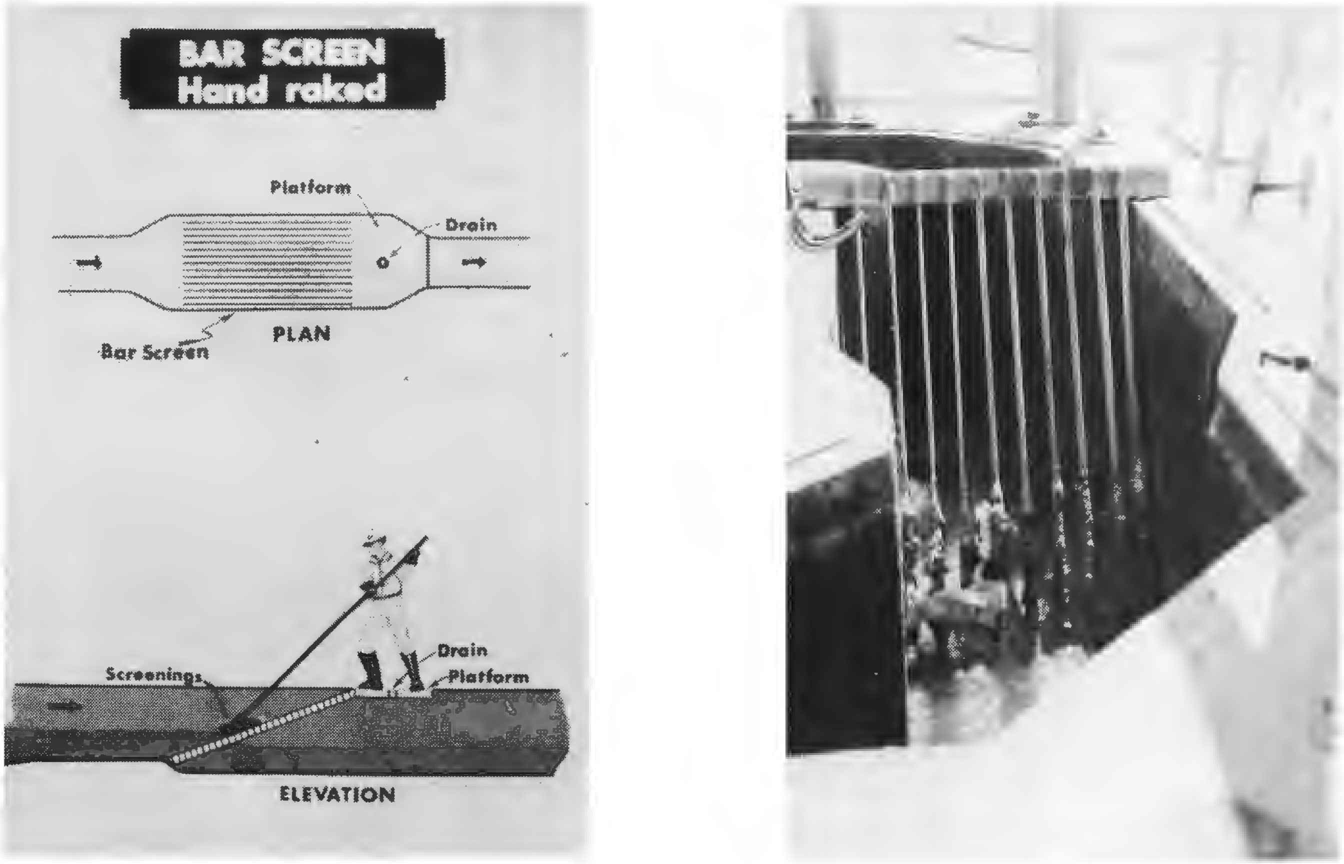


Fig. 3.3 Flow diagram of wastewater treatment plant processes



(Courtesy Water Pollution Control Federation)

Fig. 3.4 Bar screens

Advanced methods of waste treatment are being developed for general cleanup of wastewater or removal of substances not removed by conventional treatment processes. They may follow the treatment processes previously described, or they may be used instead of them. Before treated wastewater is discharged to the receiving waters, it should be disinfected to prevent the spread of disease.

In the following sections these treatment processes will be briefly discussed to provide an overall concept of a treatment plant. Details will be presented in later chapters to provide complete information on each of these processes.

3.3 PRETREATMENT

3.30 General

Pretreatment processes commonly consist of screening, shredding,[5] and grit removal to separate coarse material from the wastewater being treated.

3.31 Screening

Wastewater flowing into the treatment plant will occasionally contain pieces of wood, roots, rags, and other debris. To protect equipment and reduce any interference with in-plant flow, debris and trash are usually removed by a bar screen (Fig. 3.4). Most screens in treatment plants consist of parallel bars placed at an angle in a channel in such a manner that the wastewater flows through the bars. Trash collects on the bars and is periodically raked off by hand or by mechanical means. In most plants these screenings are disposed of by burying or burning. In some cases they are automatically ground up and returned to the wastewater flow for removal by a later process.

Fig. 3.5 Screened & ground

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[5] Shredding. A mechanical treatment process which cuts large pieces of wastes into smaller pieces so they won't plug pipes or damage equipment (comminution).

3.32 Shredding

Devices are also available which cut up or shred material while it remains in the wastewater stream. The most common of these are the barminutor (Fig. 3.6) and the comminutor (Fig. 3.7). One of these devices usually follows a bar screen.

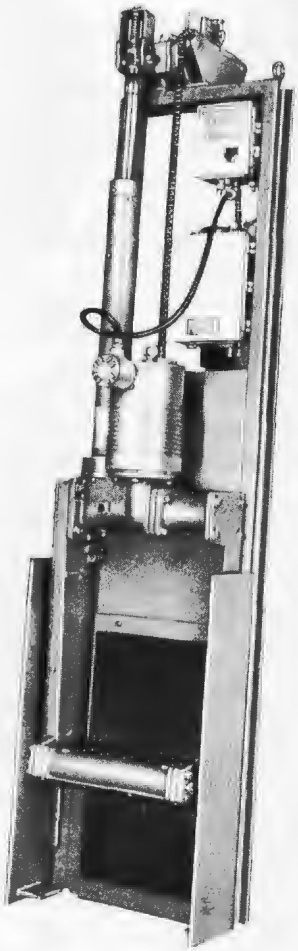

Fig. 3.6 Barminutor

Fig. 3.7 Comminutor

(Courtesy Chicago Pump)

3.33 Grit Chambers

Most sewer pipes are laid at a slope steep enough to maintain a wastewater flow of two feet per second (fps). If the velocity is reduced slightly below that, say to 1.5 fps, some of the larger, heavier particles will settle out. If the velocity is reduced to about 1 fps, heavy inorganic material such as sand, eggshells, and cinders will settle; but the lighter organic material will remain in suspension. The settled inorganic material is referred to as grit.[6] Grit should be removed early in the treatment process because it is abrasive and will rapidly wear out pumps and other equipment. Since it is mostly inorganic, it cannot be broken down by any biological treatment process and thus should be removed as soon as possible.

Fig. 3.8 Removal of eggshells

Grit is usually removed in a long, narrow trough called a Grit Chamber (Fig. 3.9). The chamber is designed to provide a flow-through velocity of 1 fps. The settled grit may be removed either by hand or mechanically. Since there is normally some organic solid material deposited along with the grit, it is usually buried to avoid nuisance conditions. Some plants are equipped with "grit washers" that clean some of the organic material out of the grit so that organic solids can remain in the main waste flow to be treated.

Many treatment plants have aerated grit chambers in which compressed air is added through diffusers to provide better separation of grit and other solids. Aeration in this manner also "freshens" a "stale" or septic wastewater, helping to prevent odors and assist the biological treatment process.

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[6] Grit. The heavy mineral material present in wastewater, such as sand, gravel, cinders, and eggshells.

Fig. 3.9 Grit chamber

WPCF MOP No. 11,
Operation of Wastewater Treatment Plants

QUESTIONS

3.3A Why is grit removed early in the treatment process?

3.3B What is usually done with grit which has been removed from the wastewater?

3.4 FLOW MEASURING DEVICES

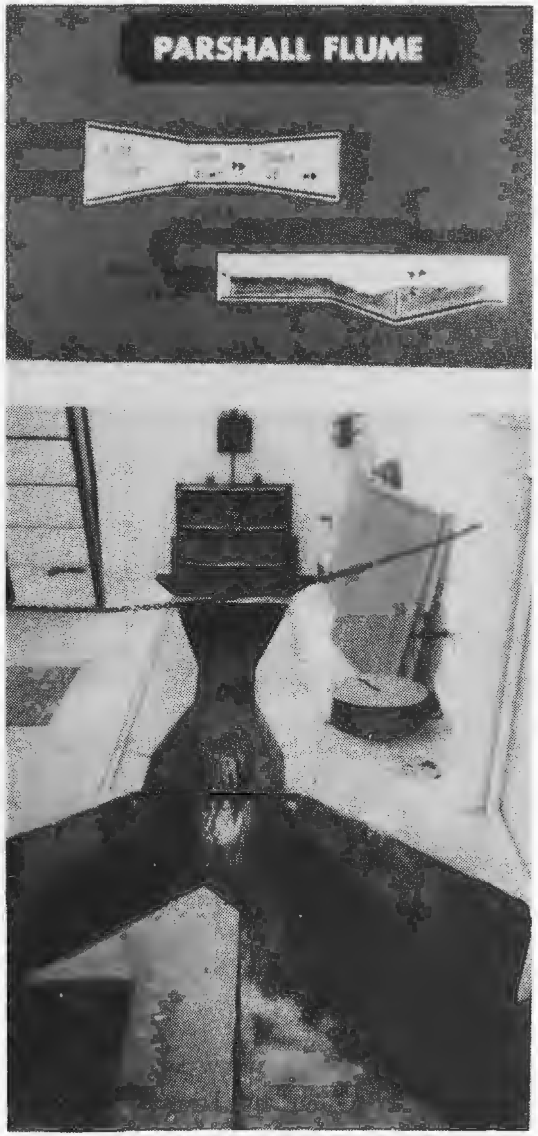
Although flow measuring devices are not for treating wastes, it is necessary to know the quantity of wastewater flow so adjustments can be made on pumping rates, chlorination rates, aeration rates, and other processes in the plant. Flow rates must be known, also, for calculation of loadings on treatment processes and treatment efficiency. Most operators prefer to have a measuring device at the headworks of their treatment plant.

The most common measuring device is a Parshall Flume (Fig. 3.10). Basically it is a narrow place in an open channel which allows the quantity of flow to be determined by measuring the depth of flow. It is a widely used method for measuring wastewater because its smooth constriction does not offer any protruding sharp edges or areas where wastewater particles may catch or collect behind the metering device.

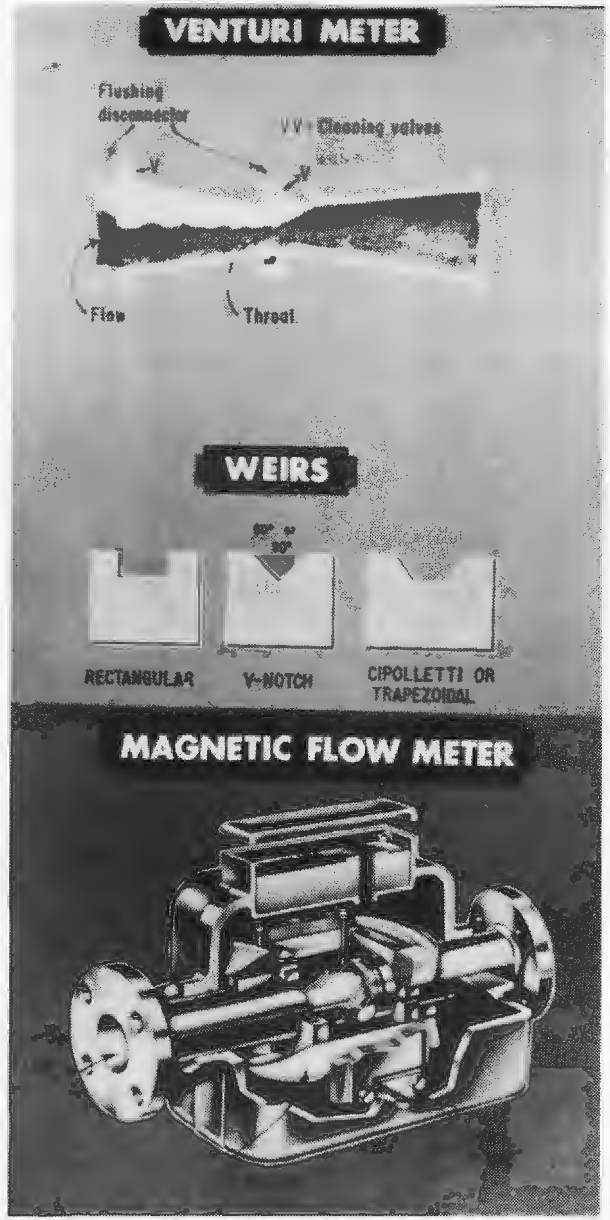
Another measuring device used in open channels is a weir[7] (Fig. 3.10). A weir is a wall placed across the channel over which the waste may fall. It is usually made of thin metal and may have either a rectangular or V-notch opening. Flow over the weir is determined by the depth of waste going through the opening. A disadvantage of a weir is the relatively dead water space that occurs just upstream of the weir. If the weir is used at the head end of the plant, organic solids may settle out in this area. When this occurs odors and unsightliness can result. Also, as the solids accumulate the flow reading may become incorrect.

A good measuring device for flows of treated or untreated wastewater is a Venturi meter (Fig. 3.10). It is a special section of contracting pipe, and it measures flow in much the same way as a Parshall Flume. It does not offer any sharp obstructions for particles to catch on. Magnetic flow meters (Fig. 3.10) also are being used successfully to measure wastewater flows.

[7] Weir (weer). A vertical obstruction such as a wall or plate, placed in an open channel and calibrated in order that a depth of flow over the weir can easily be converted to a flow rate in MGD (million gallons per day).



End Photo of Parshall Flume



(Drawings courtesy of Water Pollution Control Federation)

Fig. 3.10 Flow meters

QUESTIONS

3.4A Why are weirs not frequently used to measure the influent to a plant?

3.4B Why is a Parshall Flume widely used for measuring wastewater flow?

3.5 PRIMARY TREATMENT

We have previously discussed the reduction in velocity of the incoming waste to approximately one foot per second in order to settle out heavy inorganic material or grit. The next step in the treatment process is normally called sedimentation or primary treatment. In this process the waste is directed into and through a large tank or basin. Flow velocity in these tanks is reduced to about 0.03 foot per second, allowing the settleable solids to fall to the bottom of the tank, thus making the wastewater much clearer. It has therefore become common practice to call these sedimentation tanks "clarifiers". The first clarifier that the wastewater flows into is called a primary clarifier. We will discuss later the need for another clarifier after the biological treatment process. This second clarifier is called a secondary clarifier.

Clarifiers normally are either rectangular (Fig. 3.11) or circular (Fig. 3.12). Primary clarifiers are usually designed to provide 1.5 to 2 hours detention time.[8] Secondary clarifiers usually provide slightly more time.

Generally the longer the detention time provided, the more removal of solids that takes place. In a tank with two hours detention time, approximately 60 percent of the suspended solids in the raw wastewater will either settle to the bottom or float to the surface and be removed. Removal of these solids will usually reduce the Biochemical Oxygen Demand (BOD)[9] of the waste approximately 30 percent. The exact removal depends on the amount of BOD contained in the settled material.

All primary clarifiers, no matter what their shape, must have a means for collecting the settled solids (called sludge[10]) and

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[8] Detention Time. The time required to fill a tank at a given flow or the theoretical time required for a given flow quantity of wastewater to flow through the tank.

[9] Biochemical Oxygen Demand or BOD (BUY-o-KEM-ik-cull OX-zi-gen de-MAND). The BOD indicated the rate of oxygen utilized by wastewater under controlled conditions of temperature and time.

[10] Sludge (sluj). The settleable solids separated from liquids during processing or deposits on bottoms of streams or other bodies of water.

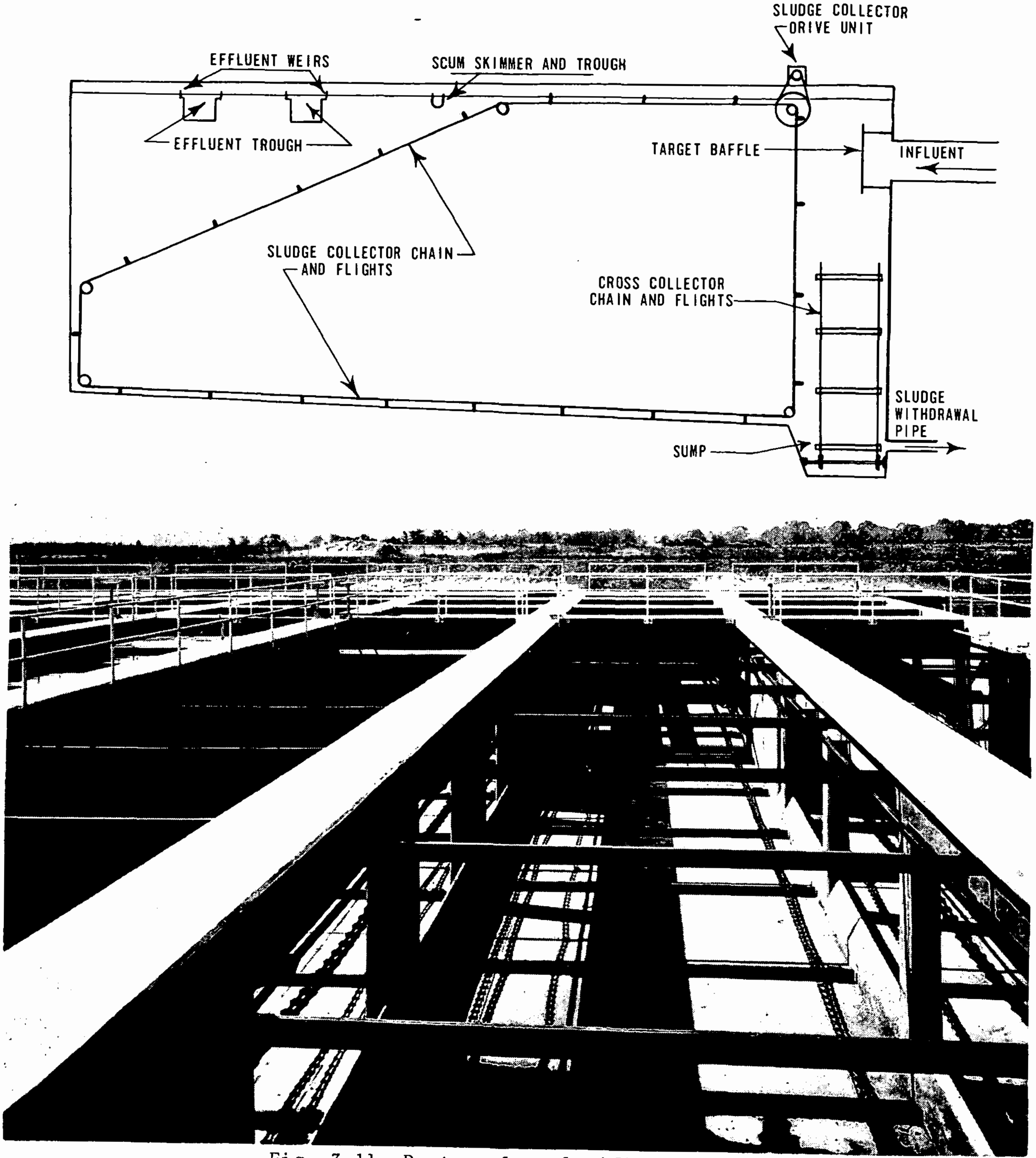

Fig. 3.11 Rectangular clarifier

(Courtesy Jeffrey)

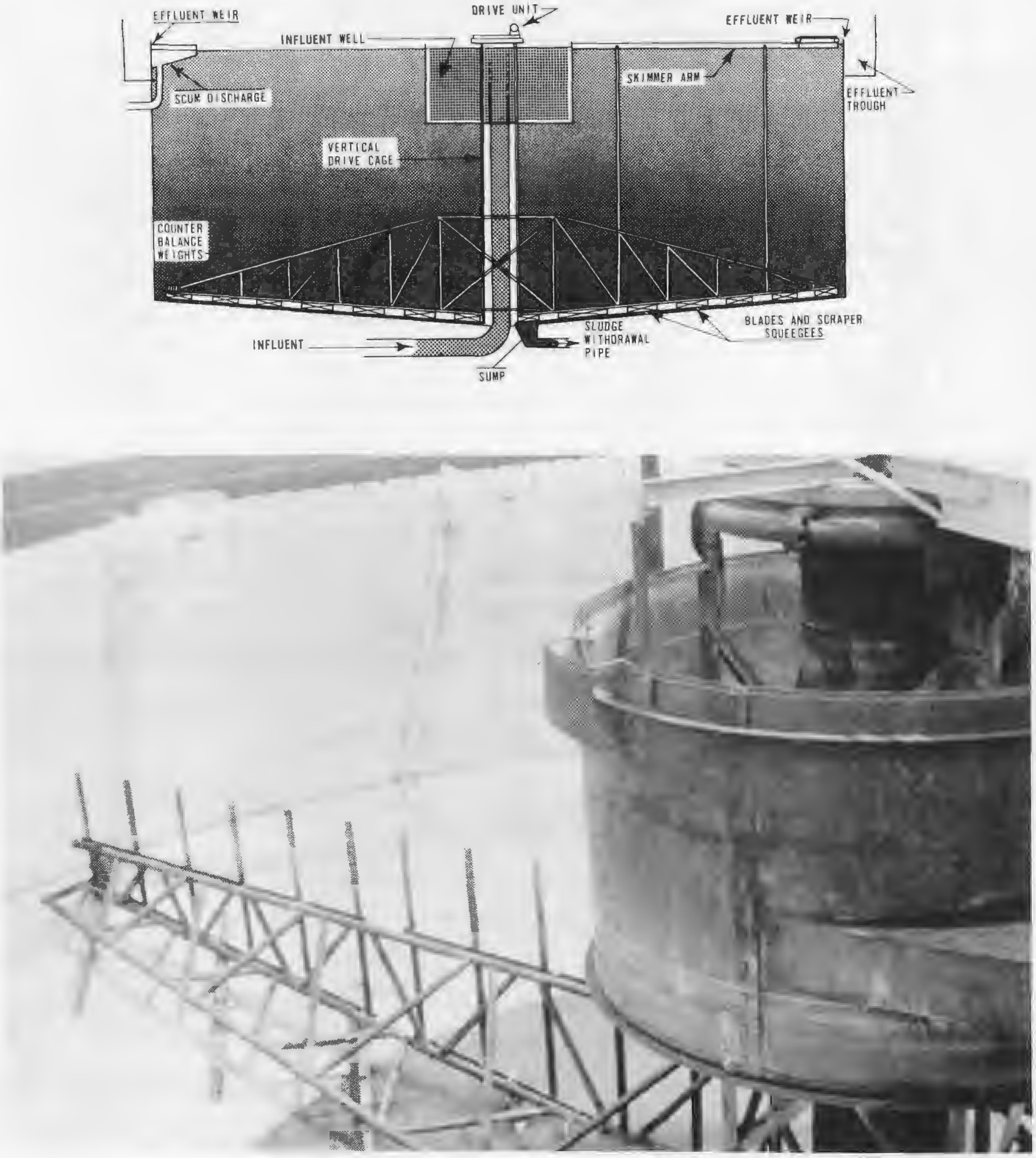

Fig. 3.12 Circular clarifier

the floating solids (called scum). In rectangular tanks, sludge and scum collectors are usually wooden beams ("flights") attached to endless chains. The collector flights travel on the surface, in the direction of the flow, conveying grease and floatable solids down to the scum trough to be skimmed off to the solids (sludge) handling facilities. The flights then drop below the surface and return to the influent end along the bottom, moving the settled raw sludge to the sludge hopper. The sludge is periodically pumped from the hopper to the sludge handling facilities.

In circular tanks, scrapers or "plows", attached to a rotating arm, rotate slowly around the bottom of the tank. The plows push the settled sludge toward the center and into the sludge hopper. Scum is collected by a rotating blade at the surface. As in the case of the rectangular tank, both scum and sludge are usually pumped to the solids or sludge handling facilities.

The clear surface water of the primary tank flows out of the tank by passing over a weir. The weir must be long enough to allow the treated water to leave at a low velocity; if it leaves at a high velocity, particles settling to the bottom or those already on the bottom may be picked up and carried out of the tank.

QUESTIONS

3.5A What is the purpose of "flights" or "plows" in a clarifier?

3.5B What happens to the sludge and scum collected in a primary clarifier?

3.6 SECONDARY TREATMENT

3.60 General

In many treatment plants the wastewater flows out of the primary clarifier into another unit where it receives secondary or biological treatment. This means that the wastewater is exposed to living organisms (such as bacteria) which eat the dissolved and nonsettleable organic material remaining in the waste. The two processes used almost universally for biological treatment are the trickling filter and activated sludge. These are both aerobic biological treatment processes, which means the organisms require dissolved oxygen (Fig. 3.13) in order to live, eat, and reproduce.

Fig. 3.13 Organisms require dissolved oxygen

3.61 Trickling Filter

The trickling filter is one of the oldest and most dependable of the biological treatment processes. Most of these plants are removing 65 to 85% of the BOD and suspended solids present in the influent.

The trickling filter is a bed of 1½ to 5-inch rock, slag blocks, or specially manufactured "media"[11] over which settled wastewater from the primary clarifier is distributed (Fig. 3.14). The settled wastewater is usually applied by an overhead rotating distributor and trickles over and around the media as it flows downward to the effluent collection channel. Since the media and the voids in between them are large (usually 2.5- to 4-inch diameter), and since the applied wastewater no longer has any large particles (they settled out in the clarifier), the trickling filter does not remove solids by a filtering action. It would be more correct to call the filter a biological contact bed or biological reactor since this is the function it performs. The filter bed offers a place for aerobic bacteria and other organisms to attach themselves and multiply as they feed on the passing wastewater. This process of feeding on, or decomposing, waste is exactly the same as the process occurring in the stream when waste is discharged to it. In the trickling filter, however, the organisms use the oxygen which enters the waste from the surrounding air, rather than using up the stream's supply of dissolved oxygen. Thus the voids between the media must be large so sufficient oxygen can be supplied by circulating air.

The wastewater being distributed on the filter usually has passed through a primary clarifier, but it still contains approximately 70 percent of its original organic matter, which represents food for organisms. For this reason a tremendous population of organisms develops on the media. This population continues to grow as more waste is applied. Eventually the layer of organisms on the media gets so thick that some of it breaks off (sloughs off) and is carried into the filter effluent channel. This material is normally called humus. Since it is principally organic matter, its presence in a stream would be undesirable. It is usually removed by settling in a secondary clarifier. Humus sludge from the secondary clarifier is usually returned to the primary clarifier to be resettled and pumped to the sludge handling facilities along with the "raw" sludge which settles out as previously described.

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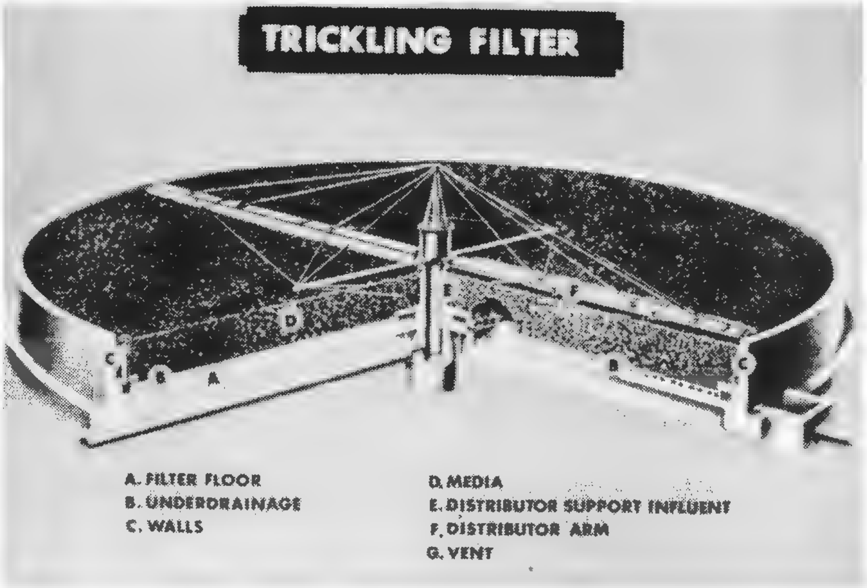
[11] Media. The material in a trickling filter over which settled wastewater is sprinkled and then flows over and around during treatment. Slime organisms grow on the surface of the media and treat the wastewater.



(Courtesy Water Pollution Control Federation)

Fig. 3.14 Trickling filter

3.62 Activated Sludge

Another biological treatment unit that is used in secondary treatment, following the primary clarifier, is the aeration tank. When aeration tanks are used with the sedimentation process, the resulting plant is called an activated sludge plant. The activated sludge process is widely used by large cities and communities where land is expensive and where large volumes must be highly treated, economically, without creating a nuisance to neighbors. The activated sludge plant is probably the most popular biological treatment process being built today for larger installations or small package plants. These plants are capable of BOD and suspended solids reduction of up to 90 or 99%. The activated sludge process is a biological process, and it serves the same function as a trickling filter. Effluent from a primary clarifier is piped to a large aeration tank (Fig. 3.15). Air is supplied to the tank by either introducing compressed air into the bottom of the tank and letting it bubble through the wastewater and up to the top, or by churning the surface mechanically to introduce atmospheric oxygen.

Aerobic bacteria and other organisms thrive as they travel through the aeration tank. With sufficient food and oxygen they multiply rapidly, as in a trickling filter. By the time the waste reaches the end of the tank (usually 4 to 8 hours), most of the organic matter in the waste has been used by the bacteria for producing new cells. The effluent from the tank, usually called "mixed liquor", consists of a suspension containing a large population of organisms and a liquid with very little BOD. The activated sludge forms a lacey network that captures pollutants.

The organisms are removed in the same manner as they were in the trickling filter plant. The mixed liquor is piped to a secondary clarifier, and the organisms settle to the bottom of the tank while the clear effluent flows over the top of the effluent weirs. This effluent is usually clearer than a trickling filter effluent because the suspended material in the mixed liquor settled to the bottom of the clarifier more readily than the material in a trickling filter effluent. The settled organisms are known as activated sludge. They are extremely valuable to the treatment

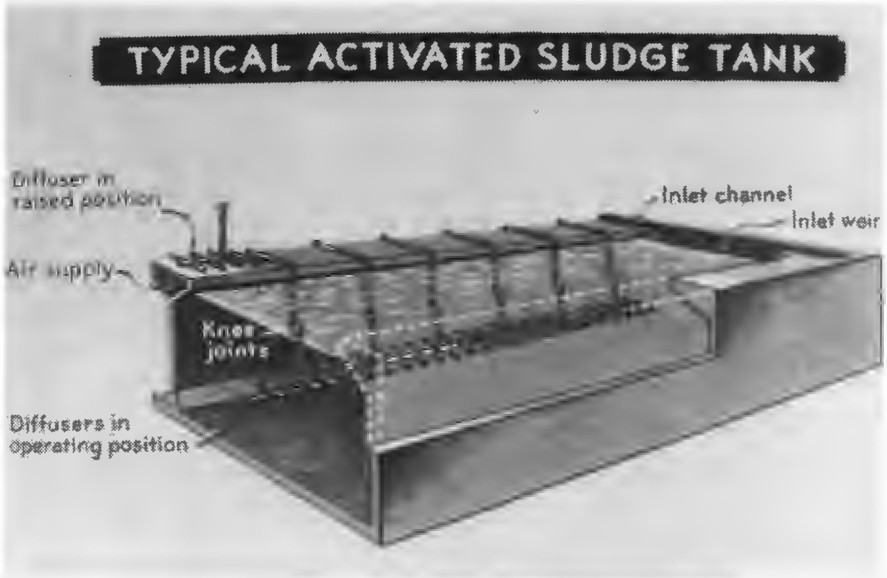


Fig. 3.15 Aeration tank

process. If they are removed quickly from the secondary clarifier, they will be in good condition and hungry for more food (organic wastes) (Fig. 3.16). They are therefore pumped back (recirculated) to the influent end of the aeration tank where they are mixed with the incoming wastewater. Here they begin all over again to feed on the organic material in the waste, decomposing it and creating new organisms.

Fig. 3.16 Hungry organisms ready for more food

Left uncontrolled, the number of organisms would eventually be too great, and therefore some must periodically be removed. This is accomplished by pumping a small amount of the activated sludge to the primary clarifier. The organisms settle in the clarifier along with the raw sludge and are removed to the sludge handling facilities.

There are many variations of the conventional activated sludge process, but they all involve the same basic principle. These variations will be discussed in Chapter 7, Activated Sludge.

3.63 Secondary Clarifiers

As previously mentioned, trickling filters and activated sludge tanks produce effluents that contain large populations of microorganisms and associated materials (humus). These microorganisms must be removed from the flow before it can be discharged to the receiving waters. This task is usually accomplished by a secondary clarifier. In this tank the trickling filter humus or activated sludge separates from the liquid and settles to the bottom of the tank. It is removed to the primary clarifier to be resettled with the primary sludge or returned to the beginning of the secondary process to continue treating the wastewater. The clear effluent flows over a weir at the top of the tank.

QUESTIONS

3.6A Would it be a good idea to use trickling filter media of various sizes so it could pack together better?

3.6B Why is a secondary clarifier needed after a trickling filter or aeration tank?

3.6C Activated sludge can be pumped from the secondary clarifier to ______________________________.

3.7 SOLIDS HANDLING AND DISPOSAL

3.70 General

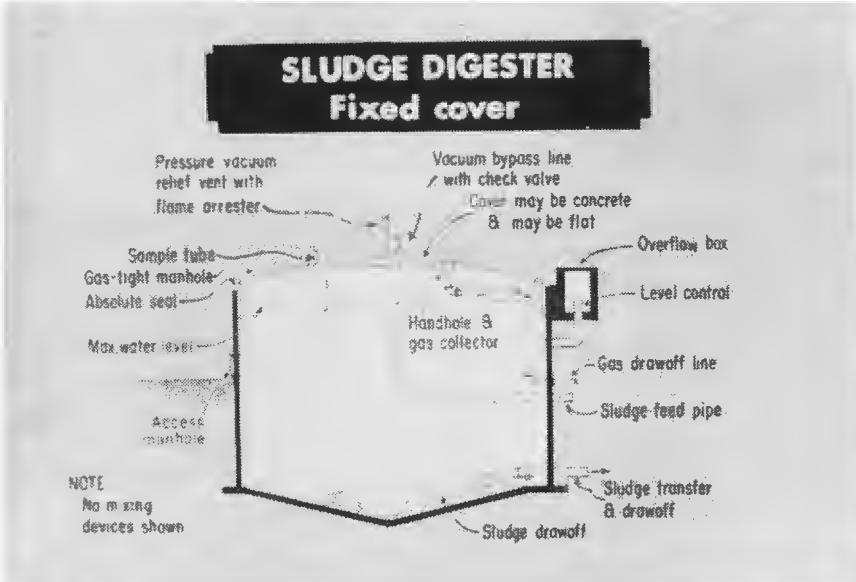
Solids removed from wastewater treatment processes are commonly broken down by a biological treatment process called sludge digestion. After digestion and dewatering the remaining material may be used for fertilizer or soil conditioner. Some solids, such as scum from a clarifier, may be disposed of by burning or burial.

3.71 Digestion and Dewatering

Settled sludge from the primary clarifier and occasionally settled sludge from the secondary clarifier are periodically pumped to a digestion tank. The tank is usually completely sealed to exclude any air from getting in (Fig. 3.17). This type of digester is called an anaerobic digester because of the anaerobic bacteria that abound in the tank. Anaerobic bacteria thrive in an environment devoid of dissolved oxygen by using the oxygen which is chemically combined with their food supply.

Two major types of bacteria are present in the digester. The first group starts eating on the organic portion of the sludge to form organic acids and carbon dioxide gas. These bacteria are called "acid formers". The second group breaks down the organic acids to simpler compounds and forms methane and carbon dioxide gas. These bacteria are called "gas formers". The gas is usually used to heat the digester or to run engines in the plant. The production of gas indicates that organic material is being eaten by the bacteria. A sludge is usually considered properly digested when 50 percent of the organic matter has been destroyed and converted to gas. This normally takes approximately 30 days if the temperature is kept at about 95°F.

Most digestion tanks are mixed to continuously bring the food to the organisms, to provide a uniform temperature, and to avoid the formation of thick scum blankets. When a digester is not being mixed the solids settle to the bottom, leaving an amber-colored liquid above the sludge known as supernatant. The



(Courtesy Water Pollution Control Federation)

Fig. 3.17 Sludge digester

supernatant is displaced from the tank each time a fresh charge of raw sludge is pumped from the primary clarifier. The displaced supernatant usually is returned from the digester back to the plant headworks and mixed with incoming raw wastes. Supernatant return should be slow to prevent overloading or shock loading of the plant.

Above the supernatant level a scum blanket will usually develop. Scum blankets consist of grease, soap, rubber goods, hair, petroleum products, plastics, and filter tips from cigarettes. These scum blankets may contain most of the added food or sludge. Digestion organisms are usually below the supernatant and little digestion will occur if the organisms and food don't get together. Control of scum blankets consists of mixing the digester contents and burning or burying skimmings instead of pumping them to the digester.

Above the scum blanket or normal water level is the gas collection area. Digester gas is normally about 70% methane and 30% carbon dioxide. When mixed with air, digester gas is extremely explosive (Fig. 3.18).

Fig. 3.18 Don't allow digester gas and air to mix

In most newer plants digesting takes place in two tanks. The first or primary digester is usually heated and mixed. Rapid digestion takes place along with most of the gas production. In the secondary tank, the digested sludge and supernatant are allowed to separate, thus producing a clearer supernatant and better digested sludge.

Digested sludge from the bottom of the tank is periodically removed for dewatering. This is accomplished in sand drying beds (Fig. 3.19), lagoons, centrifuges, and vacuum filters (Fig. 3.20). The sludge is then burned, buried, or used as fertilizer on certain crops (not on crops which are eaten without cooking). Sludge that has been adequately digested drains readily and is not offensive.

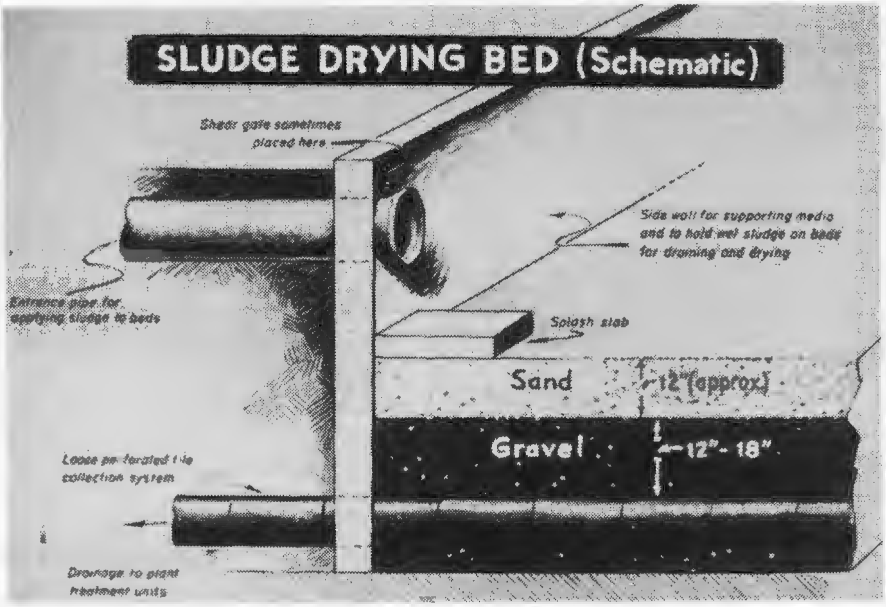


Fig. 3.19 Sludge drying bed

(Courtesy Water Pollution Control Federation)

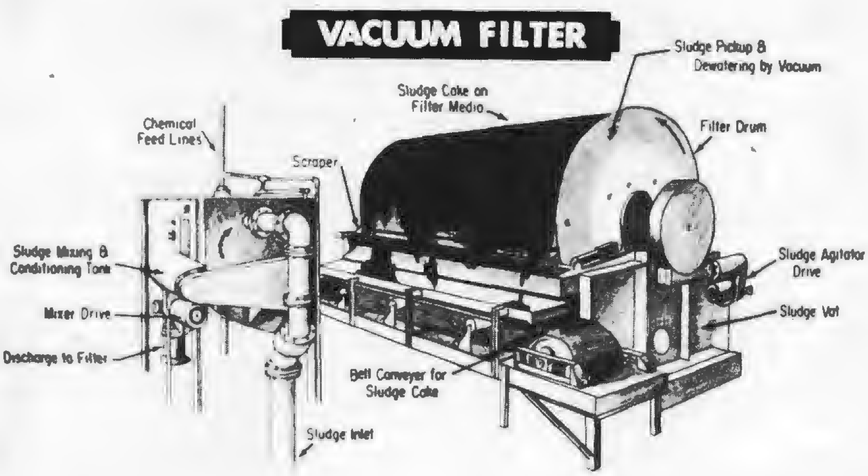


Fig. 3.20 Vacuum filter

(Courtesy Water Pollution Control Federation)

Some of today's activated sludge treatment plants are equipped with aerobic digesters. An aerobic digester is ususally an open tank with compressed air being blown through the sludge. Destruction of organic matter is accomplished by bacteria which require dissolved oxygen to survive. One advantage of this process is that there is no explosive gas being produced. On the other hand, this is also a disadvantage since the anaerobic digester gas is used as a fuel for boilers and engines around the plant. Aerobic sludge from an aerobic digester doesn't thicken as readily as sludge from an anaerobic digester. Aerobic sludge filters about as well as an equivalent concentration of anaerobic sludge.

3.72 Incineration

Burning of wet sludge by wet oxidation or of dewatered sludge are possible methods of ultimate disposal; however, the process must not create an air pollution problem. To prevent skimmings from clarifiers causing operational problems, incineration or burial are used.

QUESTIONS

3.7A What two basic types of bacteria are present in an anaerobic digester?

3.7B Why are digesters mixed?

3.7C List some of the ways to dispose of digested sludge.

3.8 WASTE TREATMENT PONDS

A special method of biological treatment deserving attention is wastewater treatment ponds (Fig. 3.21). They do not resemble the concrete and steel structures or the mechanical devices that have been previously discussed. But these simple depressions in the ground are capable of producing an effluent comparable to some of the most modern plants with respect to BOD and bacteria reduction.

In some treatment plants, wastewater being treated may flow through a coarse screen and flow meter before it flows through a series of ponds. In other plants the ponds may be located after primary treatment, while in some plants they are placed after trickling filters. The type of treatment processes and the location of ponds are determined by the design engineer on the basis of economics and the degree of treatment required to meet the water quality standards of the receiving waters.

When wastewater is discharged to a pond, the settleable solids fall to the bottom just as they do in a primary clarifier. The solids begin to decompose and soon use up all the dissolved oxygen in the nearby water. A population of anaerobic bacteria then continues the decomposition, much the same as in an anaerobic digester. As the organic matter is destroyed, methane and carbon dioxide are released. When the carbon dioxide rises to the surface some of it is used by algae, which convert it to oxygen by the process of photosynthesis.[12] This is the same process used by living plants. Aerobic bacteria, algae, and other microorganisms feed on the dissolved solids in the upper layer of the pond much the same way they do in a trickling filter or aeration tank. Algae produce oxygen for the other organisms to use.

Some shallow ponds (3 to 6 feet deep) have dissolved oxygen throughout their entire depth. These ponds are called aerobic ponds. They usually have a mechanical apparatus adding oxygen plus their oxygen supply from algae.

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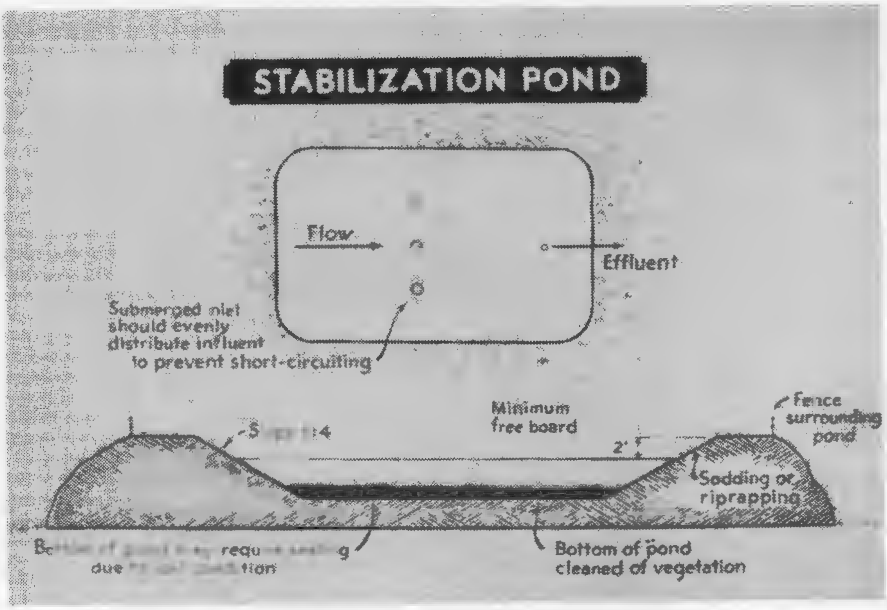
[12] Photosynthesis (foto-SIN-tha-sis). A process in which chlorophyll (green plant tissue) converts carbon dioxide and inorganic substances to oxygen and additional plant material utilizing sunlight for energy. Land plants grow by the same process.



(Courtesy Water Pollution Control Federation)

(Courtesy Water and Sewage Works Magazine)

Fig. 3.21 Pond

Deep (8 to 12 feet), heavily loaded ponds may be devoid of oxygen throughout their depth. These ponds are called anaerobic ponds. At times, these ponds can be quite odorous, and they are used in sparsely populated areas only.

Ponds that contain an aerobic top layer and an anaerobic bottom layer are called facultative ponds. These are the ponds normally seen in most areas. If they are properly designed and operated, they are virtually odor free and produce a well-oxidized (low BOD) effluent.

Occasionally ponds are used after a primary treatment unit. In this case, they are usually called oxidation ponds. When they are used to treat raw wastewater, they are called raw wastewater lagoons or waste stabilization ponds.

The effluent from ponds is usually moderately low in bacteria. This is especially true when the effluent runs from one pond to another or more (series flow). The long detention time, usually a month or more, is required in order for harmful bacteria and undesirable solids to be removed from the pond effluent. If the receiving waters are used for water supply or body contact sports, chlorination of the effluent may still be required.

QUESTION

3.8A How are facultative ponds similar to:

1. a clarifier?
2. a digester?
3. an aeration tank?

3.9 ADVANCED METHODS OF TREATING WASTEWATER

The treatment processes described so far in this chapter are considered conventional treatment processes. As our population grows and industry expands, more effective treatment processes will be required. Advanced methods of waste treatment may follow conventional processes, or they may be used instead of these processes. Sometimes advanced methods of waste treatment are called tertiary (TER-she-AIR-ee) treatment because they frequently follow secondary treatment. Advanced methods of waste treatment include coagulation-sedimentation (used in water treatment plants), adsorption, and electrodialysis. Other new treatment processes that may be used in the future include reverse osmosis, chemical oxidation, and the use of polymers.

Advanced methods of treatment are used to reduce the nutrient content (nitrates and phosphates) of wastewater to prevent blooms of algae in lakes, reservoirs, or streams. Carbon filters are used to reduce the last traces of organic materials. In some parts of the arid west advanced methods are used to enable the use of the plant effluent for recreational reservoirs.

QUESTION

3.9A If wastewater from a secondary treatment plant were coagulated with alum or lime and settled in a clarifier, would this be considered a method of advanced waste treatment?

3.10 DISINFECTION

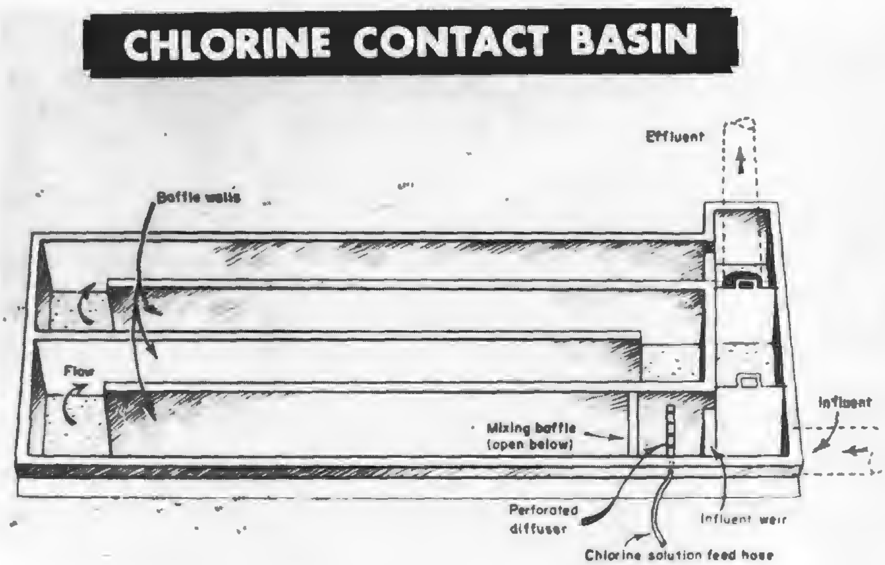
Although the settling process and biological processes remove a great number of organisms from the wastewater flow, there remain many thousands of bacteria in every milliliter of wastewater leaving the secondary clarifier. If there are human wastes in the water, it is possible that some of the bacteria are pathogenic, or harmful to man. Therefore, if the treated wastewater is discharged to a receiving water that is used for a drinking water supply or swimming or wading, the water pollution control agency or health department will usually require disinfection of the effluent prior to discharge.

Disinfection is usually defined as the killing of pathogenic organisms. The killing of all organisms is called sterilization. Sterilization is not accomplished in treatment plants as the final effluent after disinfection always contains some living organisms due to the inefficiency of the killing process.

Disinfection can be accomplished by almost any process that will create a harsh environment for the organisms. Strong light, heat, oxidizing chemicals, acids, alkalies, poisons, and many other substances will disinfect. Most disinfection in wastewater treatment plants is accomplished by chlorine, which is a strong oxidizing chemical.

Chlorine gas is used in most treatment plants although some of the smaller plants use a liquid chlorine solution as their source. The dangers in using chlorine gas, however, have prompted some of the larger plants to switch to hypochlorite solution (bleach) even though it is more expensive.

Chlorine gas is withdrawn from pressurized cylinders containing liquid chlorine and mixed with water or treated wastewater to make up a strong chlorine solution. Liquid hypochlorite solution can be used directly. The strong chlorine solution is then mixed with the effluent from the secondary clarifier. The effluent is then directed to a chlorine contact basin. The basin can be any size or shape, but better results are obtained if the tank is long and narrow. This shape prevents rapid movement or short circuiting through the tank. Square or rectangular tanks can be baffled to achieve this effect (Fig. 3.22). Tanks are usually designed to provide approximately 20 to 30 minutes theoretical contact time, although the trend is to longer times. If the plant's outfall line is of sufficient length, it may function as an excellent contact chamber since short circuiting will not occur.



(Courtesy Water Pollution Control Federation)

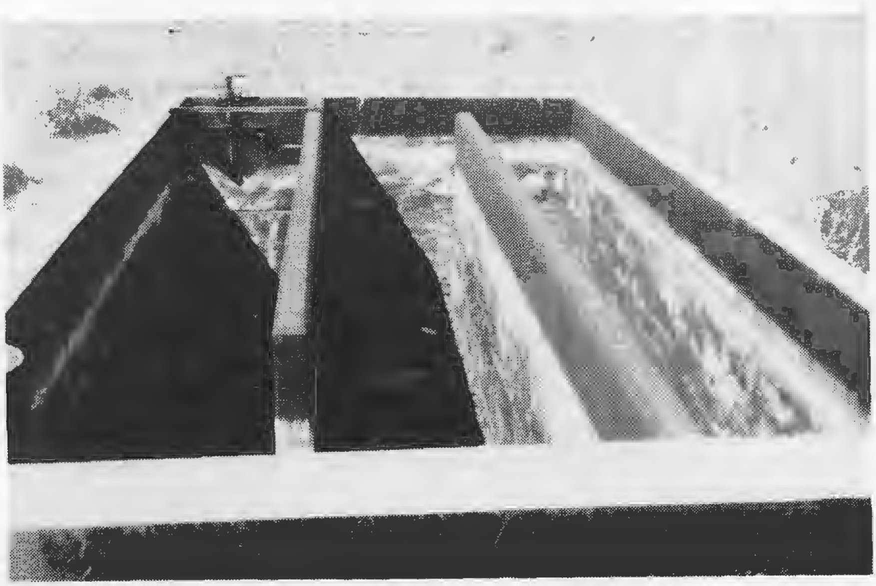


Fig. 3.22 Chlorine contact basin

QUESTIONS

3.10A Does disinfection usually kill all organisms in the plant effluent?

3.10B Which would provide better chlorine contact, a 10,000-gallon cubical tank or a length of 10-inch pipe flowing full and containing the same volume as the cubical tank?

3.11 ADDITIONAL READING

Some books you can read to obtain further information on the treatment plant and the various processes involved are:

a. MOP 11

b. New York Manual

c. Texas Manual

d. Sewage Treatment Practices, by Bloodgood

e. Babbitt, Harold E., and E. Robert Bauman, Sewerage and Sewage Treatment, John Wiley and Sons, New York, Eighth Edition, 1958. $10.75.

f. Summary Report, Advanced Waste Treatment, July 1964-July 1967, U. S. Department of Interior, FWPCA, WP-20-AWTR-19. Available from the Publications Office, Ohio Basin Region, Environmental Protection Agency, Water Quality Office, Cincinnati, Ohio 45226.

g. Santee Recreation Proceedings, Santee, California, U.S. Department of Interior, FWPCA, WP-20-7 (1967). Available from Publications Office source given in (f) above.

h. A Primer on Waste Water Treatment, prepared by the Office of Public Information, Federal Water Quality Administration, CWA-12, October 1969. Available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Price $0.55.

SUGGESTED ANSWERS

Chapter 3. Wastewater Facilities

3.1A The operator should know the origin of wastes reaching his plant, the time it takes, and how the wastes are transported (flow by gravity or by gravity and pumped). Such knowledge will help him to spot troubles and take corrective action.

3.1B Sanitary, storm, combined.

3.1C If the flowtime to reach the plant is very long, hydrogen sulfide gas may develop which can cause corrosion damage to concrete in the transportation system and in the plant. Undesirable odors develop, and solids are difficult to settle too.

3.1D Flows are sometimes bypassed during storms because a plant does not have the capacity to handle the additional wastewater.

3.3A Grit should be removed early in the treatment process because it is abrasive and will wear out pumps and other equipment.

3.3B Grit removed from the wastewater is usually buried to avoid causing a nuisance.

3.4A Weirs are not frequently used to measure influent flows because solids may collect behind the weir causing odors and causing flow measurements to be off.

3.4B Parshall Flumes are widely used for measuring wastewater flow because they have no obstructions.

3.5A "Flights" in rectangular tanks move scum along the surface to a scum trough and push sludge along the bottom to a hopper for removal to the sludge handling facility. "Plows" scrape sludge along the bottom of circular tanks to a hopper for removal.

3.5B Sludge and scum are usually pumped to the sludge handling facilities such as a digester. Scum should be burned or buried if possible.

3.6A No. If the media were packed together, air could not circulate and the organisms on the media would not get enough oxygen.

3.6B A secondary clarifier is needed after a trickling filter or aeration tank to allow organisms in the treated wastewater to be removed by settling.

3.6C Aeration tank or waste sludge handling facilities. Waste activated sludge could be pumped to either of the two places listed.

3.7A (1) a group that eats organic sludge to form organic acids and carbon dioxide gas (acid formers); and (2) a group that breaks down the organic acids into simpler compounds and forms methane and carbon dioxide gas (gas formers).

3.7B Digesters are mixed to bring food and organisms together and prevent the formation of a scum blanket.

3.7C Digested sludge may be disposed of by using sand drying beds, centrifuges, vacuum filters, or lagoons. Ultimately the dried sludge may be used as a soil conditioner or it may be buried.

3.8A A facultative pond acts like a clarifier by allowing solids to settle to its bottom, a digester because solids on the bottom are decomposed by anaerobic bacteria, and an aeration tank because of the action of aerobic bacteria in the upper layer of the pond.

3.9A Yes.

3.10A No.

3.10B The pipe would provide better chlorine contact because water cannot short-circuit (take a short route) through a pipe, but it might not move evenly through a tank and thus some of the water would have a shorter contact time.

OBJECTIVE TEST

Chapter 3. Wastewater Facilities

Please mark correct answers in the proper columns on the IBM answer sheet, as directed at the end of Chapter 1. Return your answer sheet to your Project Director.

3.1 Name three different types of sewers.

1. Sanitary, Pipes, Storm
2. Sanitary, Storm, Conventional
3. Sanitary, Storm, Combined
4. Sanitary, Storm, Groundwater
5. Conventional, Surface, Combined

3.2 Combined sewers (1. are) or (2. are not) a problem to treatment plant operators.

3.3 The following are biological treatment processes.

1. Trickling Filters
2. Grit Removal
3. Digesters
4. Ponds
5. Shredders

3.4 The purpose of screening is:

1. Thin the Wastewater
2. Remove Large Objects and Debris
3. Grade the Solids into Different Sizes
4. Protect Public Health

3.5 Flow measurements are important because they are used to:

1. Determine Loading on Units
2. Determine Treatment Efficiency
3. Adjust Pumping Rates
4. Determine Cl_2 Rates
5. Determine if a Plant is Handling its Design Capacity

3.6 The solids settled in a clarifier are called:

1. Dissolved Solids
2. Colloidal Solids
3. Emulsions
4. Sludge
5. Scum

3.7 The trickling filter (1. does) or (2. does not) remove solids by a filtering action.

3.8 Why is the digester gas mixed with air dangerous?

1. It will Explode
2. It Stinks
3. It Kills Grass

3.9 (1. Disinfection) or (2. Sterilization) is usually defined as the killing of pathogenic organisms, and

3.10 the killing of all organisms is called (1. disinfection) or (2. sterilization).

3.11 Ponds are capable of reducing:

1. Land Area and Cost
2. Mosquitoes and Weeds
3. BOD and Bacteria
4. Odors and Algae
5. None of these

Please write time required to work lesson on your answer sheet.

CHAPTER 4

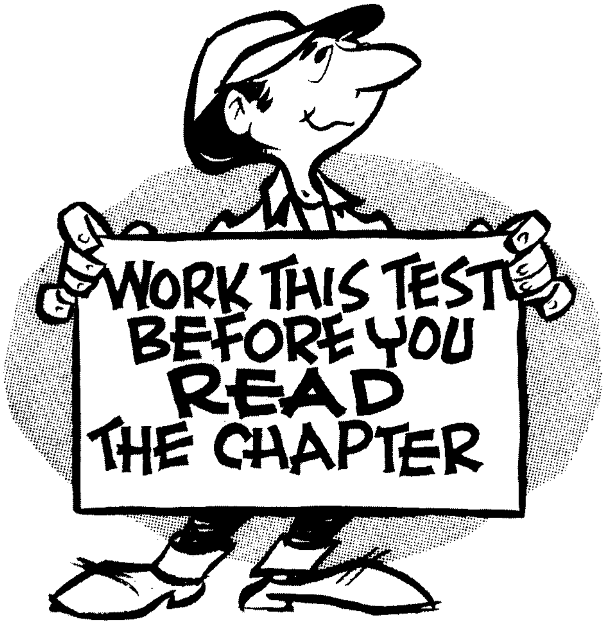
RACKS, SCREENS, COMMINUTORS, AND GRIT REMOVAL

by

Larry Bristow

PRE-TEST

Chapter 4. Racks, Screens, Comminutors, and Grit Removal



The objective of the Pre-Test is to indicate to you the important topics in this chapter, as well as to indicate how well the material was presented to you. It is okay if you don't know many of the answers.

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1.

Return the answer sheet to your Project Director.

1. An operator must always wash his hands before eating or smoking to prevent becoming infected with a water-borne disease.
    1. True
    2. False

2. The following items may be found in a treatment plant influent.
    1. Cans
    2. Clothes
    3. Toys
    4. Rocks
    5. Eggshells

3. Detritus is a common name for skimmings.
    1. True
    2. False

4. Pretreatment may include:

   1. Bar Screen
   2. Grit Chamber
   3. Detritus
   4. Flow meter
   5. Clarifier

5. What should be done <u>first</u> if a problem develops in a mechanically cleaned screen?

   1. Reach in with your hand and fix the equipment.
   2. Attemplt to fix the screen with the proper tools.
   3. Look at screen and identify problem.
   4. Turn off the electrical power to the screen.
   5. Find someone to help in case you get into trouble.

6. The methods used to dispose of screenings include:

   1. Dumping into nearby river
   2. Incineration
   3. Shredding or Grinding
   4. Selling for hog food
   5. Burial

7. Grit is composed of:

   1. Grease
   2. Sand
   3. Rubber Goods
   4. Eggshells
   5. Wood

8. A stick travels 30 feet in 20 seconds in a grit chamber. What is the flow velocity in the grit chamber?

   1. 0.5 ft/sec
   2. 0.67 ft/sec
   3. 1.0 ft/sec
   4. 1.5 ft/sec
   5. 2.0 ft/sec

TABLE OF CONTENTS

Chapter 4. Racks, Screens, Comminutors, and Grit Removal

GLOSSARY

Chapter 4. Racks, Screens, Comminutors, and Grit Removal

Aerobic Decomposition (AIR-O-bick): Decomposition and decay of organic material in the presence of free or dissolved oxygen.

Anaerobic Decomposition (AN-air-O-bick): Decomposition and decay of organic material in an environment containing no "free" or dissolved oxygen.

Clarifier (KLAIR-i-fire) (settling tank, sedimentation basin): A tank or basin in which wastewater is held for a period of time, during which the heavier solids settle to the bottom and the lighter material will float to the water surface.

Comminutor (com-min-OO-ter): A device used to reduce the size of the solid chunks in wastewater by shredding (comminuting). The shredding action can be visualized if you imagine many scissors cutting or hammering to shreds all the large influent solids material.

Decomposition, Decay: Generally aerobic processes that convert unstable materials into more stable forms by chemical or biological action. Waste treatment encourages decay in a controlled situation in order that the material may be disposed of in a stable form. When organic matter decays under anaerobic conditions (putrefaction), undesirable odors are produced. In aerobic processes, the odors are much less objectionable than those produced by anaerobic decomposition.

Detritus (die-TRY-tus): The heavy, coarse material carried by wastewater.

Digester (die-JEST-er): A tank in which sludge is placed to allow sludge digestion to occur. Digestion may occur under anaerobic (more common) or aerobic conditions.

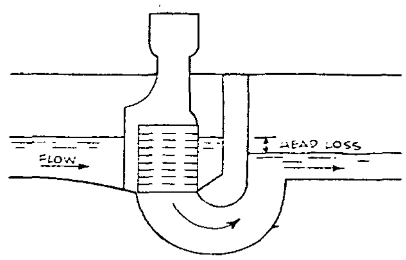
Dissolved Oxygen: Atmospheric oxygen dissolved in water or wastewater, usually abbreviated DO.

Effluent (EF-lu-ent): Wastewater or other liquid--raw, partially or completely treated--flowing from a basin, treatment process, or treatment plant.

Grit: The heavy mineral material present in wastewater, such as sand, gravel, cinders, and eggshells.

Grit Removal: Grit removal is accomplished by providing an enlarged channel which causes the velocity of the flowing wastewater to be reduced and allows the heavier grit to settle to the bottom of the channel where it can be removed.

Head Loss: "Head" is a common term used in discussing pumps. It is a way of expressing pressure in terms of the height of a vertical column of water. In the sketch, the head loss is the height to which the water must build up until there is sufficient pressure to force that particular amount of water through the slots in the comminutor drum.



Influent (IN-flu-ent): Wastewater or other liquid--raw or partially treated--flowing into a reservoir, basin, treatment process, or treatment plant.

Inorganic Material: Material such as sand, salt, iron, calcium, and other mineral materials which are not converted in large quantities by organism action. Inorganic materials are chemical substances of mineral origin and may contain carbon and oxygen, whereas organic materials are chemical substances of animal or vegetable origin and contain mainly carbon and hydrogen along with other elements.

Organic Material: Material which comes from animal or vegetable sources. Organic material generally can be consumed by bacteria and other small organisms. Inorganic materials are chemical substances of mineral origin and may contain carbon and oxygen, whereas organic materials contain mainly carbon and hydrogen along with other elements.

Preaeration: A preparatory treatment of wastewater consisting of aeration to freshen the wastewater, remove gases, add oxygen, promote flotation of grease, and aid coagulation.

Pretreatment: Use of racks, screens, comminutors, and grit removal devices to remove metal, rocks, sand, eggshells, and similar materials which may hinder operation of a treatment plant.

Putrefaction (PU-tree-FACK-shun): Biological decomposition of organic matter with the production of ill-smelling products associated with anaerobic conditions.

Putrescible (pu-TRES-sib-bull): Putrescible material will decompose under anaerobic conditions and produce nuisance odors.

Rack: Parallel metal bars or rods evenly spaced and in the influent channel that remove rags, rocks, and cans.

Raw Wastewater: Plant influent or wastewater before treatment.

Screen: A device with openings generally uniformly sized to retain or remove suspended or floating objects in wastewater larger than the openings. A screen may consist of bars, rods, wires, gratings, wire mesh, or perforated plates.

Septic (SEP-tick): A condition produced by the growth of anaerobic organisms. If severe, the wastewater turns black, giving off foul odors and creating a heavy oxygen demand.

Sludge (sluj): The settleable solids separated from liquids, during processing or deposits on bottoms of streams or other bodies of water.

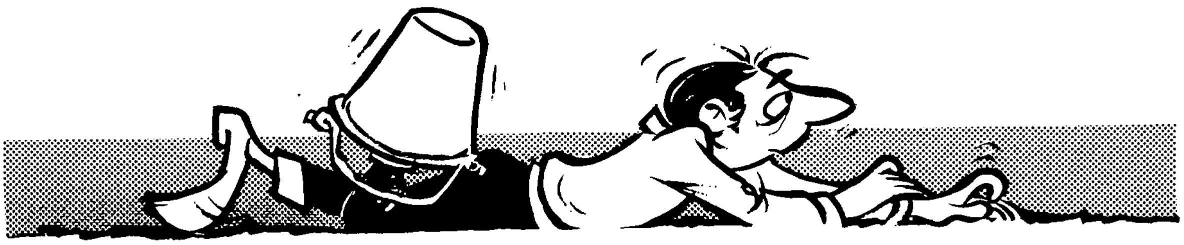
Sludge Digestion: A process by which organic matter in sludge is gasified, liquefied, mineralized, or converted to a more stable form by anaerobic (more common) or aerobic organisms.

Weir, Proportional (weer): A specially shaped weir in which the flow through the weir is directly proportional to the head.

CHAPTER 4. RACKS, SCREENS, COMMINUTORS, AND GRIT REMOVAL

4.0 CAUTION

Many wastewater treatment plant operators have been seriously injured due to unnecessary accidents. According to a survey by the Water Pollution Control Federation in 1967, the wastewater treatment and pollution control industry has a higher accident rate than any other industry reporting to the National Safety Council. Working in a wastewater treatment plant is not necessarily more dangerous than working in other industries. The poor record of the past may have been caused by operators not being aware of unsafe conditions, not immediately correcting these conditions when they became obvious, and not knowing safe procedures.



There are many potential safety hazards around a wastewater treatment plant. Accidents can be reduced by thinking safety. The operator should protect himself from injury by maintaining firm footing, keeping walk areas clear, immediately cleaning up spills, and shutting off the electrical power before working on equipment.

You must take adequate precautions to prevent becoming infected with water-borne diseases such as dysentery or typhoid. At any given moment in time, some people in your community are ill; and disease organisms and viruses from these people are in the wastewater reaching your plant. The operator who cleans equipment such as pumps, bar screens, and grit chambers often must place his hands in raw wastewater. Also, the tools used to work on equipment frequently become contaminated. Good personal hygiene must be observed by all operators at all times. Always wash your hands thoroughly before eating or smoking.

A good practice is to change work clothing before going home. Any clothing that has been worn at the wastewater treatment plant must be laundered separately from the family wash.

QUESTIONS

TRUE OR FALSE:

4.0A The wastewater and pollution control industry in 1967 had an accident rate higher than any other industry reporting to the National Safety Council.

4.0B Electrical power must always be shut off before working on equipment.

4.0C An operator should always wash his hands thoroughly before eating or smoking.

4.1 INTRODUCTION TO PRETREATMENT

In various ways, a little or a lot of almost everything finds its way into sewers and ends up at the wastewater treatment plant. Cans, bottles, pieces of scrap metal, sticks, rocks, bricks, plastic toys, plastic lids, caps from toothpaste tubes, towels and other rags, sand--all are found in the plant influent.[1]

These materials are troublesome in various ways. Pieces of metal, rocks, and similar items will cause pipes to plug, may damage or plug pumps, or jam sludge collector mechanisms in settling tanks (clarifiers).[2] Sand, eggshells, and similar materials (grit) can plug pipes, cause excessive wear in pumps, and use up valuable space in the sludge digesters.[3]

If a buried or otherwise inaccessible pipe is plugged, or a sludge collector mechanism jams, or a critical pump is put out of commission, serious consequences can result. Reduced plant efficiency allows a heavy pollutional load on the receiving waters, causing health hazards to downstream water users, sludge deposits in stream or lake (with resultant odors and unsightliness), and sometimes causing the death of fish and other aquatic life. Also, a good deal of hard (sometimes rather unpleasant) work is involved, and usually there are heavy (and unbudgeted) expenses.

With these things in mind, it is evident that an important part of a wastewater treatment plant is the equipment used to remove the rocks and other materials as early as possible. These items of equipment are screens, racks, comminutors, and grit removal devices and are called pretreatment facilities. See Fig. 4.1 for location of these processes in a typical plant.

---

[1] Influent (IN-flu-ent). Wastewater or other liquid--raw or partly treated--flowing into a reservoir, basin, treatment process, or treatment plant.

[2] Clarifier (KLAIR-i-fire) (settling tank, sedimentation basin). A tank or basin in which wastewater is held for a period of time so that the heavier solids settle to the bottom and the lighter material will float to the water surface.

[3] Digester (die-JEST-er). A tank in which sludge is placed to allow sludge digestion to occur. Digestion may occur under anaerobic (more common) or aerobic conditions.

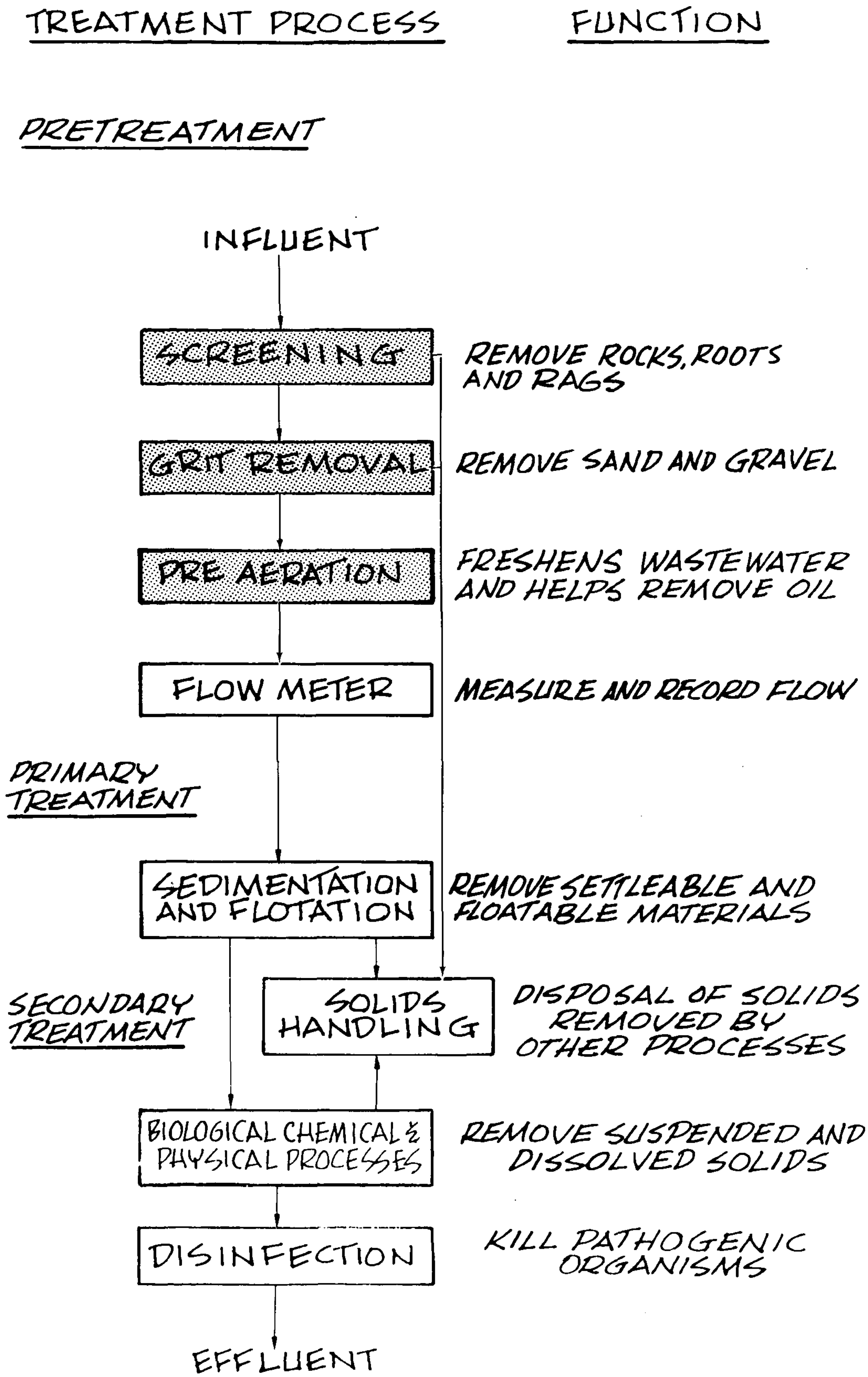


Fig. 4.1 Flow diagram of typical plant

QUESTIONS

4.1A The following items may be found in a treatment plant influent:

a. Cans
b. Toys
c. Rubber Goods
d. Pieces of Wood
e. All of These

4.1B What items of equipment are used to remove rocks, pieces of wood, metal, and rags from wastewater?

4.1C Why should coarse material (rocks, boards, metal, etc.) be removed at the plant entrance?

4.2 SCREENS AND RACKS

Parallel bars may be placed at an angle in a channel in such a manner that the wastewater will flow through the bars, but the large solids will be caught on the bars. These bars are commonly called racks when the spacing between them is 3" to 4" or more. When the spacing is about 1" to 2", they are usually called bar screens.

4.20 Manually Cleaned Bar Screens

Manually cleaned bar screens (Fig. 4.2) require frequent attention. As debris collects on the screen, it blocks the channel, causing the wastewater to back up into the sewer. This, in turn, causes organic materials[4] to settle out; the dissolved oxygen[5] is depleted; and septic[6] conditions develop, producing hydrogen sulfide which causes a rotten egg odor and is corrosive to concrete, metal, and paint. If cleaning of the screens is infrequent, the sudden rush (when they do get cleaned) of septic wastewater creates a sudden "shock" load on the plant, sometimes resulting in a poor quality plant effluent.[7]

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[4] Organic Material. Material which comes from animal or vegetable sources. Organic material generally can be consumed by bacteria and other small organisms. Inorganic materials are chemical substances of mineral origin and may contain carbon and oxygen, whereas organic materials contain mainly carbon and hydrogen along with other elements.

[5] Dissolved Oxygen. Atmospheric oxygen dissolved in water or wastewater, usually abbreviated DO.

[6] Septic (SEP-tick). Wastewater devoid of dissolved oxygen. If severe, the wastewater turns black, giving off foul odors and creating a large oxygen demand.

[7] Effluent (EF-lu-ent). Wastewater or other liquid--raw, partially or completely treated--flowing from a basin, treatment process, or treatment plant.

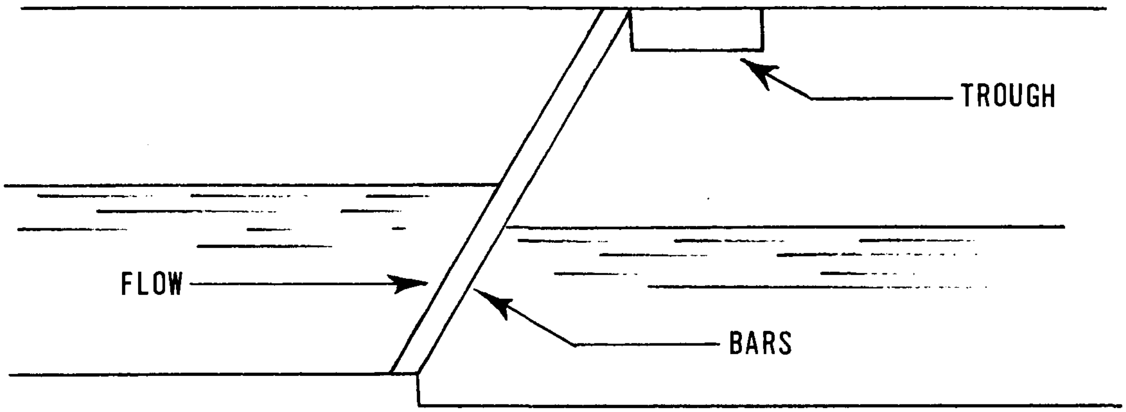


Fig. 4.2 Manually cleaned bar screen

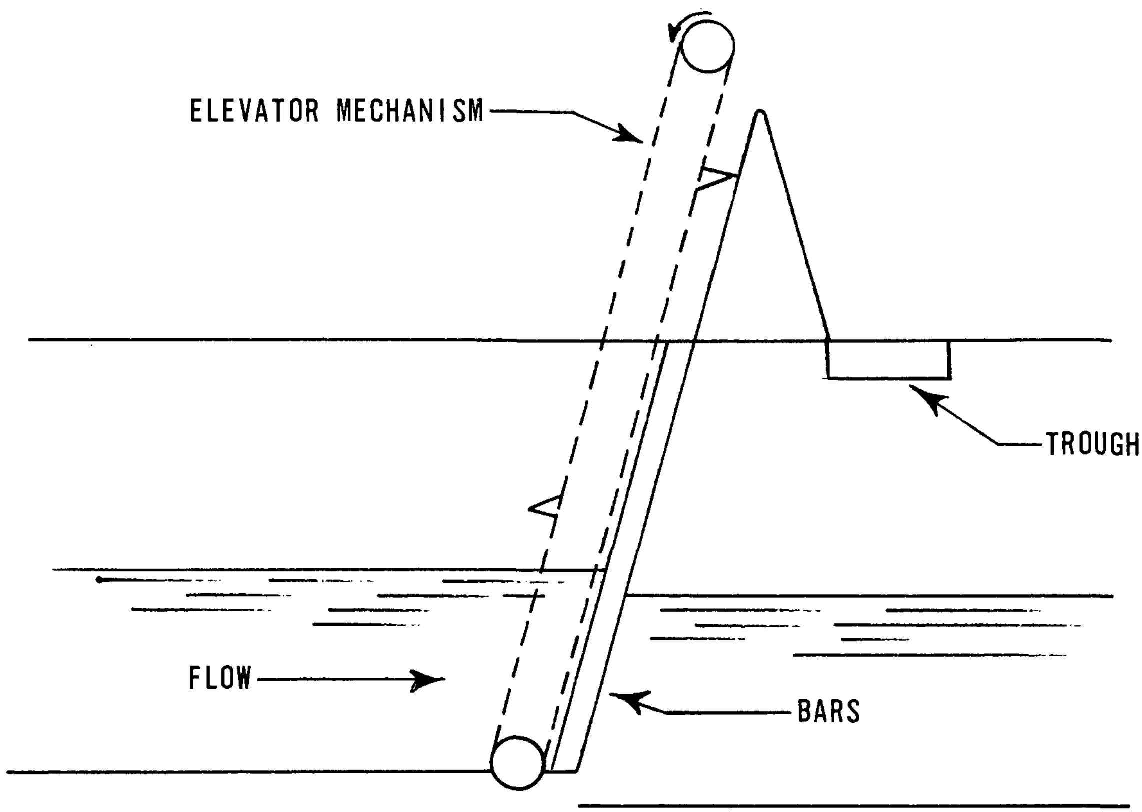


Fig. 4.3 Mechanically cleaned bar screen

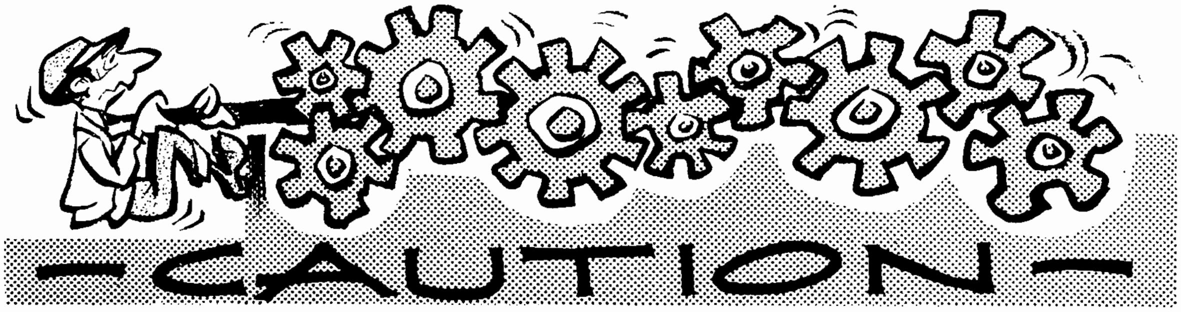
Cleaning of bar screens is accomplished with a rake with tines (prongs) which will fit between the bars. Extreme caution should be taken when raking the screen--footing may be poor due to the water and grease underfoot, lack of enough room to stand, location of the receptacle for the debris, etc. You should look this area over carefully to spot hazards and take corrective action.

Good housekeeping, a guard rail, a hanger or other storage for the rake, good footing, etc. will greatly reduce the possibility of injury.

4.21 Mechanically Cleaned Screens

Mechanically cleaned screens (Fig. 4.3) overcome the problem of wastewater backing up and greatly reduce the time required to take care of this part of your plant. There are various types of mechanisms in use, the more common being traveling rakes which bring the debris up out of the channel and into hoppers or other receptacles. You should keep these units well lubricated and adjusted. Follow the manufacturer's recommendations carefully. A few minutes spent in proper maintenance procedures can save hours or days of trouble and help to keep the plant operating efficiently.

Occasionally some debris will be present which the equipment cannot remove. Periodic checks should be made so that these materials can be removed by hand. To determine if some material is stuck in the screen, divert the flow through another channel or "feel" across the screen with a rake or similar device.



Always shut the unit off first. Never reach into the operating range of machinery while it is running. Slow-moving equipment is especially hazardous. Because it moves slowly, it does not appear dangerous. However, most geard-down machinery is so powerful that it can crush almost any obstruction. A HUMAN HAND, FOR INSTANCE, OFFERS LITTLE RESISTANCE TO THIS TYPE OF EQUIPMENT.

Various other mechanical methods are in use, involving actual coarse screens or perforated sheet metal. These units are automatically cleaned with scrapers, rotating brushes, water sprays, or air jets. The screens may be in the form of belts, discs, or drums set in a channel so that the wastewater flows through the submerged portion, with the collected debris being removed as it passes the brushes or sprays.

4.3 DISPOSAL OF SCREENINGS

The material removed from the screens is very offensive and hazardous. It produces obnoxious odors and draws rats and flies. Burial, incineration, and shredding or grinding are three common methods of disposal. If the screenings are buried, at least six inches of earth cover must be provided immediately. The final earth cover must be deep enough to prevent flies from reaching the screenings through cracks caused by settling. At small plants with manually cleaned bar screens, an enterprising operator can make a "press" from a piece of steel pipe or casing, using a heavy screw, rack and pinion, or even an automobile jack to provide pressure, to dewater the screenings before disposal. The practice of using grinders (shredders, disintegraters, etc.) to cut up screenings and return them to the effluent can impose a great load on following treatment processes.

Depending on plant location and surroundings, you may find it necessary to plan ahead to find areas required for disposal of screenings. If burial is used, you should estimate how long a certain area can be used before you must find additional space for disposal. The disposal site volume divided by the daily volume of screenings produced will tell you how many days the site will last. For example, assume your plant has a flow of two million gallons per day (MGD) and that over a two-week period you remove an average of 30 gallons of screenings daily. This figures out to four cubic feet (cu ft) per day. You bury the screenings each day in a pit which you estimate will hold 15 cubic yards of screenings in addition to the soil used to cover up the screenings.

(1 cu ft = about 7.5 gallons for practical purposes)

Thus:

$$\text{Volume, cu ft/day or Filling Rate} = \frac{\text{Volume, gal/day}}{7.5\text{ gal/cu ft}}$$

$$= \frac{30\text{ gal/day}}{7.5\text{ gal/cu ft}}$$

$$= 4\text{ cu ft/day}$$

You should convert gallons to cubic feet (ft^3 or cu ft) or cubic yards (yd^3, cu yd) because earth work is figured on this basis. With this information, you are now prepared to estimate how long before the pit will be filled up.

First, convert the 15 cu yd (pit) capacity to cu ft:

$$\text{Pit Capacity, cu ft} = \text{Capacity, cu yd} \times 27\ \frac{\text{cu ft}}{\text{cu yd}}$$

$$= 15\text{ cu yd} \times 27\ \frac{\text{cu ft}}{\text{cu yd}}$$

$$\begin{array}{r} 27 \\ \times 15 \\ \hline 135 \\ 27 \\ \hline 405 \end{array}$$

$$= 405\text{ cu ft}$$

Second, divide the pit capacity by the daily volume of screenings to find time before pit is full:

$$\text{Time, days} = \frac{\text{Pit Capacity, cu ft}}{\text{Filling Rate, cu ft/day}}$$

$$= \frac{405 \text{ cu ft}}{4 \text{ cu ft/day}}$$

$$= \text{About 101 days}$$

Thus you have about 101 days from the time you begin to bury screenings in the pit until you will have to dig another. You should keep daily records of the volume of screenings buried to be sure it stays about the same. If it increases very much, it could be due to an increase in daily wastewater flow or perhaps some unnecessary disposal of rags or other material into the sewer. You may get anywhere from 0.5 to 12 cubic feet of screenings per million gallons of wastewater flow, but it should stay fairly constant for your plant unless something unusual is happening.

You can check on the daily flow in MGD, or during any time period, by reading your flow totalizer. The totalizer records the total flow through the plant. If you record the totalizer reading at the start and at the end of any time period, the difference is the total flow for that time period.

QUESTIONS

4.2A Manually cleaned bar screens should be cleaned frequently to prevent:

a. the screen from breaking
b. septic conditions from developing upstream
c. a shock load on the plant when eventually cleaned
d. formation of hydrogen sulfide, which causes rotten egg odors and corrosion of concrete and paints
e. all of these

4.2B What safety precautions should be taken when cleaning a bar screen?

4.2C What should be done first if a problem develops in a mechanically cleaned screen?

4.3A How can screenings be disposed of?

4.3B A plant receives a flow of 4.4 million gallons (MG) on a certain day. The day's screenings are calculated to be 11 cubic feet. How many cubic feet of screenings were removed per MG of flow?

4.4 COMMINUTION (com-min-OO-shun)

Comminutors are devices which act as a cutter and a screen. Their purpose is to shred (comminute) the solids and leave them in the wastewater. This overcomes problems of screenings disposal. As with screens, they are mounted in a channel, and the wastewater flows through them. The rags, etc., are shredded by cutters (teeth) until they can pass through the openings. Pieces of wood and plastic are rejected and must be removed by hand. Most of these units have a shallow pit in front of them to catch rocks and scrap metal. The flow to the comminutor should be shut off periodically and the debris removed from the trap. The frequency of checking the trap can be determined from experience. However, it is not wise to allow more than a few days between checks.

A comminutor consists of a rotating drum with slots for the wastewater to pass through (Fig. 4.4). Cutting teeth are mounted in rows on the drum. The teeth pass through cutter bars or "combs" with very small clearances so that a shearing action is obtained. The wastewater passes into the vertically mounted drum through the slots in the drum and flows out the bottom. A rubber seal, held in place by a bolted-down ring, prevents leakage under the drum. This seal should be checked whenever the rock and scrap metal trap is checked.

Some comminutors also have a mercury seal (Fig. 4.5) to keep water out of the bearings. This is because these units are designed so that, at their rated capacity, the top of the drum will be under several inches of water. This head loss[8] will be specified in the manufacturer's instructions. The mercury seal should be checked annually or after a particularly heavy flow. Drain the mercury; weigh it (the amount of mercury will be specified by weight); and if it is dirty, strain it through some heavy material (such as denim or chamois) before putting it back in the comminutor. (You will probably have to

---

[8] Head Loss. "Head" is a common term used in discussing pumps. It is a way of expressing pressure in terms of the height of vertical column of water. In this case, the head loss is the height to which the water must build up in front of the drum until there is sufficient pressure to force that particular amount of water through the slots (Fig. 4.4).

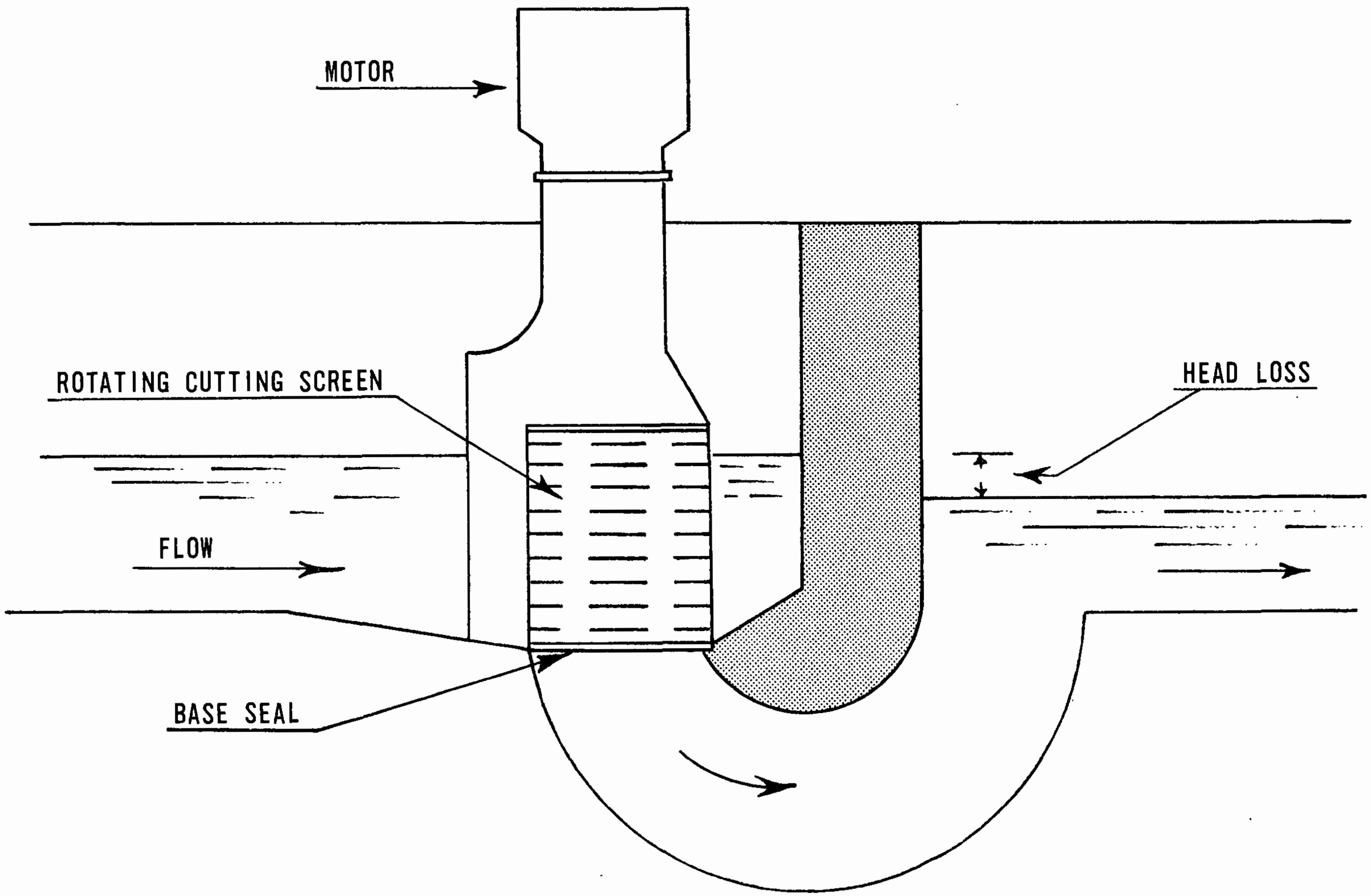


Fig. 4.4 Comminutor

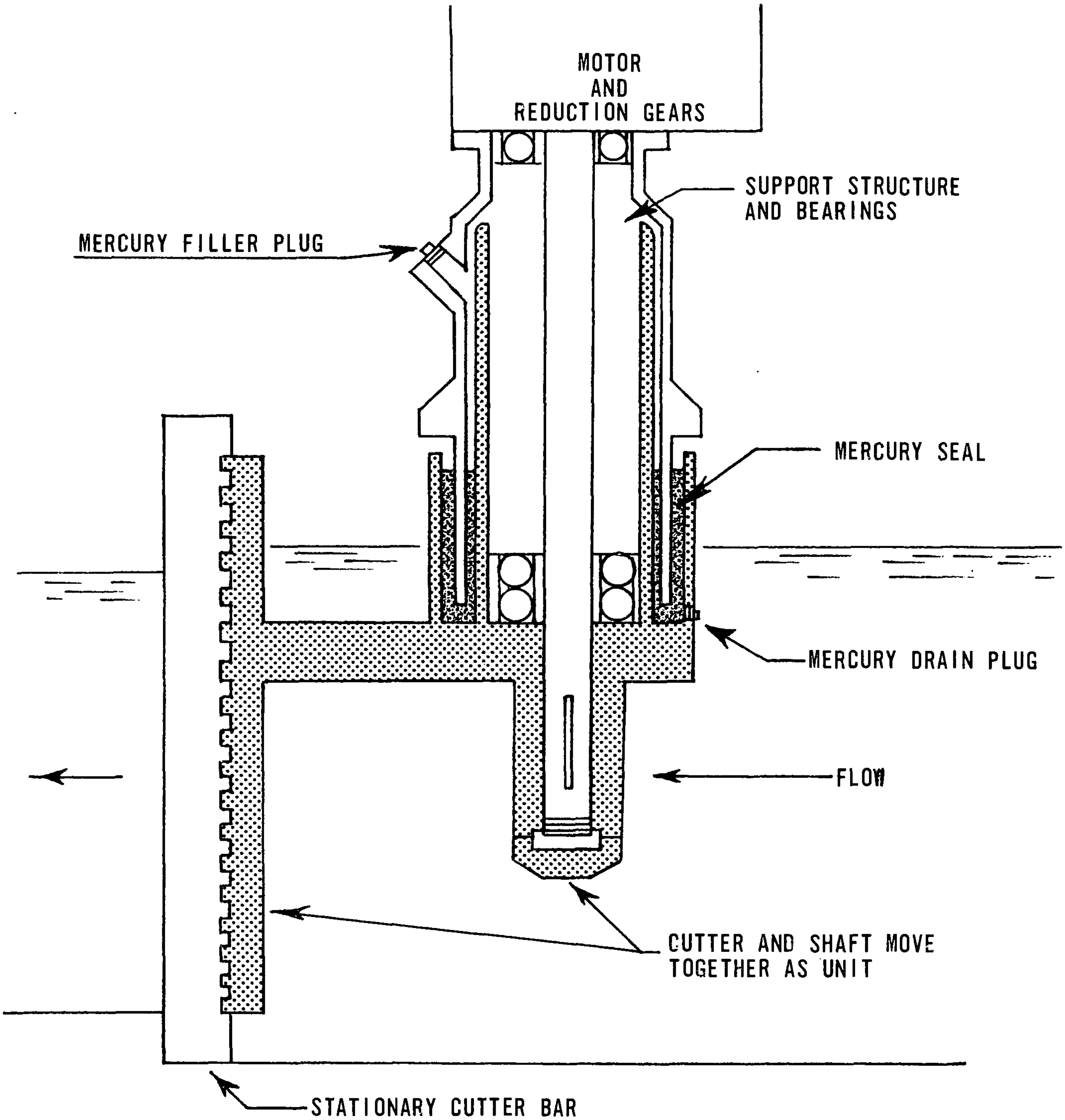
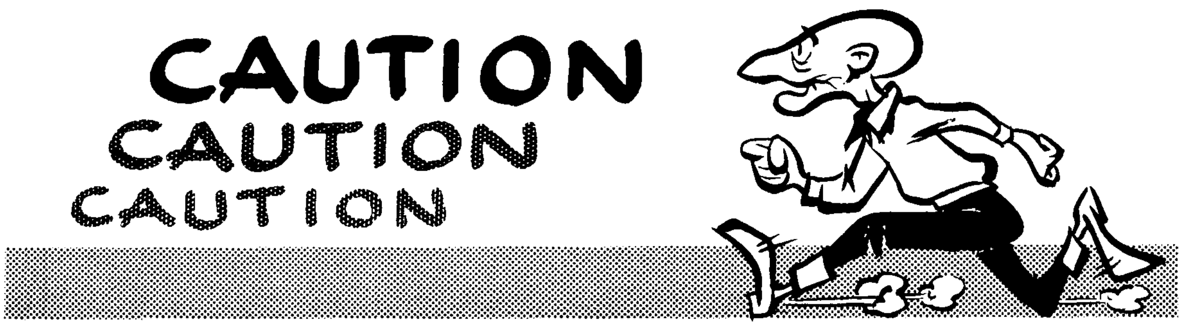


Fig. 4.5 Mercury seal in comminutor

squeeze the mercury through the cloth or, if laboratory equipment is available, use a suction flask.) Add more mercury if needed.



Mercury is poisonous. Breathing the fumes can be fatal **or cause** loss of hair and teeth. Wash up thoroughly after handling it. Remove gold rings, etc., from your hands first, as they may end up coated with mercury. If your ring is thus coated, it will have to be heated to burn off the mercury. If you must handle or work with mercury, be sure to work over a large tray in order to catch any spills. Plenty of fresh air ventilation is an absolute must.

There are many variations of the comminutor. One of the more common ones has the trade name of "barminutor" (Fig. 4.6). This unit consists of a bar screen made of U-shaped bars and a rotating drum with teeth and "shear bars". The rotating drum travels up and down the bar screen. Careful attention must be given to maintaining the oil level in these machines; otherwise, water may get into the bearings. Consult the manufacturer's instructions for detailed procedures.

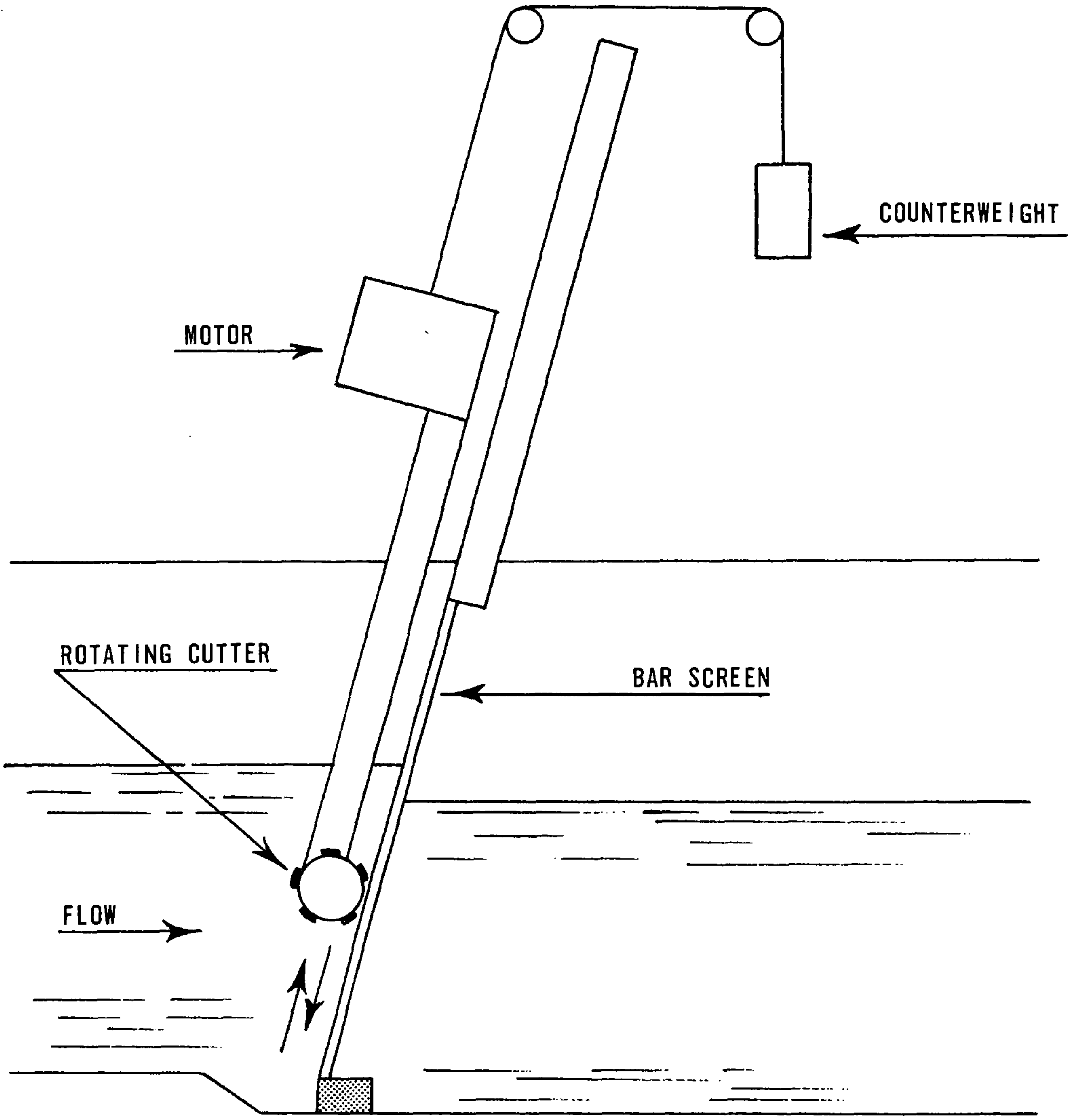


Fig. 4.6 Barminutor

QUESTIONS

4.4A What are the advantages of comminuting machines over screens?

4.4B When should you check the mercury seal in a comminutor?

4.4C Handling mercury is hazardous because:

a. It is poisonous

b. Breathing fumes may be fatal

c. Breathing fumes may cause loss of hair and teeth

4.5 GRIT REMOVAL

Grit (sand, eggshells, cinders, etc.) is the heavier mineral matter in wastewater which will not decompose or "break down". It causes excessive wear in pumps. A mixture of grit, tar, grease and other cementing materials can form a solid mass in pipes and digesters that will not move by ordinary means. Consequently, grit should be removed as soon as possible after reaching the plant.

4.6 GRIT CHAMBERS (Fig. 4.7)

The simplest means of removing grit from the wastewater flow is to pass it through channels or tanks which allow the velocity of flow to be reduced to a range of 0.7 to 1.4 ft/sec. The objective is to allow the grit to settle to the bottom, while keeping the lighter organic solids moving along to the next treatment unit. Experience has shown that a flow-through velocity of one foot per second (ft/sec) is best.

Velocity is controlled by several means. With multiple-channel installations, the operator may vary the number of channels (chambers) in service at any one time to maintain a flow velocity of approximately one ft/sec in the grit chambers. Other methods involve the use of proportional weirs (Fig. 4.8) at the outlet for automatic regulation.

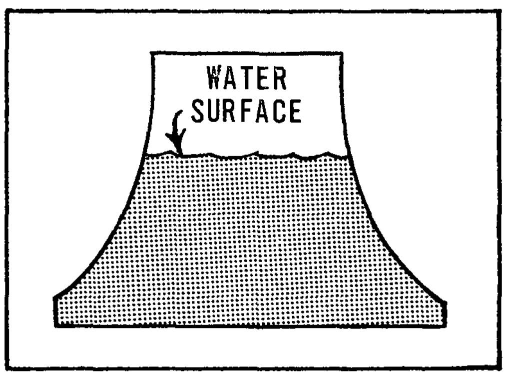


Fig. 4.8 Proportional weir

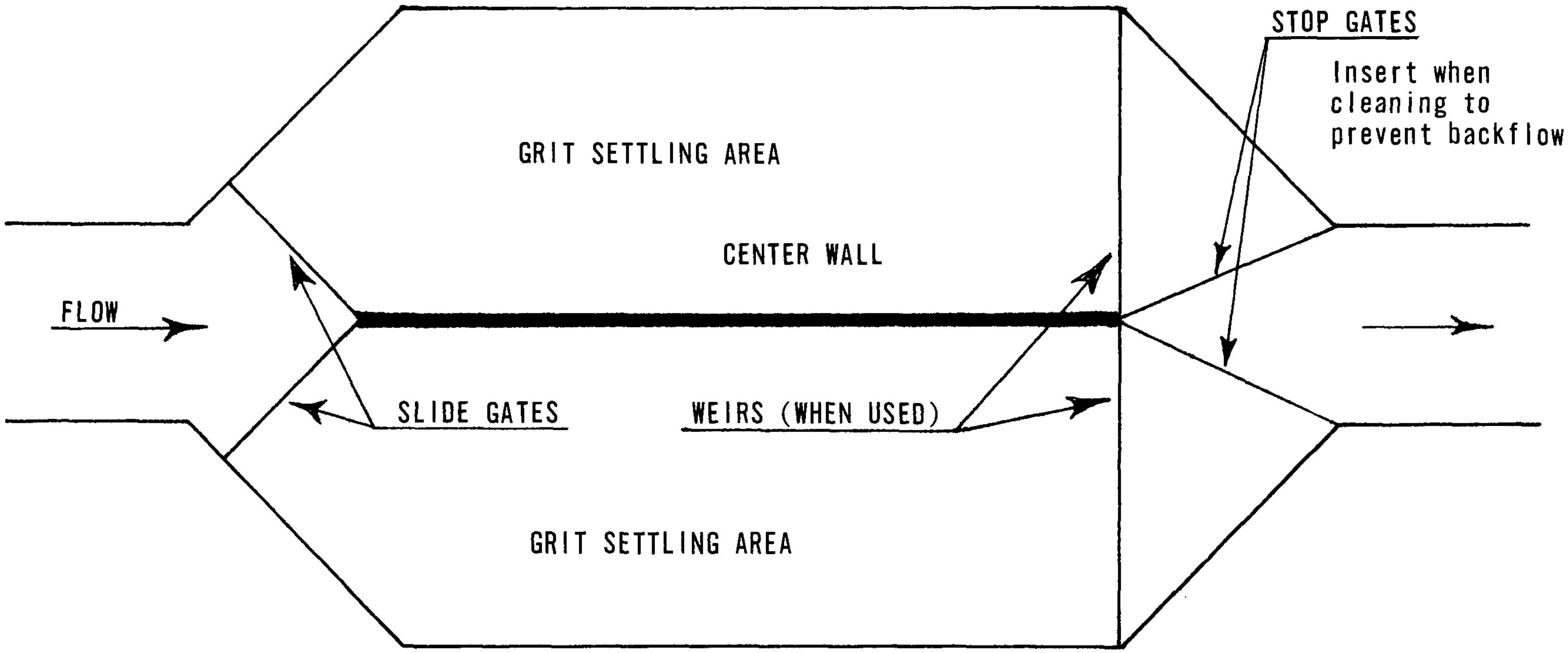


Fig. 4.7 Grit Chamber

The proportional weir in Fig. 4.8 will tend to decrease the velocity in the grit chambers when the flows increase because the exit area will decrease, thus increasing the depth of water flow in the channel. If the operator wishes to increase the velocity in a grit chamber, he could use a proportional weir and turn it over so the exit area increased as the flow increased. This would tend to keep the depth of water flow in the channel low and cause higher velocities. A barrier with a variable height at the outlet of the grit chamber can be used instead of a proportional weir to regulate velocities.

Flow velocities also may be regulated by the shape of the grit chamber instead of placing devices at the outlet. Some grit chambers have cross-sectional shapes similar to a proportional weir. The operator may regulate the velocities in a grit chamber by using boards to change cross-sectional shape, but he should seriously consider any maintenance or operational problems that might develop when trying to keep the grit chamber clean.

A simple method of estimating the velocity is to place a stick in the channel and time its travel for a measured distance. Calculate as follows:

$$\text{Velocity, ft/sec} = \frac{\text{Distance traveled, ft}}{\text{Time, sec}}$$

Example:

A stick travels 25 feet in 20 seconds.

Solution:

$$\text{Velocity, ft/sec} = \frac{\text{Distance, ft}}{\text{Time, sec}}$$

$$= \frac{25 \text{ ft}}{20 \text{ sec}}$$

$$= 1.25 \text{ ft/sec}$$

$$\begin{array}{r} 1.25 \\ 20 \overline{)25.00} \\ \underline{20} \\ 5\,0 \\ \underline{4\,0} \\ 1\,00 \\ \underline{1\,00} \\ 0 \end{array}$$

The actual velocity probably will be slightly higher than your estimate, but it is a very quick way to check the grit chamber velocity.

A more accurate method of determining the average velocity in the grit chamber is to find the cross-sectional area of the wastewater flowing in the grit chamber and the quantity of flow (from the flow meter) and calculate as shown in the following example.

Example:

Assume your grit chamber is two feet wide. The wastewater is flowing at a depth of one foot, and the flow meter registers a flow of 1 MGD. The cross-sectional area of the flow is (depth, ft x width, ft = 1 ft x 2 ft) = 2 sq ft. The flow must be converted into cubic measure. We learned that one cubic foot equals 7.5 gallons. Thus, from calculations below, 1 MGD = 1.55 cu ft/sec (cubic feet per second, cfs):

$$1 \text{ MGD} = \frac{(1{,}000{,}000 \ \frac{\text{gal}}{\text{day}})}{(7.5 \ \frac{\text{gal}}{\text{cu ft}} \times 24 \ \frac{\text{hr}}{\text{day}} \times 60 \ \frac{\text{min}}{\text{hr}} \times 60 \ \frac{\text{sec}}{\text{min}})}$$

Using this new conversion factor:

$$\text{Average Velocity, ft/sec} = \frac{\text{Flow Rate, cu ft/sec}}{\text{Area, sq ft}}$$

$$= \frac{1.55 \text{ ft}^3\text{/sec}}{2 \text{ ft}^2}$$

$$= 0.77 \text{ ft/sec}$$

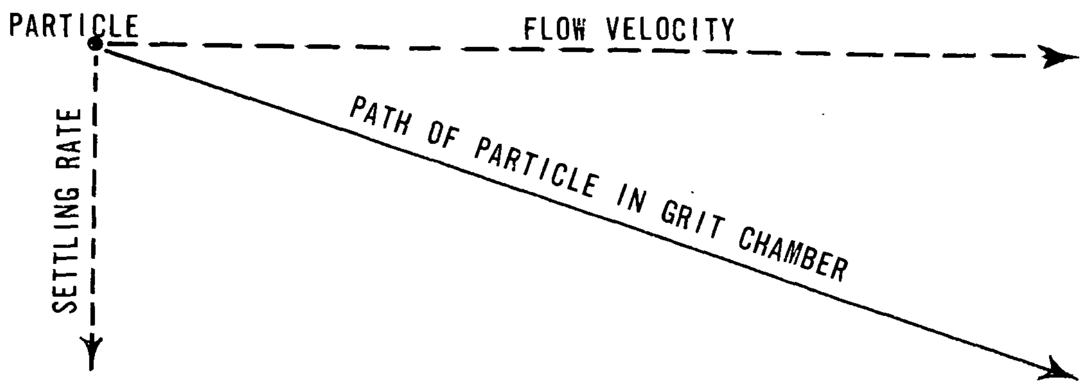
To obtain this answer, we converted the flow from MGD to ft^3/sec and divided the flow (1.55 cu ft/sec) by the cross sectional area of the wastewater in the channel (2 sq ft).

Since we have checked the velocity, we should now determine if the length of the channel is appropriate for our flow conditions. All particles settle at different rates based on their size and weight. Most grit chambers are designed to remove 0.2 mm (millimeter) size sand and all other heavier material. Experiments have shown this size particle will settle downward at about 0.075 ft/sec. This means that if wastewater is flowing in a channel at a depth of one foot and a particle of 0.2 mm is introduced at the surface it will take:

$$\text{Settling Time, sec} = \frac{\text{Depth, ft}}{\text{Settling Rate, ft/sec}}$$

$$= \frac{1 \text{ ft}}{0.075 \text{ ft/sec}}$$

$$= 13.3 \text{ seconds to settle}$$



If this waste were flowing at one foot per second, it would travel for 13.3 seconds, or a distance of 13.3 feet, before the particle reached the channel bottom. If the waste were flowing at a depth of three feet in the channel, it would take 13.3 seconds/ft x 3 ft = 39.9 seconds or 39.9 feet before the particle reached the bottom. Therefore, the required length of any grit chamber can be checked by using the formula:

$$\text{Length, ft} = \frac{(\text{depth of chamber, ft})\ (\text{flow velocity, ft/sec})}{(\text{Settling Rate, ft/sec})}$$

$$= (\text{settling time, sec})\ (\text{flow velocity, ft/sec})$$

and for 0.2 mm sand and a flow velocity of 1 ft/sec:

$$\text{Length, ft} = \frac{(\text{depth, ft})\ (1.0\ \text{ft/sec})}{(0.075\ \text{ft/sec})}$$

$$= \frac{1.0 \times \text{depth, ft}}{0.075}$$

$$= 13.3 \times \text{depth, ft}$$

In case of dead spots (where organic materials settle out and become putrescrible[9]), a deflector (Fig. 4.9) installed at one side may cure the trouble. Be sure you don't create a new dead spot. Also, certain trouble spots could be filled in with concrete.

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[9] Putrescible (pu-TRES-sib-bull). Putrescible material will decompose under anaerobic conditions and produce nuisance odors.

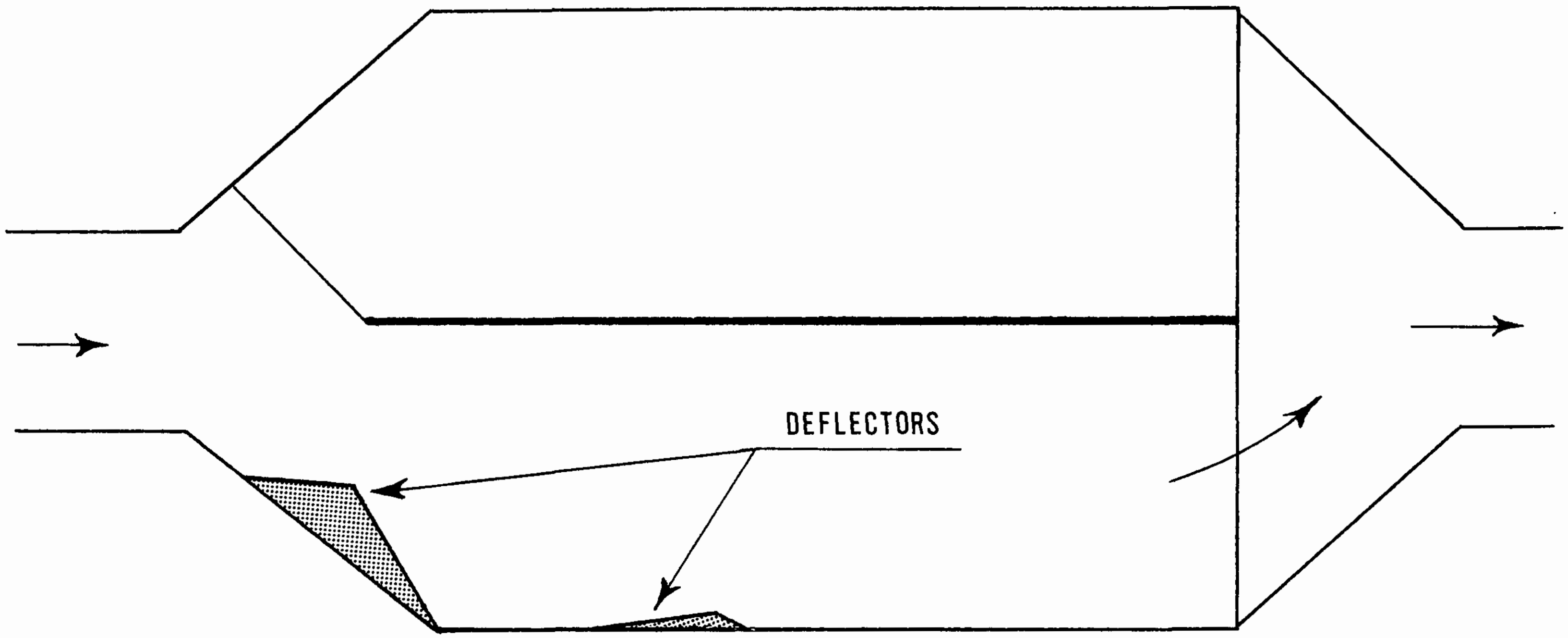

Fig. 4.9 Deflectors installed in a grit chamber

Removal of grit ranges from use of a scoop shovel to various types of collectors and conveyors. For hand-cleaned chambers, the frequency of cleaning is determined by experience. If the channel can be removed from service during the cleaning operation, the job is made easier, and no grit is washed into the plant.

Since there is always a small amount of organic matter in the grit chamber, disposal of grit should be treated the same as screenings. Burial is the most satisfactory disposal method. Failure to quickly cover grit results in odors and attracts flies and rats.

Cleaning grit chambers manually can be quite hazardous. Take precautions against slipping and back strain. Beware of dangerous gases when working in covered grit chambers.

There are many types of mechanical grit collector mechanisms. Common ones are chain-driven scrapers (called "flights") (Fig. 4.10) that are moved slowly along the bottom and up an incline out of the water to a hopper, or along the bottom to an underwater trough where a screw conveyor lifts the grit to a storage hopper or truck. Some designs use conveyor belts with buckets attached.

An aerated grit chamber is actually a tank with a sloping bottom and a hopper or trough in the lower end (Fig. 4.11). Air is injected along the wall of the tank above the trough. The rolling action of the water in the tank moves the grit along the bottom to the grit hopper. Grit is removed from the hopper by a conveyor system.

Aerated grit chambers are most frequently found at activated sludge plants where there is a readily available air supply, and the pre-aeration helps to "freshen" the wastewater. The older wastewater becomes the more difficult it is to treat. A freshening process tends to make later processes more effective.

Fig. 4.10 Chain-driven scrapers (flights)

(Courtesy Jeffrey Mfg. Co.)

A grit chamber with a slower flow velocity than recommended may allow appreciable organic matter to settle out with the grit. This mixture of grit and organic matter is called detritus.[10] In some plants grit chambers are called detritus tanks. Organic matter may be separated from the grit by blowing air through or washing the detritus to resuspend the organic matter. Centrifuges also are used to separate grit from sludge or organic matter from grit.

[10] Detritus (de-TRI-tus). The heavy, coarse material carried by wastewater.

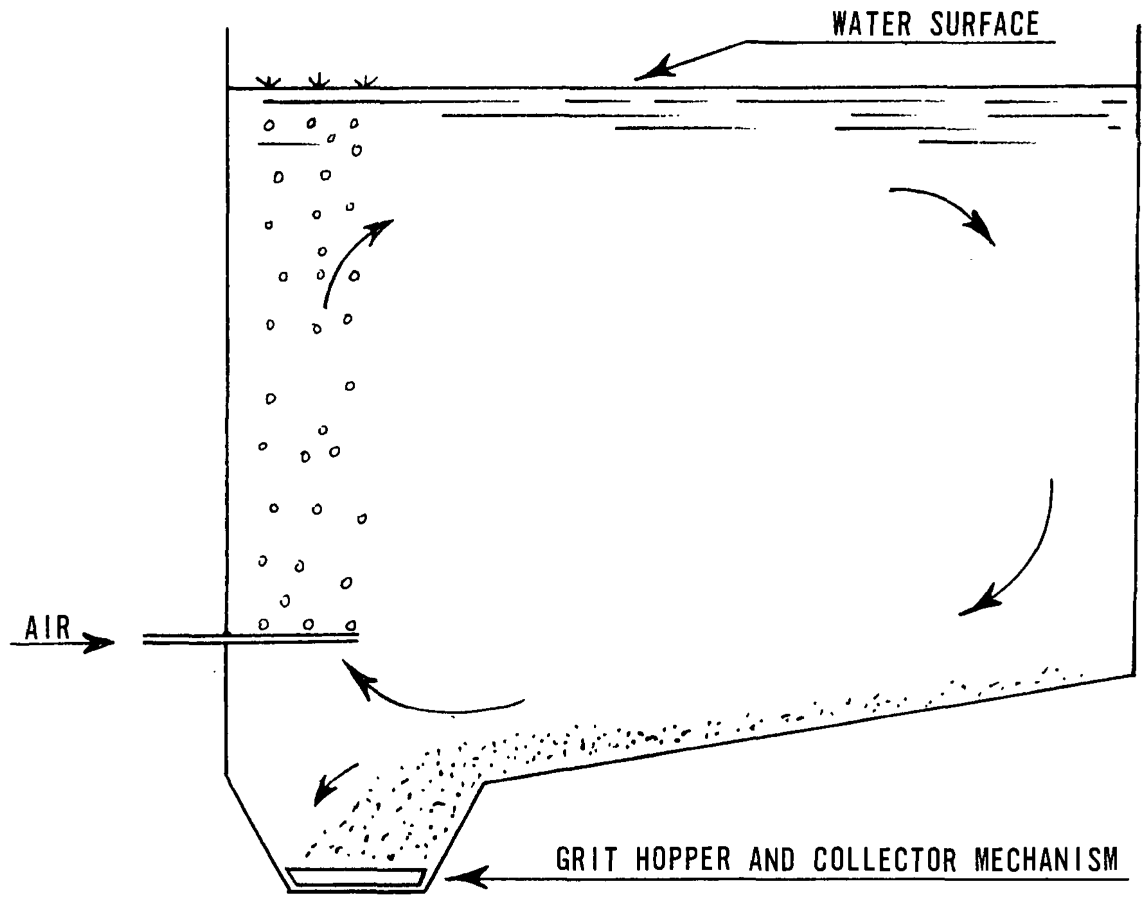

Fig. 4.11 Aerated grit chamber

QUESTIONS

4.5A Grit is composed mostly of which of the following substances?

a. Grease

b. Sand

c. Rubber Goods

d. Eggshells

e. Wood

4.5B Why bother to remove grit?

4.6A How can you control the velocity in a grit chamber in order to maintain velocities within a range of approximately 0.7 to 1.4 fps?

4.6B A stick travels 20 feet in 40 seconds in a grit chamber.

a. What is the velocity in the chamber?

b. What corrective action should be taken, if any?

4.6C What is most hazardous about manually cleaning a grit chamber?

4.6D Assume you wish to calculate the velocity in the grit chamber at your plant's peak flow. Examining the flow charts, you determine that peak flows are usually about 2.75 MGD. The grit chamber is three feet wide, and the flow depth is 17 inches at peak flow. What is the velocity in the grit chamber under these conditions?

4.7 QUANTITIES OF GRIT

Plants having well-constructed separate wastewater collection systems can usually expect to average 1 to 4 cu ft of grit per million gallons. These quantities have been rising in recent years due to household garbage grinders. They can also be expected to increase during storm periods.

Plants receiving waste from combined collection systems can expect to average 4 to 15 cu ft of grit per million gallons with peaks during storm periods many times higher. Grit collected during storm periods has been reported at over 500 cu ft per million gallons, probably the result of flow from broken sewers or open channels.

Records of grit quantities should be kept in the same manner as for screenings.

QUESTION

4.7A Your plant has an average flow of 2.0 MGD. An average of 4 cu ft of grit is removed each day. How many cu ft of grit per MG of flow are removed?

4.8 GRIT WASHING

In some cases it is necessary or desirable to use grit as fill material. Since a small amount of organic material settles out with the sand, etc., it becomes necessary to "wash" the grit. There are a number of devices built for this purpose. Most use water to wash the grit as it is being removed from the grit chamber (Fig. 4.12). In aerated grit chambers, the grit is ordinarily free enough of organics that it may be considered "washed". Chapter 5 of the Water Pollution Control Federation's Manual of Practice No. 11 has additional information and should be read carefully by the operator.

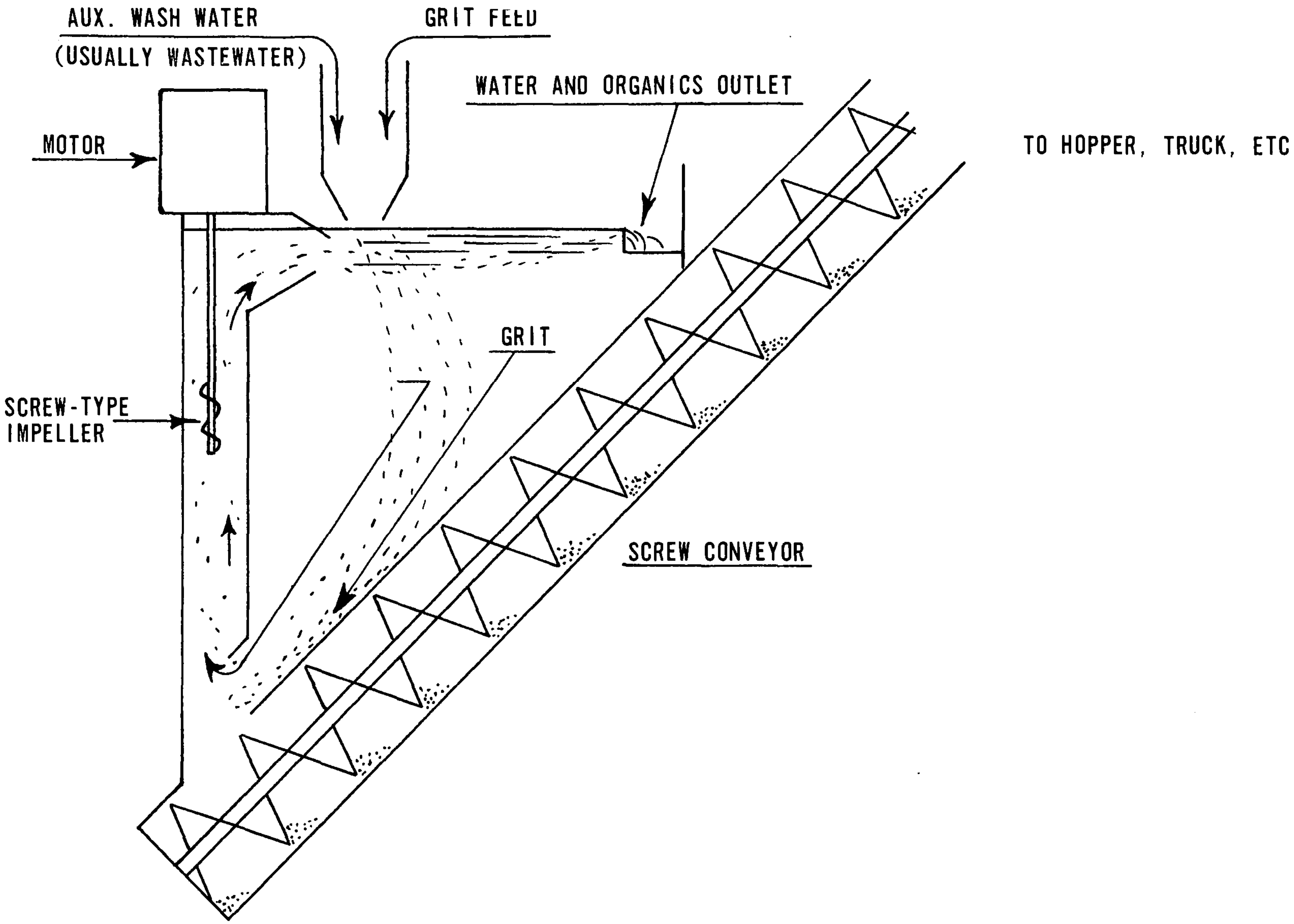

Fig. 4.12 Grit washer

QUESTION

4.8A Why is it sometimes necessary or desirable to "wash" grit?

4.9 PREAERATION

Preaeration is a wastewater treatment process used to freshen wastewater, remove gases, add oxygen, promote flotation of grease, and aid coagularion. The freshening of wastewater improves the effectiveness of following treatment processes. The process is usually located before primary sedimentation (Fig. 4.1). Other processes used to accomplish freshening include ozonation and prechlorination.

Preaeration consists of aerating wastewater in a channel or separate tank for 10 to 30 minutes. Aeration may be accomplished by either mechanical surface aeration units or diffused air system.[11] Air application rates with a diffused air system normally range from 0.5 to 1.0 cu ft of air per gallon of wastewater treated.

4.10 ADDITIONAL READING

a. MOP 11, pages 17-24

b. New York Manual, pages 27-29

c. Texas Manual, pages 160-173

d. Sewage Treatment Practices, by Bloodgood, pages 19-22 and 26-34

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[11] See Chapter 7, Activated Sludge, for a discussion of aeration facilities.

SUGGESTED ANSWERS

Chapter 4. Racks, Screens, Comminutors, and Grit Removal

4.0A True

4.0B True

4.0C True

4.1A (e) All of these.

4.1B Large pieces of material, such as rocks, boards, metal, and rags, are removed by racks, screens, and grit removal devices.

4.1C Coarse material must be removed at the plant entrance to prevent damage to pumps, plugging of pipes, and filling of digesters.

4.2A (b), (c), and (d). Usually bar screens are very sturdy and will not collapse under the load from a blockage or an uncleaned screen.

4.2B Check to make sure that your footing will be secure by removing any slippery substances such as water and grease. Be certain there is adequate space to safely lift the screenings and a receptacle for the screenings (debris).

4.2C Identify the problem. Shut the machine off before working on the equipment. Any moving equipment is hazardous, regardless of its speed.

4.3A Screenings may be disposed of by covering them with a minimum of six inches of earth or incineration.

4.3B
$$\text{Quantity Removed, cu ft/MG} = \frac{\text{Volume Removed, cu ft/day}}{\text{Average Flow, MGD}}$$

$$= \frac{11 \text{ cu ft/day}}{4.4 \text{ MGD}}$$

$$= 2.5 \text{ cu ft/MG}$$

$$\begin{array}{r} 2.5 \\ 4.4\overline{)\,11.0} \\ \underline{8\,8} \\ 2\,2\,0 \\ \underline{2\,2\,0} \\ 0 \end{array}$$

4.4A Advantages of comminuting machines over screens include the elimination of screenings disposal, flies, and odor problems. A disadvantage is that plastic and wood may be rejected and must be removed by hand.

4.4B The mercury seal in a comminutor should be checked yearly or after a high water level has been experienced. If a given high water level has not disrupted the seal, you know that the unit is safe at least up to that level.

4.4C (a), (b), and (c). Mercury must be handled with caution at all times.

4.5A (b) and (d). Grit is composed of heavy material that will settle in the grit chamber at proper flow velocities.

4.5B Grit must be removed to prevent wear in pumps, plugged lines, and the occupation of valuable space in digesters.

4.6A (a) Vary the number of channels in service in a multiple-channel installation.

(b) Use of proportional weirs.

(c) Lining sides with planks if velocity is too low. This could occur in a new plant.

You have the right idea if your answer includes possible adjustments of the cross-sectional area of the flow channel.

4.6B (a) Velocity = 0.5 ft/sec.

(b) Reduce cross-sectional area.

4.6C Slipping or a back injury. Beware of dangerous gases when working in a covered grit chamber. Also, there have been instances of gasoline or similar material leaking into the sewer and creating a potentially explosive hazard.

4.6D (a) Convert the flow of 2.75 MGD to cu ft/sec.

$$\text{Flow, cu ft/sec} = \text{Flow, MGD} \times \frac{1.55 \text{ cu ft/sec}}{\text{MGD}}$$

$$= (2.75 \text{ MGD})\left(\frac{1.55 \text{ cu ft/sec}}{\text{MGD}}\right)$$

$$= 4.3 \text{ cu ft/sec}$$

$$\begin{array}{r} 2.75 \\ \underline{1.55} \\ 13\ 75 \\ 137\ 5 \\ \underline{275} \\ 4.2625 \end{array}$$

4.6D (b) Convert depth of flow from 17 inches to feet.

$$\text{Depth, ft} = \frac{17\text{ in}}{12\text{ in/ft}}$$

$$= 1.4\text{ ft}$$

$$\begin{array}{r} 1.4 \\ 12\overline{)17.} \\ \underline{12} \\ 5\ 0 \\ 4\ 8 \end{array}$$

(c) Calculate cross-sectional area of channel.

$$\text{Area, sq ft} = (\text{Depth, ft})(\text{Width, ft})$$

$$= (1.4\text{ ft})(3\text{ ft})$$

$$= 4.2\text{ sq ft}$$

(d) Calculate velocity.

$$\text{Average Velocity, ft/sec} = \frac{\text{Flow, cu ft/sec}}{\text{Area, sq ft}}$$

$$= \frac{4.26\text{ cu ft/sec}}{4.2\text{ sq ft}}$$

$$= 1.01\text{, or 1 ft/sec}$$

$$\begin{array}{r} 1.01 \\ 4.2\overline{)4.2\ 6} \\ \underline{4\ 2} \\ 0\ 60 \\ 42 \end{array}$$

4.7A Grit removals should be recorded as cubic feet of grit per million gallons of flow.

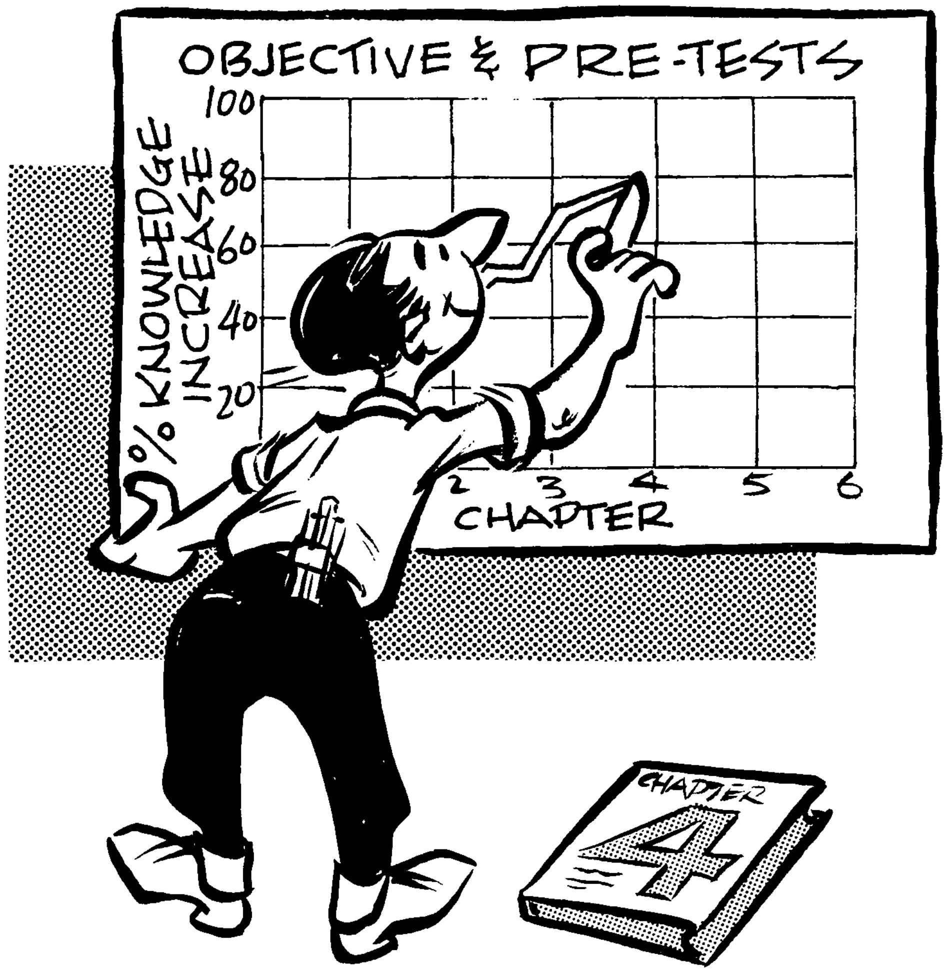
Answer: 2 cu ft of grit/million gallons

NOTE: Uniform reporting of results is important. Everyone should use the same units. The operator should obtain a copy of the Water Pollution Control Federation Manual of Practice No. 6, "Units of Expression for Wastes and Waste Treatment", and use the units as recommended. The Manual can be obtained from the Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016, for 50¢ for WPCF members and 75¢ for others.

4.8A Grit is "washed" to remove organic material before disposal. If the organic matter is not removed, then odors could develop; and if used as fill material, the fill could settle when the organics decompose.

EXPLANATION OF OBJECTIVE AND PRE-TESTS

One of the reasons for the Objective and Pre-Tests is to evaluate the extent the chapter increased your knowledge of the subject.



Write your name and answers on the answer sheets and the time it took you to complete the lesson.

DISCUSSION AND REVIEW QUESTIONS

Chapter 4. Racks, Screens, Comminutors, and Grit Removal

DO NOT USE IBM ANSWER SHEET. Please write your answers in your notebook.

1. Why should coarse material (rocks, boards, metal, etc.) be removed at the plant entrance?

2. Why do you think the wastewater treatment and pollution control industry had a higher accident rate in 1967 than any other industry reporting to the National Safety Council?

3. What are the advantages of comminutors over screens?

4. What precautions should be taken when cleaning a grit chamber?

5. How can an operator regulate the velocity in a grit chamber?

6. A stick travels 30 feet in 50 seconds in a grit chamber. What is the flow velocity in the grit chamber? Please show your calculations in a neat fashion so someone can help you if necessary.

7. Calculate the grit removed from a grit chamber in cubic feet per million gallons if during a 24-hour period the average flow was 3 MGD and 4.5 cu ft of grit were removed.

OBJECTIVE TEST

Chapter 4. Racks, Screens, Comminutors, and Grit Removal

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. Return the answer sheet to your Project Director.

1. An operator must always wash his hands before eating or smoking to prevent becoming infected with a water-borne disease.

    1. True
    2. False

2. The following items may be found in a treatment plant influent.

    1. Cans
    2. Clothes
    3. Toys
    4. Rocks
    5. Eggshells

3. Detritus is a common name for skimmings.

    1. True
    2. False

4. Pretreatment may include a :

    1. Bar Screen
    2. Grit Chamber
    3. Detritus
    4. Flow Meter
    5. Clarifier

5. What should be done <u>first</u> if a problem develops in a mechanically cleaned screen?

    1. Reach in with your hand and fix the equipment.
    2. Attempt to fix the screen with the proper tools.
    3. Look at screen and identify problem.
    4. Turn off the electrical power to the screen.
    5. Find someone to help in case you get into trouble.

6. The methods used to dispose of screenings include:

    1. Dumping into a nearby river
    2. Incineration
    3. Shredding or Grinding
    4. Selling for hog food
    5. Burial

7. Grit is composed of:

    1. Grease
    2. Sand
    3. Rubber Goods
    4. Eggshells
    5. Wood

8. A stick travels 30 feet in 20 seconds in a grit chamber. What is the flow velocity in the grit chamber?

    1. 0.5 ft/sec
    2. 0.67 ft/sec
    3. 1.0 ft/sec
    4. 1.5 ft/sec
    5. 2.0 ft/sec

Please write on your IBM answer sheet the total time required to work this chapter.

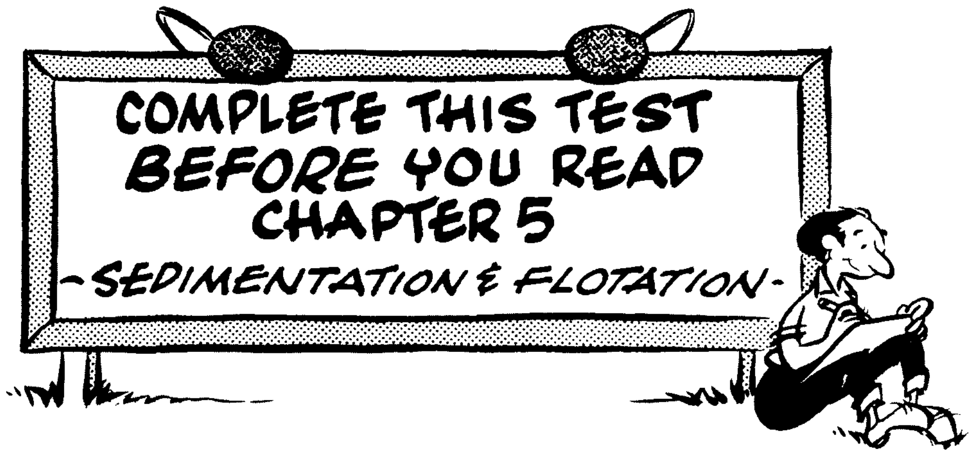
CHAPTER 5

SEDIMENTATION AND FLOTATION

by

Elmer Herr

EXPLANATION OF PRE-TEST



The purpose of the Pre-Test is to indicate to you the items that are important in this chapter. Do not be disappointed if you don't know any of the answers.

Please write your name and answers on the IBM answer sheet.

PRE-TEST

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one answer to each question.

EXAMPLE

The purpose of detaining water in a sedimentation tank is to:

1. Store for future use
2. Allow solids to settle to the bottom
3. Allow grease to float to the surface
4. Hold until trickling filter is ready
5. Provide chlorine contact time

To answer this question, you should mark on your answer sheet:

	1	2	3	4	5
EXAMPLE:		■	■		

---

1. Skimmed solids may be disposed of by:
   1. Pumping to digester
   2. Burying with material from bar screen
   3. Incineration
   4. Sold for grease and oil content
   5. None of these

2. What items should be checked before starting a clarifier?
   1. Remove debris from pipes and tank
   2. Lubricate equipment
   3. Sample effluent
   4. Turn off chlorinator
   5. Run a clarity test

3. Generally, pH is significantly affected by a clarifier:
   1. True
   2. False

4. An operator can tell if "thin" sludge is being pumped by:

   1. The sound of the sludge pump
   2. The smell of the sludge
   3. The color of the sludge
   4. Pressure gauge readings on the suction and discharge of the pump
   5. Visual observation

5. The maintenance program for a properly operating clarifier should include:

   1. Sample influent
   2. Regular inspection
   3. Keep a list of repairs
   4. Prompt adjustment or repair when necessary
   5. Lubricate equipment at regular intervals

6. Dangerous gases an operator may encounter in and around a treatment plant include:

   1. Hydrogen sulfide
   2. Nitrogen
   3. Chlorine
   4. Fumes from gasoline
   5. Methane

7. What factors influence the settling characteristics of solids in a clarifier?

   1. Flow velocity and/or turbulence
   2. Temperature
   3. Laboratory analyses
   4. Short circuiting
   5. Detention time

8. If short circuiting occurs in a clarifier, the operator should:

   1. Check the wiring
   2. Identify the cause
   3. Change fuses
   4. Try installing baffles
   5. Restart the pump

9. Plant analysis of samples is a reliable method of measuring clarifier efficiency:

   1. True
   2. False

10. What are "sloughings"?

    1. Troughs
    2. Slop
    3. Material washed off trickling filter media
    4. Waste activated sludge
    5. Grit

11. Secondary or final clarifiers are needed to:

    1. Increase sludge digestion
    2. Allow septic conditions to develop
    3. Provide a home for organisms
    4. Remove solids from biological processes
    5. None of these

12. An Imhoff tank has:

    1. Two compartments
    2. Sludge scrapers
    3. A piping system that allows the flow in the tank to be reversed from one end to the other end
    4. A separate sludge digestion compartment under the settling area
    5. Gas vents

13. Primary clarifiers are designed to remove colloidal solids:

    1. True
    2. False

14. Estimate the detention time in a 20,000-gallon sedimentation tank if the flow is 0.2 MGD. Select the closest answer.

    1. 1.5 hr
    2. 1.8 hr
    3. 2.0 hr
    4. 2.4 hr
    5. 2.8 hr

15. Estimate the detention time in a sedimentation tank 90 ft long, 30 ft wide, and 12 ft deep, if the flow is 3.0 MGD. Select the closest answer.

    1. 1.5 hr
    2. 1.8 hr
    3. 2.0 hr
    4. 2.4 hr
    5. 2.8 hr

TABLE OF CONTENTS

Chapter 5. Sedimentation and Flotation

GLOSSARY

Chapter 5. Sedimentation and Flotation

Activated Sludge Process (ACK-ta-VATE-ed sluj): A biological wastewater treatment process in which a mixture of wastewater and activated sludge is aerated and agitated. The activated sludge is subsequently separated from the treated wastewater (mixed liquor) by sedimentation, and wasted or returned to the process as needed.[1]

Bulking (BULK-ing): Bulking occurs in activated sludge plants when the sludge becomes too light and will not settle properly.

Coagulants (ko-AGG-you-lents): Chemicals added to destabilize, aggregate and bind together colloids and emulsions to improve settleability, filterability, or drainability.

Colloids (KOL-loids): Very small solids (particulate or insoluble material) in a finely divided form that remain dispersed in liquid for a long time due to their small size and electrical charge.

Density (DEN-sit-tee): The weight per unit volume of any substance. The density of water (at 4°C) is 1.0 gram per cubic centimeter (gms/cc) or about 62.4 lbs per cubic foot.

Detention Time: The time required to fill a tank at a given flow or the theoretical time required for a given flow of wastewater to pass through a tank.

Emulsion (e-MULL-shun): A liquid mixture of two or more liquid substances not normally dissolved in one another, but one liqui held in suspension in the other.

Flights: Scraper boards, made from redwood or other rot-resistant woods, used to collect and move settled sludge or floating scum.

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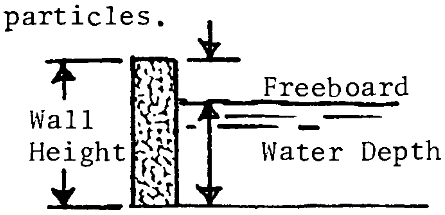
[1] See Chapter 7, Activated Sludge.

Flocculated (FLOCK-you-lay-ted): An action resulting in the gathering of fine particles to form larger particles.

Freeboard: The vertical distance from the normal water surface to the top of the confining wall.



Launders (LAWN-ders): Sedimentation tank effluent troughs.

Lineal (LIN-e-al): The length in one direction of a line. For example, a board 12 ft long has 12 lineal feet in its length.

Millimicron (MILL-e-MY-cron): One thousandth of a micron or a millionth of a millimeter.

Molecule (MOLL-ee-kule): The smallest portion of an element or compound retaining or exhibiting all the properties of the substance.

Septic Conditions (SEP-tick): A condition produced by anaerobic organisms. If severe, the wastewater turns black, giving off foul odors and creating a heavy oxygen demand.

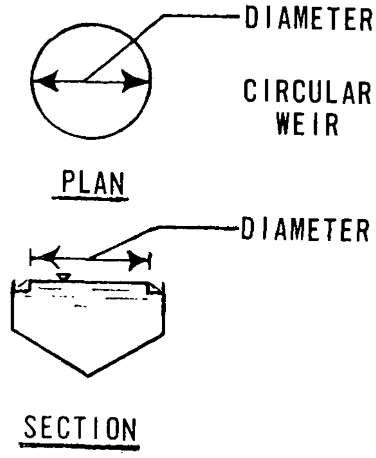
Sloughings (SLUFF-ings): Trickling filter slimes that have been washed off the filter media. They are generally quite high in BOD and will degrade effluent quality unless removed.

Sludge Gasification: Sludge gasification will form bubbles of gas in the sludge and cause large clumps of sludge to rise and float on the water surface.

Specific Gravity: Weight of a particle or substance in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (or 39°F). Wastewater particles usually have a specific gravity of from 0.5 to 2.5.

Trickling Filter (TRICK-ling): A treatment process in which the wastewater trickles over media that provides the opportunity for the formation of slimes which clarify and oxidize the wastewater.

Weir Diameter (weer): Circular clarifiers have a circular weir within the outside edge of the clarifier. All the water leaving the clarifier flows over this weir. The diameter is the length of a line from one edge of a weir to the opposite edge and passing through the center of the circle formed by the weir.



CHAPTER 5. SEDIMENTATION AND FLOTATION

(Lesson 1 of 3 Lessons)

5.0 INTRODUCTION

Raw or untreated wastewater contains some materials which will settle to the bottom or float to the water surface readily when the wastewater velocity is allowed to become very slow. Sewers are designed to allow the raw wastewater to flow rapidly to prevent this from happening. Grit chambers (see Chapter 4) are designed to allow the wastewater to flow at a slightly slower rate than in the sewers so that heavy, inorganic grit will settle to the bottom where it can be removed. Settling tanks decrease the wastewater velocity far below the velocity in a collection sewer.

In most municipal wastewater treatment plants, the treatment unit which immediately follows the grit chamber (see Figs. 5.1 and 5.2 for typical plant layout) is the sedimentation and flotation unit. This unit is sometimes called a settling tank, sedimentation tank, or clarifier. The most common name is primary clarifier, since it helps to clarify or clear up the wastewater.

A typical plant (Figs. 5.1 and 5.2) may have clarifiers located at two different points. The one which immediately follows the bar screen or comminutor or grit chamber (some plants don't have all of these) is called the primary clarifier, merely because it is the first clarifier in the plant. The other, which follows the biological treatment unit (if there is one), is called the secondary clarifier. The two types of clarifiers operate almost exactly the same way. The reason for having two types is that the biological treatment unit converts more solids to the setteable form, and they have to be removed from the treated wastewater.

The main difference between the two types of clarifiers is in the sludge density handled. Primary sludges are usually denser than secondary sludges. Effluent from a secondary clarifier is normally clearer than primary effluent.

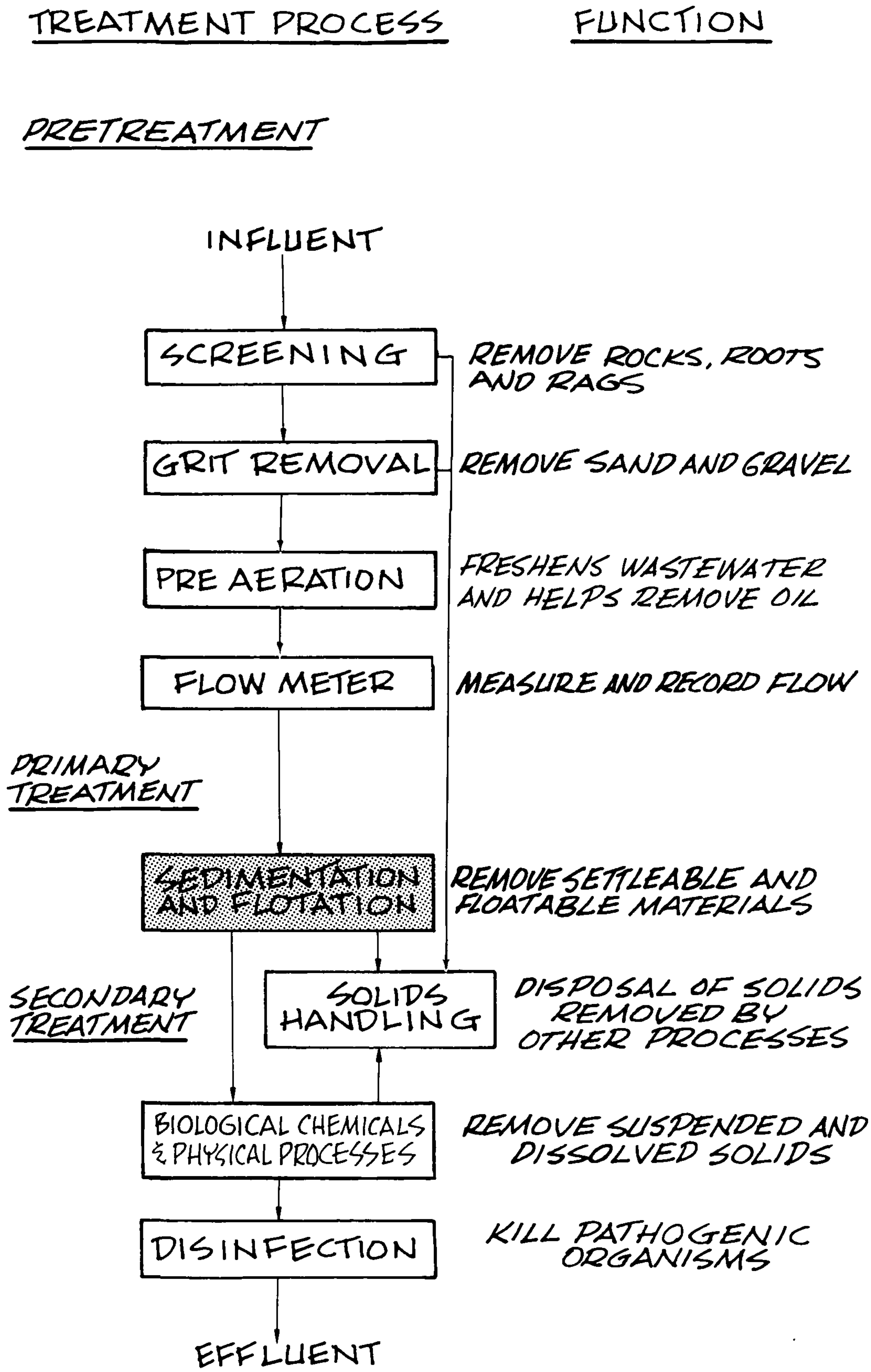


Fig. 5.1 Flow diagram of typical plant

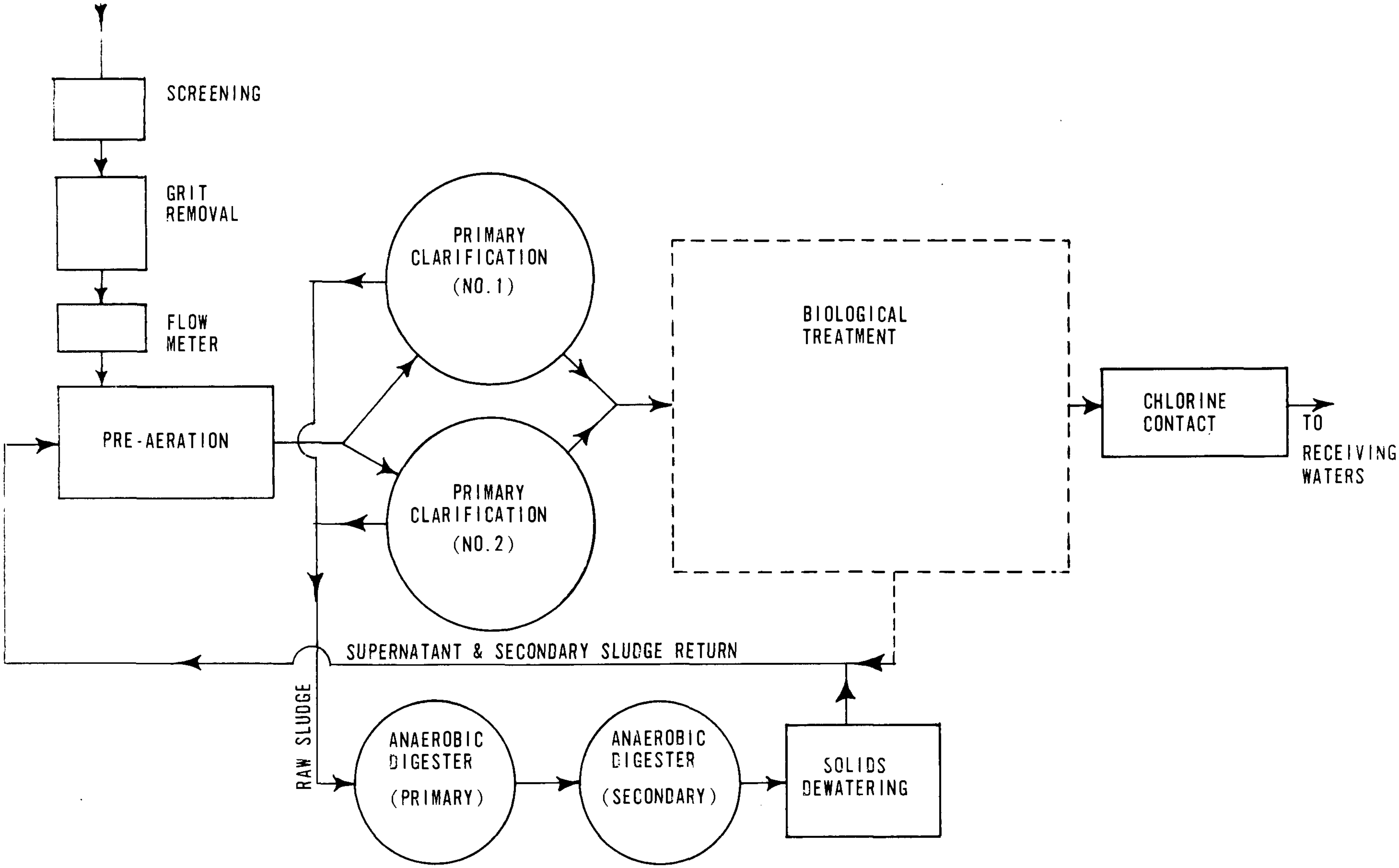


Fig. 5.2 Plan diagram of a typical primary wastewater treatment plant

Solids which settle to the bottom of a clarifier are scraped to one end (in rectangular clarifiers) or to the middle (circular clarifiers) into a sump. From the sump the solids are pumped to the sludge handling or sludge disposal system. Systems vary from plant to plant and include sludge digestion, vacuum filtration, incineration, land disposal, lagoons and burial. Figures 5.3 and 5.4 show detailed sketches of rectangular and circular clarifiers.

Disposal of skimmed solids varies from plant to plant. They may be buried with material cleaned off the bar screen, incinerated, pumped to the digester, or they may be even sold for their grease and oil content. Pumping skimmed solids to a digester is not considered good practice because skimmings can cause operational problems in digesters.

This chapter contains information on start-up, daily operation, and maintenance procedures; sampling and laboratory analyses; some problems to look out for; safety; and basic principles of sedimentation and flotation. You may wish to refer to the two chapters containing details of laboratory analyses and mathematics for further information.

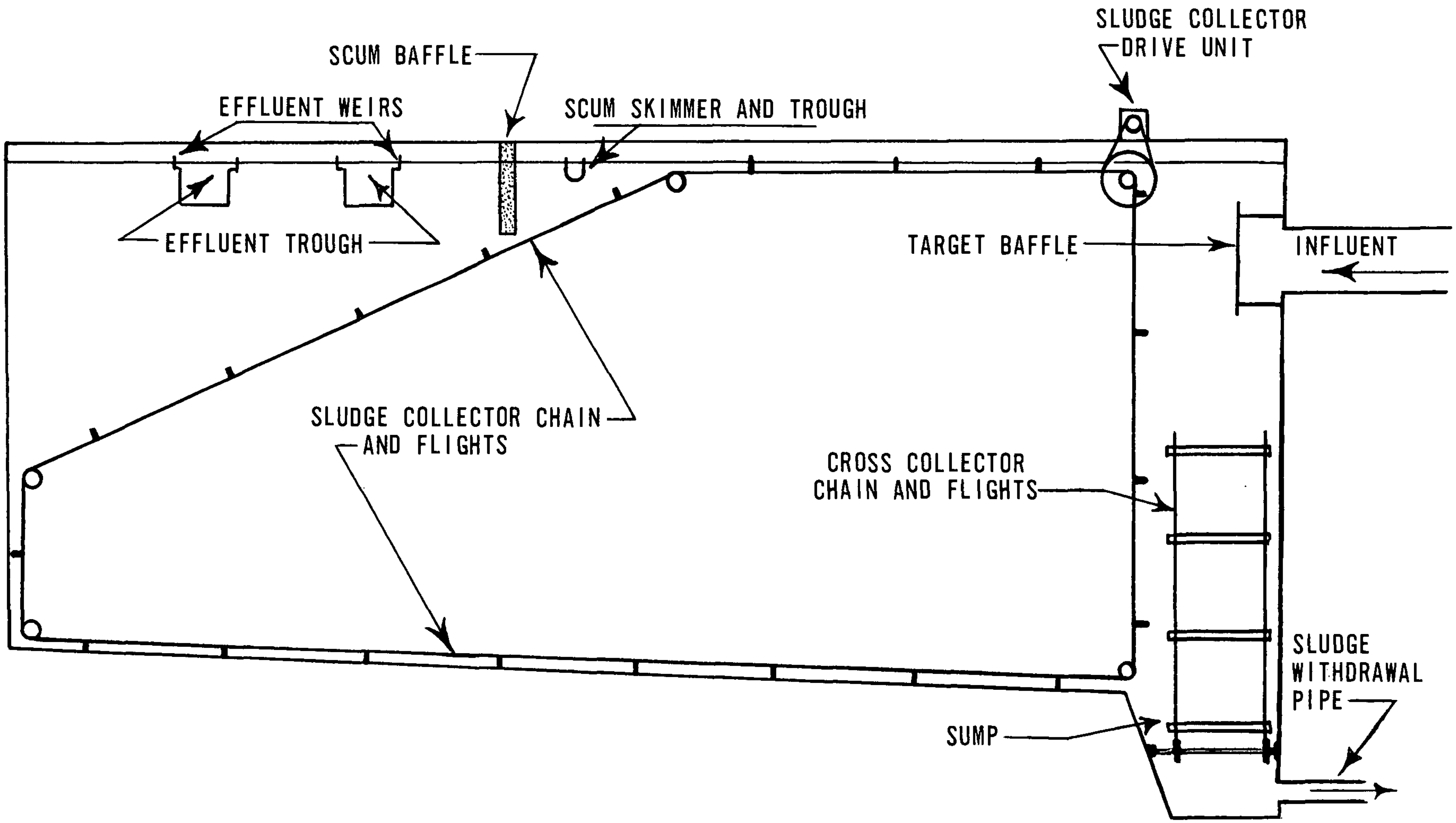


Fig. 5.3 Rectangular sedimentation basin

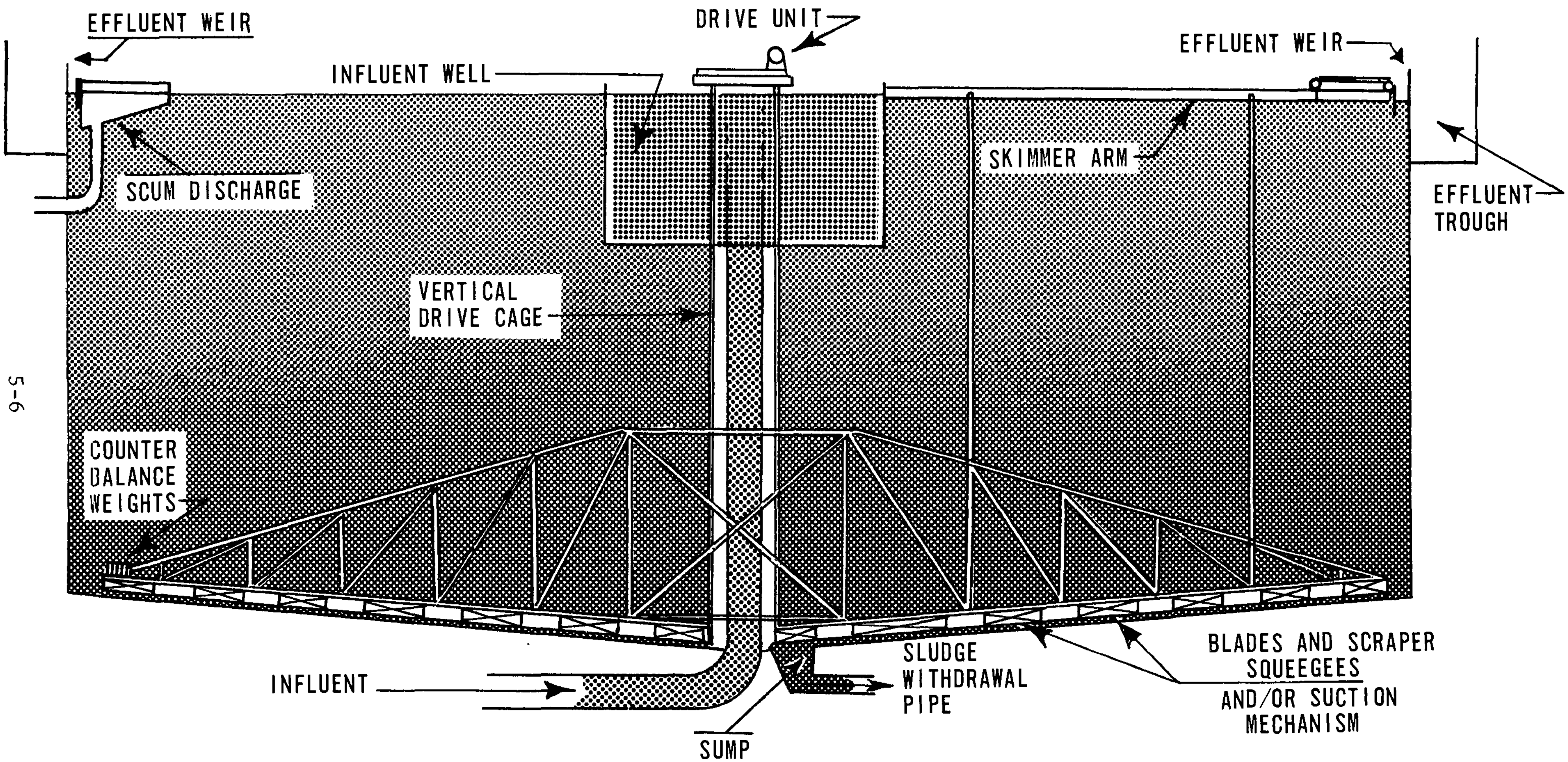


Fig. 5.4 Circular clarifier

5.1 OPERATION AND MAINTENANCE

5.10 Start-up

Before starting up a new unit or one which has been out of service for cleaning or repair, inspect the tank carefully as outlined in this section. Now is a good time to become familiar with the "internal workings" of the clarifier because they are usually under water.

A. Circular Clarifiers

Check items:

1. Control gates for operation

2. Clarifier tank for sand and debris

3. Collector drive mechanism for lubrication, drive alignment, and complete assembly

4. Squeegee blades on the collector plows for proper distance from the floor of the tank

5. Tank sumps or hoppers and return lines for debris and obstructions

If everything checks out properly, turn the mechanism on and let it make several revolutions, checking that the squeegee does not travel high and low, missing the bottom or scraping in some areas. The scraping action should control the entire area form the outside wall to the sludge hopper. Also be certain that the mechanism runs smoothly without jerks or jumps. If the unit is water lubricated, be sure sufficient water is in the tank to cover the center bearing.

If the unit is equipped with a stall alarm, test it to see if the mechanism will stop on overload. With the unit running, time the period for the plows to make one complete revolution around the tank and record the time for later reference.

Check the amperage that the motor draws and record. Let the unit operate for several hours; and if no problems develop, it should be okay.

B. Rectangular Clarifiers

The tank hoppers, channels, control gates, and weirs should be checked the same as the circular clarifiers. The sludge collectors are different in rectangular clarifiers. Wooden flights[2] are laid across the tank and each end of the flight is attached to an endless chain along both sides of the tank. The collector chains are driven by connecting shaft and sprockets dragging the flights along rails imbedded in the floor of the tank, and along each side just under the surface of the water.

Each wooden flight is equipped with metal wearing shoes to ride the rails.

Check to insure that the flights are straight across the tank, and that the chain on one side is not one or two links ahead or behind the chain on the opposite side. If this occurs, the wooden flights will run at an angle across the tank, piling the sludge higher on the trailing side.

Caution should be exercised before starting the sludge collectors in an empty clarifier if they have not been operational for several weeks. The wearing shoes on the flights may have started rusting where they are sitting

on the rails. A good practice is to lift each individual flight off the rail to be certain it is free and apply a light grease or 90 wt. oil to the shoe and rail. If these

---

[2] Flights. Scraper boards, made from redwood or other rot-resistant woods, used to collect and move settled sludge or floating scum.

precautions are not taken, when the collector is turned on the flight shoes could stick to the rails, and the whole collector system could be pulled down to the floor of the tank. Once the collectors are started in a new tank, each flight should be checked for a clearance of one to two inches between the wall and the end of the flight. If a flight is too long, it may rub the tank wall and break the flight, jamming other flights and breaking them. Once a broken flight is detected, it should be replaced or removed from the chain drives.

5.11 Daily Operation and Maintenance

During normal operations you should schedule the following daily activities:

1. Inspection. Practice frequent inspections with a stop, look, listen, and then think routine.

2. Cleanup. Wash off with water under pressure accumulations of solid particles, grease, slime, and other material from walkways, handrails, and all other exposed parts of the structure and equipment.

3. Lubrication. Grease all moving equipment according to manufacturer's specifications and check oil levels in motors where appropriate.

4. Preventive Maintenance. Follow manufacturer's specifications.

5. Flight boards. Examine bolts for looseness and corrosion.

6. Chain and sprocket. Check for wear because 0.005 ft in wear on each of 400 link pins will cause about 2 ft of extra slack.

7. Record-keeping. Write in your pocket notebook any unusual observations and transfer these notes to the plant record sheet (typical sheet is shown in the Appendix).

8. Sampling and Laboratory Analysis. Details are in the next section (5.2).

9. Sludge and Scum Pumping. See section 5.3

5.2 SAMPLING AND LABORATORY ANALYSIS

5.20 General

Proper analysis of representative samples is the only conclusive method of measuring the efficiency of clarifiers. Tests may be conducted in the plant at the site where the sample is collected or in the laboratory. The particular tests depend upon whether the effluent from the clarifier goes to another treatment process or is discharged to receiving waters.

Detailed procedures for performing control tests in primary treatment plants and sedimentation processes in other plants are outlined in Chapter 14, Laboratory Procedures and Chemistry. The frequency of testing and the expected ranges will vary from plant to plant. Strength of the wastewater, freshness, characteristics of the water supply, weather, and industrial wastes will all serve to affect the "common" range of the various test results.

	Tests	Frequency	Location	Common Range
1.	Dissolved Oxygen (DO)	Daily	Effluent	0 - 2 mg/l
2.	Settleable Solids	Daily	Influent Effluent	5 - 15 ml 0.5 - 4 ml
3.	pH	Daily	Influent Effluent	6.5 - 8.0* 6.5 - 8.0*
4.	Temperature	Daily	Influent	50 - 85°*
5.	BOD	Weekly (Minimum)	Influent Effluent	150 - 400 mg/l 60 - 160 mg/l
6.	Suspended Solids	Weekly (Minimum)	Influent Effluent	150 - 400 mg/l 60 - 150 mg/l
7.	Chlorine Residual (if needed)	Daily	Plant Effluent	0.5 - 3.0 mg/l
8.	Coliform Group Bacteria (if needed)	Weekly	Effluent	500,000 - 100,000,000 per 100 ml

*Depends on region, water supply and discharges to the collection system

5.21 Sampling

Samples of the influent to the clarifier and the effluent from it will give you information on the clarifier efficiency for removal of solids, bacteria, and BOD. As with all sampling, the purpose is to collect samples which represent the true nature of the wastewater or stream being sampled. The amount of solids, BOD, bacteria, and the clarity and pH will probably vary throughout the day, week, and year. You must determine these variations in order to understand how well your clarifier is doing its job. Details on laboratory analysis and data recording are contained in Chapter 14, Laboratory Procedures and Chemistry.

5.22 Calculation of Clarifier Efficiency

To calculate the efficiency of any wastewater treatment process, you need to collect a sample of the influent and the effluent of the process, preferably composite samples for a 24-hour period. The particular water quality indicators (BOD, suspended solids) you are interested in are measured and the efficiency is calculated. You can calculate the efficiency of a clarifier in removing several different items, such as efficiency in removing BOD or efficiency in removing suspended solids. Calculations of treatment efficiency are for process control purposes. Your main concern must be the quality of the plant effluent, regardless of percent of wastes removed.

Example:

The influent BOD to a primary clarifier is 200 mg/l, and the effluent BOD is 140 mg/l. What is the efficiency of the primary clarifier in removing BOD?

Formula:

$$\text{Efficiency, \%} = \frac{(\text{In} - \text{Out})}{\text{In}} \, 100\%$$

$$= \frac{(200 \text{ mg/l} - 140 \text{ mg/l})}{200 \text{ mg/l}} \, 100\%$$

$$= \frac{(60 \text{ mg/l})}{200 \text{ mg/l}} \, 100\%$$

$$= (.30) \, 100\%$$

$$= 30\% \text{ BOD Removal}$$

5.23 Typical Clarifier Efficiencies

Following is a list of some typical percentages for primary clarifier efficiencies:

	Expected Removal Efficiency
Settleable solids	90% to 95%
Suspended solids	40% to 60%
Total solids	10% to 15%
Biochemical oxygen demand	25% to 35%
Bacteria	25% to 75%

pH will generally not be affected significantly by a clarifier. You can expect wastewater to have a pH of about 6.5 to 8.0, depending on the region, water supply and wastes discharged into the collection system.

Clarifier efficiencies are affected by many factors, including:

1. Types of solids in the wastewater, especially if there is a significant amount of industrial wastes.

2. Age of wastewater when it reaches the plant. Older wastewater becomes stale or septic, and solids do not settle properly because gas bubbles form under them.

3. Rate of wastewater flow as compared to design flow.

4. Mechanical conditions and cleanliness of clarifier.

5.24 Response to Poor Clarifier Performance

If laboratory analysis or visual inspection indicates that a clarifier is not performing properly, then the source of the problem must be identified and corrective action taken.

Problem	Check Items (pages 5-14 to 16)
1. Floating chunks of sludge	1, 2, 3, 4, 5
2. Large amounts of floating scum	2.3*, 2.4*, 2.5*
3. Loss of solids over effluent weirs	1, 2, 3, 4, 5, 2.7*, 2.8*
4. Low removal efficiencies	5
5. Low pH plus odors	1, 2, 3, 4, 5, 6
6. Deep sludge blanket, but pumping thin sludge	3, 2.1*, 2.2*, 2.3*, 2.6*
7. Sludge collector mechanism jerks or jumps	6
8. Sludge collector mechanism will not operate. Drive motor thermal overloads, or overload protective switches keep tripping.	6

*Check Item 2 is divided into two parts, (a) circular clarifier and (b) rectangular clarifier. If you have a floating scum problem (Problem 2 above), check under 2. COLLECTOR MECHANISM (page 5-15) either section (a) circular or (b) rectangular items 3, 4, and 5, depending on the type of clarifier in your plant.

CHECK ITEMS

1. SLUDGE PUMP

   a. Piston Pumps

      1. Ball check seating
      2. Shear pin
      3. Packing adjustment
      4. Drive belts
      5. High pressure switch
      6. Pumping time

   b. Positive Displacement Scru (screw) Pumps

      1. Pump gas bound
      2. Rotor plugged
      3. Drive belt
      4. Packing adjustment
      5. Pumping time

   c. Centrifugal Pumps

      1. Pump gas bound
      2. Packing adjustment
      3. Impeller plugged
      4. Pumping time

   d. Air Injector

      1. Air supply
      2. Foot valves
      3. Slide valves
      4. Electrodes
      5. Pumping time

2. COLLECTOR MECHANISM

a. <u>Circular Clarifier</u>

1. Drive motor
2. Overload switch
3. Skimmer dump arm
   (a) operation
   (b) rubber squeegee
4. Scum trough
5. Scum box

b. <u>Rectangular Clarifier</u>

1. Drive motor
2. Clutch and drive gear
3. Flights
4. Scum trough
5. Skimmer operation
6. Cross collector
7. Inlet line or slot
8. Target baffle

3. PIPES AND SLUDGE SUMP

Sometimes pipes or sumps may be cleaned by back flushing.

4. QUALITY OF SUPERNATANT RETURN FROM DIGESTER

5. INFLUENT

a. <u>Change in Composition or Temperature</u>

b. <u>Change in Flow Rate</u>

An increase in flow rate can cause hydraulic overload. This can be determined by calculating the detention time, weir overflow rate, and surface loading rate (Section 5.61). If a tank is hydraulically under-loaded, a tank should be removed from service or effluent recirculated back to the primary clarifier to reduce the length of detention time.

6. JERKING, JUMPING, OR STALLED COLLECTOR MECHANISM

   a. Sludge Blanket Too Deep

      Pump out sludge if mechanism is all right

   b. Drive Unit May Have Bad Sprocket or Defective Chain Link

   c. Broken Flight, or Rock or Stick Jammed Between Flight or Squeegee Blade and Floor of Tank

      If items (b) or (c) occur, or mechanism won't operate properly, tank must be dewatered. Never attempt to back up or help pull a collector mechanism because severe equipment damage will result.

Your corrective action will depend on the source of the problem and the facilities available in your plant.

QUESTIONS

5.2A List five basic laboratory measurements used to determine clarifier efficiency.

5.2B About what percentage of settleable solids should you expect to be removed by your clarifier?

5.2C At what two points should samples be collected for measuring clarifier efficiency?

5.2D What is the suspended solids efficiency of a primary clarifier if the influent concentration is 300 mg/l and the effluent is 120 mg/l?

5.3 SLUDGE AND SCUM PUMPING

The particles which settle to the floor of the clarifier are called sludge. The accumulated sludge should be removed frequently, and this is accomplished by mechanical cleaning devices and pumps in most tanks. (See Fig. 5.3 and 5.4) Mechanically cleaned tanks need not be shut down for cleaning. Septic conditions[3] may develop rapidly in primary clarifiers if sludge is not removed at regular intervals. The proper interval is dependent on many conditions and may vary from thirty minutes to eight hours, and as much as twenty-four hours in a few instances. Experience will dictate the proper frequency of removal. Sludge septicity can be recognized when sludge gasification[4] causes large clumps of sludge to float on the water surface. Septic sludge is generally very odorous and acid (has a low pH).

Excess water should be eliminated from the sludge if possible because of its effects on the volume of sludge pumped and on digester operation. A good thick primary sludge will contain from 4.0 to 8.0 percent dry solids as indicated by the Total or Suspended Solids Test in the laboratory. Conditions which may affect sludge concentration are the specific gravity, size and shape of the particles, and temperature, and turbulence in the tank.

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[3]Septic conditions (SEP-tick). A condition produced by anaerobic organisms. If severe, the wastewater turns black, giving off foul odors and creating a heavy oxygen demand.

[4]Sludge gasification. A process in which soluble and suspended organic matter are converted into gas. Sludge gasification will form bubbles of gas in the sludge and cause large clumps of sludge to rise and float on the water surface.

Withdrawal (pumping) rates should be slow in order to prevent pulling too much water with the sludge. While the sludge is being pumped, take samples frequently and examine them visually for excess water. If the samples show a "thin" sludge, it is time to stop pumping. Practice learning to recognize the differences between thin or concentrated sludges. There are several methods for determining "thick" or "thin" sludge without a laboratory analysis:

1. Sound of the sludge pump. The sludge pump will usually have a different sound when the sludge is thick than when it is thin.
2. Pressure gauge readings. Pressure will be higher on the discharge side of the pump when sludge is thick.
3. Sludge density gauge readings.
4. Visual observation of a small quantity (gallon or less).
5. Watch sludge being pumped through a site glass in the sludge line.

When you learn to use the indicators listed above, you should compare them frequently with lab tests. The laboratory Total Solids Test is the only accurate method for determining exact density. However, this analytical procedure is too slow for controlling a routine pumping operation. Many operators use the centrifuge test to obtain quick results.

Floating material (scum) may leave the clarifier at the effluent unless a method has been provided for holding it back. A baffle is generally provided in the tank at some location to collect scum. Primary clarifiers often have a scum collection area where the scum is skimmed off by some mechanical method, usually a skimming arm or a paddle wheel. If mechanical methods are not provided, use hand tools such as skimming dipper attached to a broom handle.

Frequently check the scum trough to be sure it is working properly. Clean the box with a brush and hot water. Scum may be disposed of by burning or burial.

See Chapter 11, Maintenance, Section 11.3 for details on how to unplug pipes and pumps.

QUESTIONS

5.3A How often should sludge be removed from a clarifier?

5.3B How can you tell when to stop pumping sludge?

5.3C How can floating material (scum) be kept from the clarifier effluent?

5.4 GENERAL MAINTENANCE

Following are some hints to help you keep your clarifiers operating properly:

1. Maintain a record and file system for future reference. This should contain sheets to write down a description and date for all repairs and regular maintenance activities such as lubrication. Other items to be kept in the file are operating instruction manuals; brochures; names, addresses, and telephone numbers of manufacturer's representatives.

2. Always lubricate equipment at the intervals recommended by the manufacturer and use the proper lubricants (follow manufacturer's recommendations). It is very important that you do not over-lubricate.

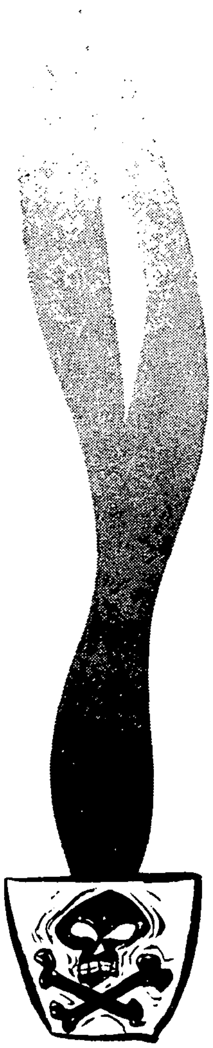
3. Clean all equipment and structures regularly.

4. Inspect and correct (if possible) all peculiar noises, leaks, pressure and vacuum gauge irregularities, belts, electrical systems, and safety devices.

5. When a sedimentation tank must be drained for inspection or repairs, keep wooden flights moist by periodic sprinkling with a hose to prevent cracking and warping.

5.5 SAFETY

1. Gases



Any enclosed area, such as a wet well for a pump, may have poisonous, asphyxiating, or explosive gases accumulated in it if ventilation is not proper. The most common of these are:

a. Hydrogen Sulfide (H_2S). Causes a "rotten egg" odor. It readily combines with oxygen to form sulfuric acid which will dissolve concrete. If you breathe too much H_2S it will paralyze your respiratory center.

b. Chlorine (Cl_2). Very irritating to eyes, mouth, and nose. Causes death by suffocation (asphyxiation) and by formation of acid in the lungs.

c. Carbon Dioxide (CO_2). Odorless, tasteless. This can cause asphyxiation by displacing oxygen from an enclosed, poorly ventilated area.

d. Carbon Monoxide (CO). Colorless, odorless, non-irritating, flammable, explosive. Look out for carbon monoxide around gas engines or leaky gas systems in poorly ventilated places.

e. Gasoline and other petroleum products. May cause fires or explosions, or displace oxygen and asphyxiate you.

f. Methane (CH_4). Explosive, odorless, and may cause asphyxiation.

For a detailed discussion of the hazards and safety precautions when dangerous gases may be present, refer to Chapter 12, Plant Safety and Good Housekeeping. The New York Manual, pages 174 and 175, Table 10, *Common Dangerous Gases Encountered in Sewers and at Sewage Treatment Plants*, contains information on the simplest and cheapest safe methods of treating for gases.

2. Falls

Avoid falls by:

a. Cleaning up oil and grease slicks on walkways promptly.

b. Walking, not running, when near open tanks.

c. Avoiding clutter. Pick up and store hoses, ropes cables, tools, buckets, lumber, etc.

d. Not sitting on, climbing through, or hanging over guardrails or handrails.

e. Providing gratings, deck covers, or safety chains on or around openings to pits below floor level.

3. Drowning

To prevent drowning:

a. Put handrails and proper walkways by all open tanks.

b. Cover open pits with gratings, deck plates, etc.

c. Have life preservers, life lines, or inner tubes handy to throw to anyone who may fall in. Appropriate equipment should be worn when necessary.

4. Strains and Overexertion

Use proper wrenches or equipment:

a. To move stuck or reluctant valves.

b. To lift heavy objects.

DISCUSSION AND REVIEW QUESTIONS

Chapter 5. Sedimentation and Flotation

(End of Lesson 1 of 3 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions are to indicate to you how well you understand the material in this section.

1. What is the function of a primary clarifier?
2. What items should be checked before starting up a new clarifier or one which has been out of service for cleaning or repair?
3. Calculate the efficiency of a clarifier removing BOD if the influent BOD is 260 mg/l and the effluent is 155 mg/l. Show your work.
4. What would you do if the solids and BOD removal efficiencies of a primary clarifier suddenly dropped and the effluent appeared to contain more solids than usual?
5. What precautions should you take to avoid strains and overexertion when working around a treatment plant?
6. How often should sludge be pumped from a primary clarifier?

CHAPTER 5. SEDIMENTATION AND FLOTATION

(Lesson 2 of 3 Lessons)

5.6 PRINCIPLES OF OPERATION

5.60 General

Sedimentation and flotation units are designed to remove physically those solids which will settle easily to the bottom or float easily to the top. Sedimentation is usually the principal basis of design in such units and will be discussed in more detail in this section. Flotation of fats, oils, hair, and other light material also is very important to protect the esthetics of receiving waters.

The sedimentation and flotation units commonly found are:

1. Primary clarifiers
2. Secondary clarifiers
3. Flotation units
4. Imhoff tanks

This section will describe each unit individually as it relates to another process or as a process by itself.

5.61 Primary Clarifiers

The most important function of the primary clarifier is to remove as much settleable and floatable material as possible. Organic settleable solid removal is very important because it causes a high demand for oxygen (BOD) in receiving water or subsequent biological treatment units in the treatment plant.

Many factors influence the design of clarifiers. Settling characteristics of suspended particles in water are probably the most important considerations. The design engineer must consider the speed at which particles will settle in order to determine the correct dimensions for the tank. Rapid movement of water (velocity) will hold most particles in suspension and carry them along until the velocity of water is slowed sufficiently for particle settling. The rate of downward travel (settling) of a particle is dependent on the weight of the particle in relation to the weight of an equal volume of water (specific gravity),[5] the particle size and shape, and the temperature of the liquid. Organic settleable solids are seldom more than 1 to 5 percent heavier than water; and, therefore, their settling rates are slow.

If the horizontal velocity of water is slowed to a rate of 1.0 to 2.0 feet of travel per minute (grit chamber velocities were around 1 ft/sec) most particles with a specific gravity of 1.05 (5% more than water) will settle to the bottom of the container. Specific gravity of water is 1.000 at 4.0 degrees Celsius (formally Centigrade) or 39°F; it weighs 8.34 lbs per gallon. Wastewater solids with a specific gravity of 1.05 will weigh 8.76 lbs per gallon (1.05 times 8.34 lbs equals 8.76 lbs per gallon). The relationship of the particle settling rate to liquid velocity may be explained very simply by use of a sketch (Fig. 5.5).

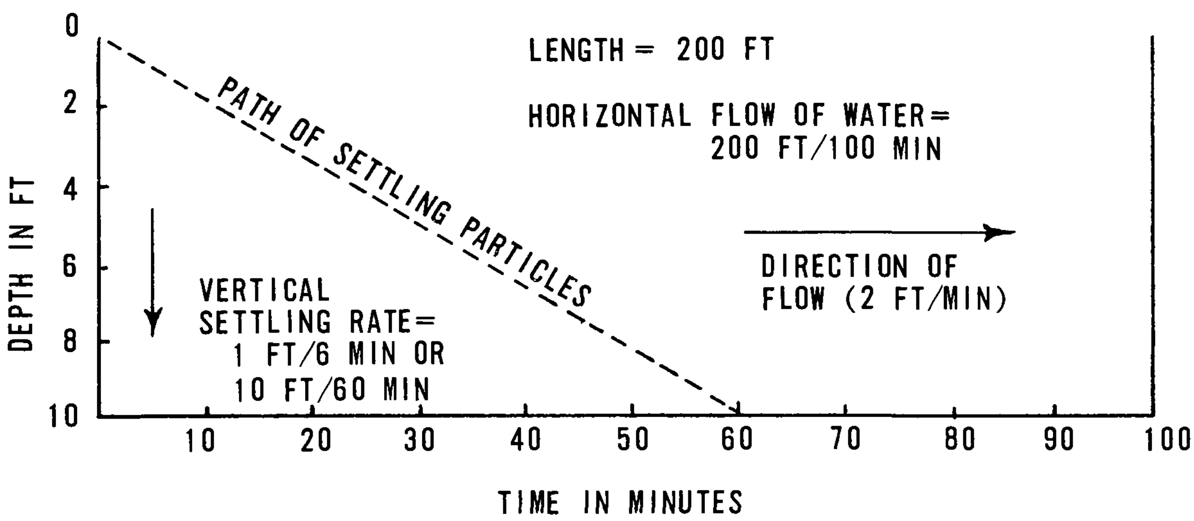


Fig. 5.5 Path of settling particle

Suppose the liquid velocity is horizontal at the rate of 2.0 feet per minute and the tank is 200 feet long. It will take 100 minutes (200 ft divided by 2.0 ft/min) to travel through the tank. If the particle, during its diagonal course of travel, settles vertically toward the

---

[5] Specific gravity. Weight of a particle or substance in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (or 39°F). Wastewater particles may have a specific gravity of from 0.8 to 2.6. If the specific gravity of a particle is less than one it will tend to float, and if greater than one it will tend to sink. Most organic sludges have a specific gravity between 1.01 and 1.05.

bottom of the tank at a rate of 1.0 foot in 6 minutes, it will rest on the floor of the tank in 60 minutes if the tank is 10 feet deep. If the particle settles at the rate of 10 feet in 60 minutes, it should settle in the first 60 percent portion of the tank because the liquid surrounding it requires 100 minutes to flow through the tank.

There are many factors which will influence settling characteristics in a particular clarifier. A few of the more common ones are as follows:

Temperature. Water expands as temperature increases (above $4^{\circ}C$) and contracts as temperature decreases (above $4^{\circ}C$). Below $4^{\circ}C$ the opposite is true. In general, as water temperature increases, settling rate of particles increases; and, as temperature decreases, so does the settling rate. Molecules[6] of water react to temperature changes. They are closer together when liquid temperature is lower; thus, density[7] increases and water becomes heavier per given volume because there is more of it in the same space. As water becomes more dense, the density difference between water and solid particles becomes less; and therefore the particles settle slower. This is illustrated in Fig. 5.6.

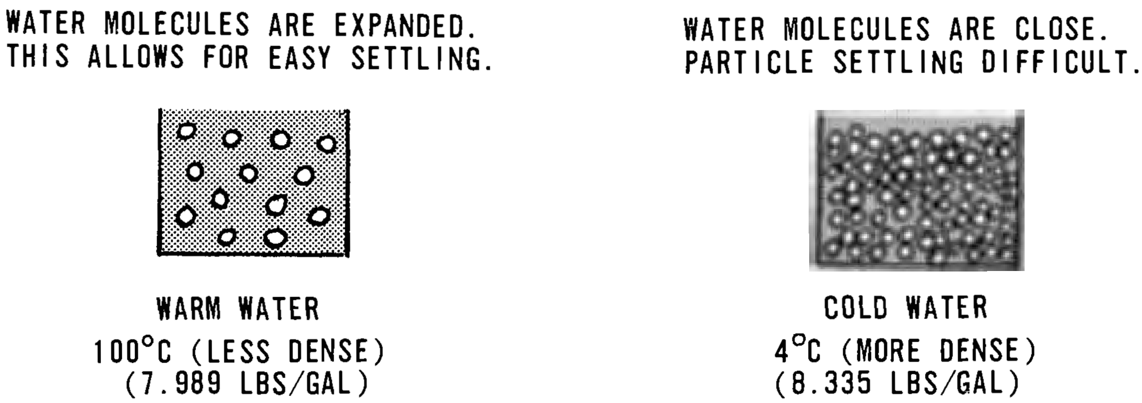


Fig. 5.6 Influence of temperature on settling

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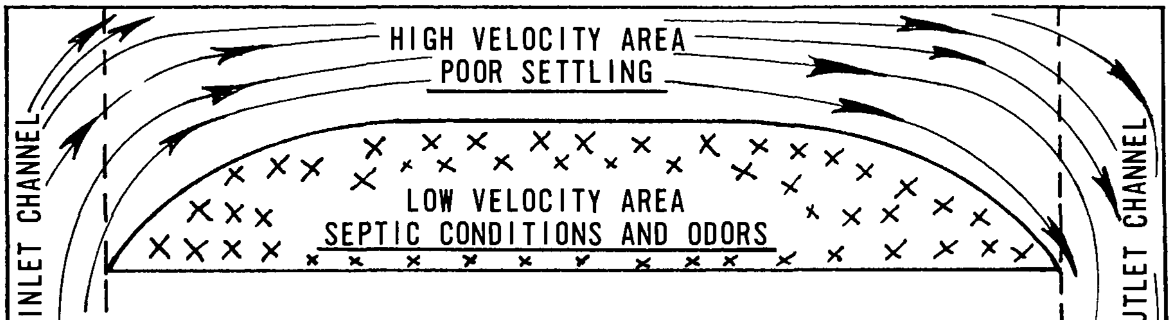
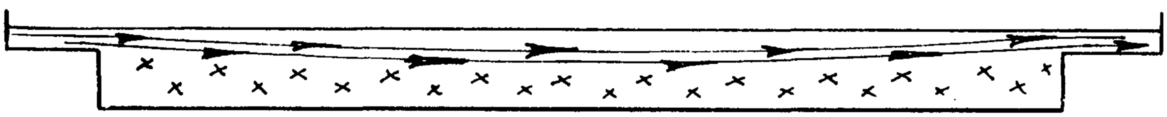
[6] Molecules (MOLL-ee-kules). The smallest portion of an element or compound retaining or exhibiting all the properties of the substance.

[7] Density (DEN-sit-tee). The weight per unit volume of any substance. The density of water (at $4^{\circ}C$) is 1.0 gram per cubic centimeter (gms/cc) or about 62.4 lbs per cubic foot. If one cubic centimeter of a substance (such as iron) weighs more than 1.0 gram (higher density), it will sink or settle out when put in water. If it weighs less (lower density, such as oil), it will rise to the top and float. Sludge density is normally expressed in gms/cc.

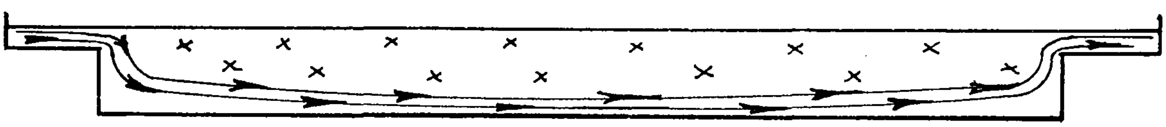
Short Circuits. As wastewater enters the settling tank, it should be evenly dispersed across the entire cross section of the tank and should flow at the same velocity in all areas toward the discharge end. When the velocity is greater in some sections than in others, serious "short circuiting" may occur. The high velocity area may decrease the detention time in that area, and particles may be held in suspension and pass through the discharge end of the tank because they do not have time to settle out. On the other hand, if velocity is too low, undesirable septic conditions may occur. Short circuiting may easily begin at the inlet end of the sedimentation tank (Fig 5.7). This is usually prevented by the use of weir plates, baffles, port openings, and by proper design of the inlet channel. Short circuiting also may be caused by turbulence and stratification of density layers due to temperature or salinity.



Top View Looking Down



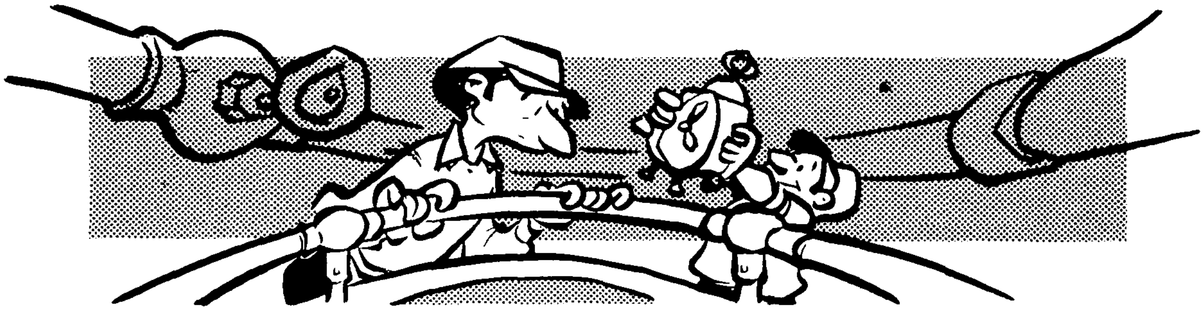
Side View - Warm Influent



Side View - Cold Influent

Fig. 5.7 Short circuiting

Detention Time.[8] Wastewater should remain in the clarifier long enough to allow sufficient settling time for solid particles. If the tank is too small for the quantity of flow and the settling rate of the particles, too many particles will be carried out the effluent of the clarifier. The relationship of "detention time" to "settling rate" of the particles is important. Most engineers design for about 2.0 to 3.0 hours of detention time. This is, of course, flexible and dependent on many circumstances.



Detention time can be calculated by use to two known factors:

1. Flow in gallons per day (gpd)
2. Tank dimensions

Example:

The flow is 3.0 million gallons per day (MGD), or 3,000,000 gal/day. Tank dimensions are 60 feet long by 30 feet wide by 10 feet deep. What is the detention time?

---

[8] Detention Time. The time required to fill a tank at a given flow or the theoretical time required for a given flow of wastewater to pass through a tank.

Formulas:

$$\text{Detention Time, hrs} = \frac{\text{Tank Volume, cu ft} \times 7.5\ \text{gal/cu ft} \times 24\ \text{hr/day}}{\text{Flow, gal/day}}$$

Tank Volume, cu ft = Length, ft x Width, ft x Depth, ft

Calculations:

Tank Volume, cu ft = Length, ft x Width, ft x Depth, ft

= 60 ft x 30 ft x 10 ft

= 18,000 cu ft

$$\text{Detention Time, hrs} = \frac{\text{Tank Volume, cu ft} \times 7.5\ \text{gal/cu ft} \times 24\ \text{hr/day}}{\text{Flow, gal/day}}$$

$$= \frac{18{,}000\ \text{cu ft} \times 7.5\ \text{gal/cu ft} \times 24\ \text{hr/day}}{3{,}000{,}000\ \text{gal/day}}$$

$$= \frac{3{,}240{,}000\ \text{gal-hr/day}}{3{,}000{,}000\ \text{gal/day}}$$

= 1.08 hours

```
   24        18,000
 x7.5           180
  120     1,440,000
 168      1 800 0
 180.0    3,240,000
```

Evaluation. If detention time is only 1.08 hours and if laboratory tests indicate poor removal of solids, then additional tank capacity should be placed into operation (if available) in order to obtain additional detention time. You must realize that flows fluctuate considerably during the day and night and any calculated detention time is for a specific flow.

Discussion. The formula given in this section allows you to calculate the theoretical detention time. Actual detention time is less than the detention time calculated using the formula and can be measured by the use of dyes, tracers, or floats.

Weir Overflow Rate. Wastewater leaves the clarifier by flowing over weirs and into effluent troughs (launders)[9] or some type of weir arrangement. The number of lineal[10] feet of weir in relation to the flow is important to prevent short circuits or high velocity near the weir or launder which might pull settling solids into the effluent. The weir overflow rate is the number of gallons of wastewater that flow over one lineal foot of weir per day. Most designers recommend about 10,000 to 20,000 gallons per day per lineal foot of weir. Higher weir overflow rates have been used for materials with a high settling rate or for intermediate treatment. Secondary clarifiers and high effluent quality requirements generally need lower weir overflow rates than primary clarifiers. The calculation for weir overflow rate requires two known factors:

1. Flow in gpd

2. Lineal feet of weir

Example:

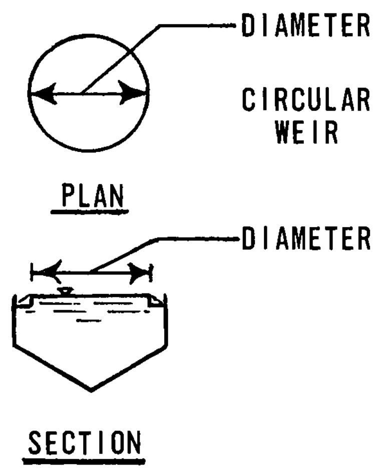
The flow is 5.0 MGD in a circular tank with a 90-foot weir diameter.[11] What is the weir overflow rate?

---

[9] Launders (LAWN-ders). Sedimentation tank effluent troughs. When the flow leaves a sedimentation unit, it usually flows into a trough after it leaves the tank. The top edge of the trough over which wastewater flows as it enters the trough is considered a weir.

[10] Lineal (LIN-e-al). The length in one direction of a line. For example, a board 12 feet long has 12 lineal feet in its length.

[11] Weir Diameter (weer). Circular clarifiers have a circular weir within the outside edge of the clarifier. All the water leaving the clarifier flows over this weir. To find the length of this weir, the weir diameter must be known. The diameter is the length of a line from one edge of a weir to the opposite edge and passing through the center of the circle formed by the weir.



Formulas:

$$\text{Weir Overflow, gpd/ft} = \frac{\text{Flow Rate, gpd}}{\text{Length of Weir, ft}}$$

Length of Circular Weir = 3.14 x Weir Diameter, ft

Calculations:

$$\text{Length of Circular Weir, ft} = 3.14 \times (\text{Weir Diameter, ft})$$

$$= 3.14 \times 90 \text{ ft}$$

$$= 283 \text{ Lineal Feet of Weir}$$

```
   3.14
     90
 ------
 282.60
```

$$\text{Weir Overflow, gpd/ft} = \frac{\text{Flow Rate, gpd}}{\text{Length of Weir, ft}}$$

$$= \frac{5{,}000{,}000 \text{ gal/day}}{283 \text{ ft}}$$

$$= 17{,}668 \text{ gpd/ft}$$

```
         17,668
283 )5,000,000
     2 83
     ----
     2 170
     1 981
     -----
       189 0
       169 8
       -----
        19 20
        16 98
        -----
         2 220
         2 264
```

Surface Settling Rate or Surface Loading Rate. This term is expressed in terms of gpd/sq ft of tank surface area. Some designers and operators have indicated that the surface loading rate has a direct relationship to the settleable solids removal efficiency in the settling tank. The suggested loading rate varies from 300 to 1200 gpd/sq ft, depending on the nature of the solids and the treatment requirements. Low loading rates are frequently used in small plants in cold climates. In warm regions, low rates may cause excessive detention which could lead to septicity. The calculation for surface loading rate requires two known factors:

1. Flow in gpd

2. Square feet of liquid surface area

Example:

The flow in a secondary plant is 5.0 MGD in a tank 90 feet long and 35 feet wide. What is the surface loading rate?

Formula:

$$\text{Surface Loading Rate, gpd/sq ft} = \frac{\text{Flow Rate, gpd}}{\text{Area, sq ft}}$$

Calculations:

$$\begin{aligned}\text{Surface Area, sq ft} &= \text{Length, ft} \times \text{Width, ft}\\ &= 90 \text{ ft} \times 35 \text{ ft}\\ &= 3150 \text{ sq ft}\end{aligned}$$

$$\begin{aligned}\text{Surface Loading Rate, gpd/sq ft} &= \frac{\text{Flow Rate, gpd}}{\text{Area, sq ft}}\\ &= \frac{5{,}000{,}000 \text{ gpd}}{3150 \text{ sq ft}}\\ &= 1587 \text{ gpd/sq ft}\end{aligned}$$

Detention Time, Weir Overflow Rate, and Surface Loading Rate are three mathematical methods of checking the performance of existing facilities against the design values. However, laboratory analysis of samples is the only reliable method of measuring clarifier efficiency. If laboratory results indicate a poorly operating clarifier, the mathematical methods may help you to identify the problem.

QUESTIONS

5.6A What is "short circuiting" in a clarifier?

5.6B Why is "short circuiting" undesirable?

5.6C How can "short circuiting" be corrected?

5.6D A circular clarifier has a diameter of 80 feet and an average depth of 10 feet. The flow of wastewater is 4.0 MGD. Calculate the following:

1. Detention Time, in hours
2. Weir Overflow Rate, in gpd/ft
3. Surface Loading Rate, in gpd/sq ft

DISCUSSION AND REVIEW QUESTIONS

Chapter 5. Sedimentation and Flotation

(End of Lesson 2 of 3 Lessons)

Please write the answers to these questions in your notebook before continuing with Lesson 3. The problem numbering continues from Lesson 1.

7. Explain how temperature influences clarifier performance.

8. Draw a clarifier and indicate what is meant by short circuiting.

9. A circular clarifier has a diameter of 60 feet and an average depth of 8 feet. The flow of wastewater is 2.0 MGD. Calculate the following:

    1. Detention Time, in hours
    2. Weir Overflow Rate, in gpd/ft
    3. Surface Loading Rate, in gpd/ft^2
    4. Comment on the hydraulic loading on the clarifier.

5.62 Secondary Clarifiers or Final Settling Tanks

Secondary clarifiers usually follow a biological process in the flow pattern of a treatment plant. (See Figs. 5.1 and 5.2.) The most common biological processes are the Activated Sludge Process[12] and the Trickling Filter.[13]

In some plants a chemical process may be used instead of a biological process, but the latter is far more common for municipal treatment plants.

The final settling tank is sometimes referred to as a "humus tank" when used after a trickling filter to settle out sloughings[14] from the filter media. Filter sloughings are a product of biological action in the filter; the material is generally quite high in BOD and will degrade the effluent quality unless it is removed. The specific description of trickling filters is covered in Chapter 6.

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[12] Activated Sludge Process (ACK-ta-VATE-ed sluj). A biological wastewater treatment process in which a mixture of wastewater and activated sludge is aerated and agitated. The activated sludge is subsequently separated from the treated wastewater (mixed liquor) by sedimentation, and wasted or returned to the process as needed.

[13] Trickling Filter. A treatment process in which the wastewater trickles over media that provide the opportunity for the formation of slimes which clarify and oxidize the wastewater.

[14] Sloughings (SLUFF-ings). Trickling filter slimes that have been washed off the filter media. They are generally quite high in BOD and will degrade effluent quality unless removed.

Secondary clarifier detention times are about the same as for primary clarifiers, but the surface loading and weir overflow rates are generally lower due to the less dense characteristics of secondary sludges. The following are ranges of loading rates for secondary clarifiers used after biological filters:

Detention Time - 1.0 to 2.0 hours

Surface Loading Rate - 300 to 1200 gpd/sq ft

Weir Overflow Rate - 5,000 to 15,000 gpd/lineal ft

The amount of solids settling out in a secondary clarifier following a trickling filter will be very irregular due to a number of varying conditions in the biological treatment process. In general, you can expect to pump about 30% to 40% as much sludge from the secondary clarifier as from the primary; thus, total sludge pumping will increase by that amount. These figures indicate how the trickling filter "creates" settleable solids which were not present in the raw wastewater in settleable form.

The sludge in the secondary settling tank will usually have a completely different appearance and characteristics than the sludge collected in a primary settling tank. It will usually be much darker in color, but should not be grey or black. A grey sludge usually indicates insufficient biological stabilization (treatment). Sludge will turn black if it is allowed to stay in the secondary clarifier too long. If this happens, then the return sludge or waste sludge pumping rate should be increased or the time of pumping lengthened or made more frequent. Secondary sludges generally require continuous or frequent pumping at a rate sufficient to maintain a reasonably concentrated sludge and a low sludge blanket in the clarifier.

The particle sizes may be very irregular with generally good (rapid) settling characteristics. The sludge may appear to be a fluffy humus type of material and will usually have little or no odor if sludge removal occurs at regular intervals. The sludge collected in the final settling tanks is sometimes disposed of by transferring to a primary settling tank to be mixed with primary sludge, and it is sometimes transferred directly to the digestion system, depending on the particular plant design and the characteristics of the sludge.

Final settling tanks which follow the activated sludge process are designed similarly to those used for the trickling filter, except that they are more conservative in design because the sludge tends to be less dense. Their purpose is identical, except that the particles to be settled are received from the aeration tank rather than the trickling filter. Most final sedimentation tanks used with the activated sludge process are mechanically cleaned due to the importance of rapidly returning sludge to the aeration tank. (This is explained in Chapter 7, Activated Sludge.) The sludge volume in the secondary tank will be greater from the activated sludge process than from the trickling filter process.

The standard laboratory tests used to measure solids removal in primary settling tanks are used also for secondary settling tanks.

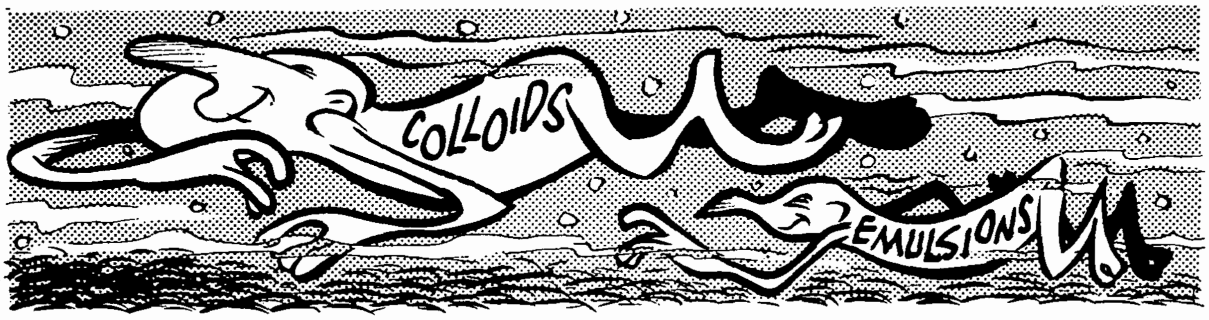
QUESTIONS

5.6E Why are secondary clarifiers needed in secondary treatment plants?

5.6F What usually is done with the sludge that settles out in secondary clarifiers?

5.7 FLOTATION PROCESSES

Wastewater always contains some solids in suspended form that neither settle nor float to the surface and therefore remain in the liquid as it passes through the clarifier. Dissolved solids will, of course, travel through the clarifiers because they are unaffected by these units. There are two other types of solids in wastewater known as "Colloids" and "Emulsions" that are very difficult to remove.



A "colloid" is a particle held in suspension due to its very small size and its electrical charge. It is usually less that 200 millimicrons[15] in size, and generally will not settle readily. If organic, it exerts a high oxygen demand, so its removal is desirable.

An "emulsion" is a liquid mixture of two or more liquid substances not normally dissolved in one another, but one liquid held in suspension in the other. It usually contains suspended globules of one or more of the substances. The globules usually consist of grease, oil, fat, or resinous substances. This material also exerts a high oxygen demand.

One method for removing emulsions and colloids is by a "flotation process", pumping air into the mixture to cause the suspended material to float to the surface where it can be skimmed off.

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[15] Millimicron (MILL-e-MY-cron). One thousandth of a micron or a millionth of a millimeter.

The particles can be flocculated[16] with air or chemical coagulants[17] and forced or carried to the liquid surface by minute air bubbles. Figure 5.8 shows the chain of events in the flotation process.

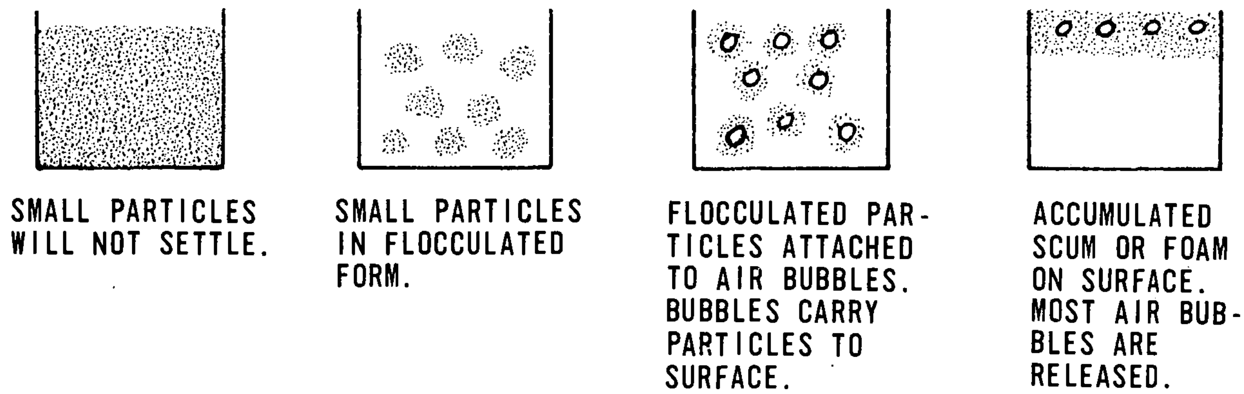

Fig. 5.8 Flotation process

Most of the air bubbles are released at the liquid surface. Particles are removed in the form of scum or foam by skimming.

There are two common flotation processes in practice today:

1. Vacuum Flotation. The wastewater is aerated for a short time in a tank where it becomes saturated with dissolved air. The air supply is then cut off and large air bubbles pass to the surface and into the atmosphere. The wastewater then flows to a vacuum chamber which pulls out dissolved air in the form of tiny air bubbles which float the solids to the top.

2. Pressure Flotation. Air is forced into the wastewater in a pressure chamber where the air becomes dissolved in the liquid. The pressure is then released from the wastewater, and the wastewater is returned to atmospheric pressure where the dissolved air is released from solution in the form of tiny air bubbles. These air bubbles rise to the surface and, as they rise, they carry solids to the surface.

---

[16] Flocculated (FLOCK-you-lay-ted). An action resulting in the gathering of fine particles to form larger particles.

[17] Coagulants (ko-AGG-you-lents). Chemicals added to destabilize, aggregate, and bind together colloids and emulsions to improve settleability, filterability, or drainability.

Any flotation process is based upon release of gas bubbles in the liquid suspension (Fig. 5.8) under conditions in which the bubbles and solids will associate with each other to form a combination with a lower specific gravity than the surrounding liquid. They must stay together long enough for the combination to rise to the surface and be removed by skimming.

QUESTIONS

5.7A Why is the "flotation process" used in some wastewater treatment plants?

5.7B Would you place the flotation process before or after primary sedimentation?

5.7C Give a very brief description of:

1. Colloid
2. Emulsion

5.7D Give a brief description of the Vacuum Flotation process.

5.8 IMHOFF TANKS

Imhoff tanks are rarely constructed today. Your plant may consist of only an Imhoff tank if it serves a very small community or if it was constructed many years ago. It is quite possible that you may never have operating responsibility for one of these units. They will be discussed for general knowledge and for the few operators who will have operating responsibility for them.

The Imhoff tank combines sedimentation and sludge digestion in the same unit. There is a top compartment where sedimentation occurs and a bottom compartment for digestion of settled particles (sludge). The two compartments are separated by a floor and a slot designed to allow settling particles to pass through to the digestion compartment (Fig. 5.9).

Wastewater flows slowly through the upper tank as in any other standard rectangular sedimentation unit. The settling solids pass through the slot to the bottom sludge digestion tank. Anaerobic digestion of solids is the same as in a separate digester. Gas bubbles are formed in the digestion area by bacteria. As the gas bubbles rise to the surface they carry solid particles with them. The slot is designed to prevent solids from passing back into the upper sedimentation area as a result of gasification where they would pass out of the unit with the effluent.

The same calculations previously used for clarifiers can be used to determine loading rates for the settling area of the Imhoff tank. (Chapter 8, Sludge Digestion, will explain the anaerobic process in the sludge digestion area of this unit.) Some typical values for design and operation of Imhoff tanks are:

Settling Area

Wastewater Detention Time	- 1.0 to 4.0 hours
Surface Settling Rate	- 600 to 1200 gpd/sq ft
Weir Overflow Rate	- 10,000 to 20,000 gpd/ft
Suspended Solids Removal	- 45% to 65%
BOD Removal	- 25% to 35%

Digestion Area

Digestion Capacity	- 1.0 to 3.0 cu ft/person
Sludge Storage Time	- 3 to 12 months

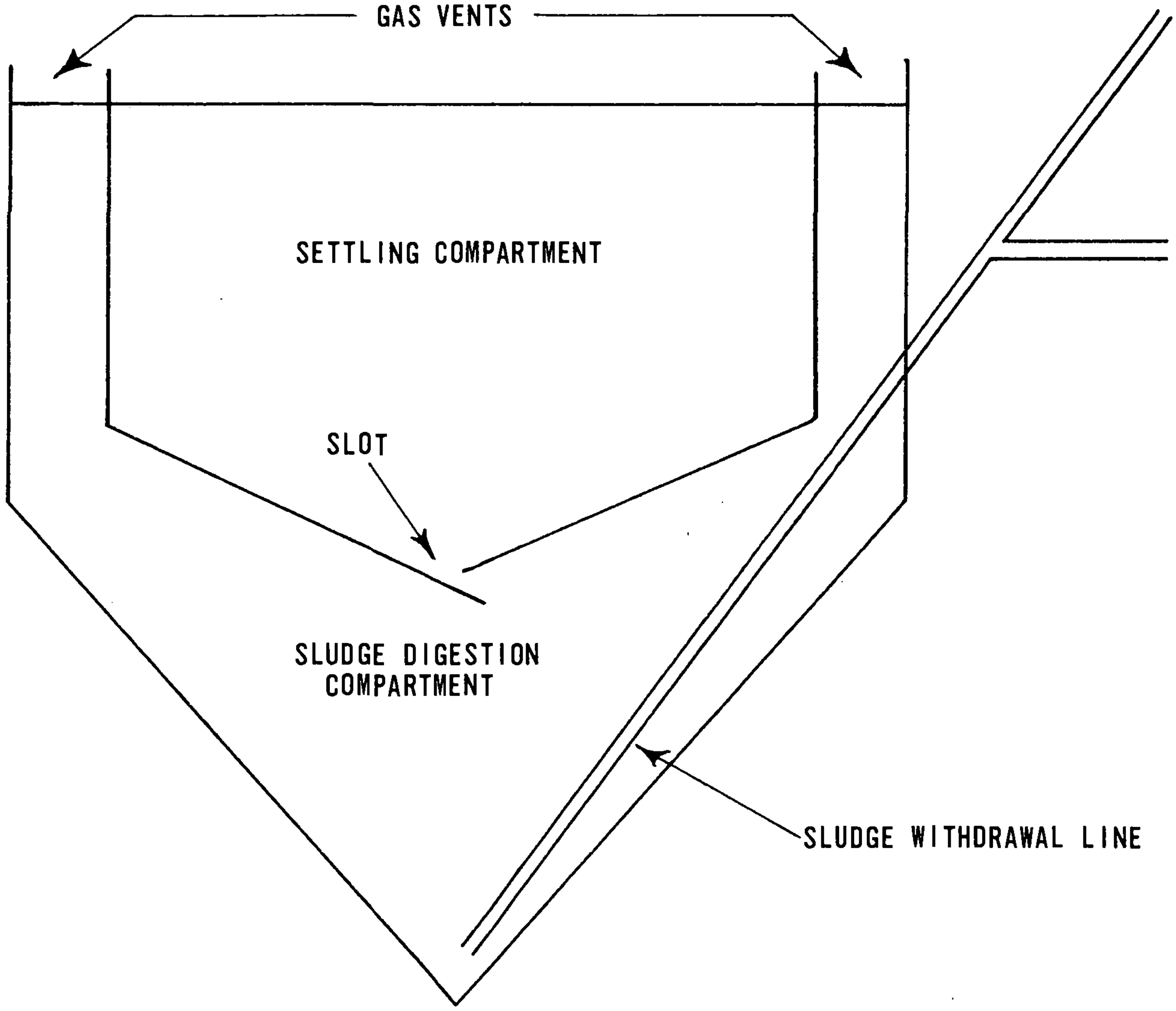

Fig. 5.9 Imhoff tank

Here are a few operational suggestions:

1. In general, there is no mechanical sludge scraping device for removing settled solids from the floor of the settling area. Solids may accumulate before passing through the slot to the digestion area. It may be necessary to push the accumulation through the slot with a squeegee or similar device attached to a long pole. Dragging a chain on the floor and allowing it to pass through the slot is another method for removing the sludge accumulation.

2. Scum from the sedimentation area is usually collected by hand tools in a separate container for disposal. It may also be transferred to the gas venting area where it will work down into the digestion compartment. Scum in the gas vents should be kept soft and broken up by soaking it periodically with water or by punching holes in it and mixing it with the liquid portion of the digestion compartment. The addition of 10 pounds of hydrated lime per 1000 connected population per day may be helpful for controlling odors from the gas vent area and also for adjusting the chemical balance of the scum for easier digestion.

3. Some Imhoff tanks have the piping and valving to reverse the direction of flow from one end toward the other end. If possible, the flow should be reversed periodically for the purpose of maintaining an even sludge depth in the digestion compartment. The sludge level in the digestion area must be lower than the slot in the floor of the settling area to prevent plugging of the slot. A line of gas bubbles directly over the slot indicates the sludge level in the digestion chamber is too high.

4. The explanation of sludge digestion in Chapter 8 will supply information that can be applied to the digestion area in the Imhoff tank. Neither sludge mixing nor heating devices are used in an Imhoff tank. Sludge loading rates, withdrawal rates, laboratory tests, and visual appearance of sludges are very similar to what they are in an <u>unheated</u> digester. If visual appearance is the only method you have of judging the sludge, it is safe to assume that if sludge in the digestion area is relatively odorless or has a musty smell and is black or very dark in color, the process is working satisfactorily.

The laboratory testing program for an Imhoff tank should be complete enough to identify operational problems and to supply necessary information to regulatory agencies. The following minimum program is suggested, assuming adequate laboratory facilities, personnel, and size of the system.

SUGGESTED ANALYSIS	USUAL RANGE	TYPICAL REMOVAL %
Settling Area		
Settleable Solids	3.0 - 10.0 ml/l	75 - 90
Suspended Solids	200 - 400 mg/l	45 - 65
pH	6.7 - 7.3	
Alkalinity	100 - 300 mg/l	
BOD	200 - 500 mg/l	25 - 35
Digestion Area		
pH	6.7 - 7.3	
Alkalinity	1000 - 3000 mg/l	
Vol. Acids	100 - 500 mg/l	

Efficiency of operation can be determined by measuring the settleable solids, suspended solids, or BOD of the influent and effluent.

QUESTIONS

5.8A What are the two components of an Imhoff tank?

5.8B Describe the sludge from an Imhoff tank which is operating properly.

5.8C How could you maintain a fairly level sludge blanket in the digester portion of an Imhoff tank?

5.8D How can you force settled material into the digestion compartment?

5.9 SEPTIC TANKS

Septic tanks are used mostly for treating the wastewater from individual homes or from small populations (such as camps) where sewers have not been provided. They operate very much like an Imhoff tank except there is not a separate digestion compartment. Detention time is usually long (12 to 24 hours) and most settleable solids will remain in the tank. They must be pumped out and disposed of periodically to prevent the tank from filling up. Part of the solids in the septic tank are liquified and discharged with the wastewater into the soil mantle. Conditions are not favorable for rapid gasification and most waste stabilization occurs in the soil.

Septic tank effluent is usually disposed of in underground perforated pipes called "leach lines", and sampling of effluent may be impossible. The ability of the soil mantle to leach the septic tank effluent is the critical factor in subsurface waste disposal systems.

For additional information on septic tanks, refer to the Manual of Septic Tank Practice, U.S. Public Health Service, Washington, D.C.

5.10 ADDITIONAL READING

a. MOP 11, pages 25-38 and 89-97

b. New York Manual, pages 31-45

c. Texas Manual, pages 174-201

d. Sewage Treatment Practices, pages 35-47

DISCUSSION AND REVIEW QUESTIONS

Chapter 5. Sedimentation and Flotation

(End of Lesson 3 of 3 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 2.

10. Why should floatable solids be removed from wastewater?

11. What is the critical factor in subsurface wastewater disposal systems?

SUGGESTED ANSWERS

Chapter 5. Sedimentation and Flotation

5.2A Settleable solids, suspended solids, total solids, BOD, and coliform group bacteria.

5.2B 90% to 95%.

5.2C Influent and effluent.

5.2D Efficiency, % $= \frac{(\text{In} - \text{Out})}{\text{In}} 100\%$

$$= \frac{(300 \text{ mg/l} - 120 \text{ mg/l})}{300 \text{ mg/l}} 100\%$$

$$= 60\%$$

5.3A Often enough to prevent septic conditions or sludge gasification.

5.3B Stop pumping sludge when it becomes thin. Thin sludge can be detected by the sound of the sludge pump, differences in sludge pump pressure gauge readings, and by visual observation of the sludge.

5.3C Scum can be kept out of the clarifier effluent by a baffle placed around the inside edge of the overflow weir.

(END OF ANSWERS TO QUESTIONS IN LESSON 1)

5.6A Short circuiting occurs in a clarifier when the flow is not uniform throughout the tank.

5.6B Short circuiting is undesirable because where the velocity is too high, particles will not have time to settle. Where the velocity is too low, undesirable septic conditions may develop.

5.6C Short circuiting may be corrected by installing weir plates or baffles.

5.6D Tank Volume, cu ft $= \frac{\pi}{4} \times (\text{Diameter, ft})^2 \times \text{Depth, ft}$

$= \frac{\pi}{4} \times (80\ \text{ft})^2 \times 10\ \text{ft}$

$= \frac{3.14}{4} \times 6400 \times 10$

$= 0.785 \times 64{,}000$

$= 50{,}240\ \text{cu ft}$

```
   .785
  64000
3140000
4710
50240.000
```

Tank Volume, gal $= 50{,}240\ \text{cu ft} \times 7.5\ \text{gal/cu ft}$

$= 376{,}800\ \text{gal}$

```
 50240
   7.5
251200
351680
376800.0
```

1. Detention Time, hrs $= \frac{\text{Tank Volume, gal} \times 24\ \text{hr/day}}{\text{Flow, gal/day}}$

$= \frac{376{,}800\ \text{gal} \times 24\ \text{hr/day}}{4{,}000{,}000\ \text{gal/day}}$

$= .376800 \times 6$

$= 2.2608$

$= 2.3\ \text{hrs}$

2. Weir Overflow Rate, gpd/ft $= \frac{\text{Flow Rate, gpd}}{\text{Length of Weir, ft}}$

$= \frac{4{,}000{,}000\ \text{gpd}}{3.14 \times 80\ \text{ft}}$

$= \frac{4{,}000{,}000\ \text{gpd}}{251.2\ \text{ft}}$

$= 15{,}923\ \text{gpd/ft}$

```
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251.2 ) 4000000.0
        2512
        14880
        12560
         23200
         22608
           5920
           5024
            896 0
            753 6
```

5.6D (Continued)

3. Surface Loading Rate

Calculate Surface Area, sq ft

$$\text{Surface Area, sq ft} = \frac{\pi}{4} \times (\text{Diameter, ft})^2$$

$$= \frac{3.14}{4} \times (80 \text{ ft})^2$$

$$= 0.785 \times 6400$$

$$= 5.024 \text{ sq ft}$$

$$\begin{array}{r} 0.785 \\ \underline{6400} \\ 314000 \\ \underline{4710} \\ 5024.000 \end{array}$$

$$\text{Surface Loading Rate, gpd/sq ft} = \frac{\text{Flow Rate, gpd}}{\text{Surface Area, sq ft}}$$

$$= \frac{4{,}000{,}000 \text{ gpd}}{5{,}024 \text{ sq ft}}$$

$$= 800 \text{ gpd/sq ft (close enough)}$$

(END OF ANSWERS TO QUESTIONS IN LESSON 2)

5.6E Secondary clarifiers are needed in secondary treatment plants to remove solids from the secondary process.

5.6F Sludge settling in the secondary clarifier may be returned to the primary clarifier to be settled with the primary sludge, pumped to the beginning of the biological process for recycling, or pumped directly to the sludge handling facilities.

5.7A The flotation process is used to remove "colloids" and "emulsions".

5.7B After.

5.7C Colloid - A very small solid that remains dispersed in a liquid for a long time due to its small size and electrical charge.

Emulsion - A liquid mixture of two or more liquid substances in a relatively stable suspension which do not combine chemically.

5.7D The vacuum flotation process consists of aerating the wastewater and applying a vacuum to pull out the air which will carry the solids to the water surface.

5.8A (1) Settling area, and (2) Sludge digestion area.

5.8B Digested sludge in an Imhoff tank is relatively odorless or has a musty smell, and it is black or very dark in color.

5.8C A fairly level sludge blanket is maintained by reversing the flow at regular intervals.

5.8D Settled material may be forced into the digestion compartment by pushing it through the connecting slot with a squeegee.

(END OF ANSWERS TO QUESTIONS IN LESSON 3)

OBJECTIVE TEST

Chapter 5. Sedimentation and Flotation

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one answer to each question.

EXAMPLE

The purpose of detaining water in a sedimentation tank is to:

1. Store for future use
2. Allow solids to settle to the bottom
3. Allow grease to float to the surface
4. Hold until trickling filter is ready
5. Provide chlorine contact time

To answer this question, you should mark on your answer sheet:

	1	2	3	4	5
EXAMPLE:		■	■		

---

1. Skimmed solids may be disposed of by:
    1. Pumping to digester
    2. Burying with material from bar screen
    3. Incineration
    4. Sold for grease and oil content
    5. None of these

2. What items should be checked before starting a clarifier?
    1. Remove debris from pipes and tank
    2. Lubricate equipment
    3. Sample effluent
    4. Turn off chlorinator
    5. Run a clarity test

3. Generally, pH is significantly affected by a clarifier:
    1. True
    2. False

4. An operator can tell if "thin" sludge is being pumped by:

    1. The sound of the sludge pump
    2. The smell of the sludge
    3. The color of the sludge
    4. Pressure gauge readings on the suction and discharge of the pump
    5. Visual observation

5. The maintenance program for a properly operating clarifier should include:

    1. Sample influent
    2. Regular inspection
    3. Keep a list of repairs
    4. Prompt adjustment or repair when necessary
    5. Lubricate equipment at regular intervals

6. Dangerous gases an operator may encounter in and around a treatment plant include:

    1. Hydrogen sulfide
    2. Nitrogen
    3. Chlorine
    4. Fumes from gasoline
    5. Methane

7. What factors influence the settling characteristics of solids in a clarifier?

    1. Flow velocity and/or turbulence
    2. Temperature
    3. Laboratory analyses
    4. Short circuiting
    5. Detention time

8. If short circuiting occurs in a clarifier, the operator should:

    1. Check the wiring
    2. Identify the cause
    3. Change fuses
    4. Try installing baffles
    5. Restart the pump

9. Plant analysis of samples is a reliable method of measuring clarifier efficiency:

    1. True
    2. False

10. What are "sloughings"?

   1. Troughs
   2. Slop
   3. Material washed off trickling filter media
   4. Waste activated sludge
   5. Grit

11. Secondary or final clarifiers are needed to:

   1. Increase sludge digestion
   2. Allow septic conditions to develop
   3. Provide a home for organisms
   4. Remove solids from biological processes
   5. None of these

12. An Imhoff tank has:
   1. Two compartments
   2. Sludge scrapers
   3. A piping system that allows the flow in the tank to be reversed from one end to the other end
   4. A separate sludge digestion compartment under the settling area
   5. Gas vents

13. Primary clarifiers are designed to remove colloidal solids:

   1. True
   2. False

14. Estimate the detention time in a 20,000-gallon sedimentation tank if the flow is 0.2 MGD. Select the closest answer.

   1. 1.5 hr
   2. 1.8 hr
   3. 2.0 hr
   4. 2.4 hr
   5. 2.8 hr

15. Estimate the detention time in a sedimentation tank 90 ft long, 30 ft wide, and 12 ft deep, if the flow is 3.0 MGD. Select the closest answer.

   1. 1.5 hr
   2. 1.8 hr
   3. 2.0 hr
   4. 2.4 hr
   5. 2.8 hr

Please write on your IBM answer sheet the total time required to work all three lessons and this objective test.

APPENDIX

Monthly Data Sheet

CLEANWATER, U.S.A.

WATER POLLUTION CONTROL PLANT

MONTHLY RECORD ____________ 19____ OPERATOR: ____________________

				RAW WASTEWATER						EFFLUENT					DIGESTION					REMARKS
DATE	DAY	WEATHER	FLOW MGD	TEMP.	pH	SETT. SOLIDS	BOD	SUSP. SOLIDS	GRIT — YD.³	pH	BOD	SUSP. SOLIDS	DO	CL_2 RES.	RAW SLUDGE GAL / DAY	SCUM GAL / DAY	% CO_2	GAS PROD. FT³/ DAY	MIXING — HRS.	
1	M	FAIR	1.200	70	7.3	8	190	208	1.0	7.2	118	110	1.0	2.1	4750	100	32	10400	4	
2	T	"	1.051	69	7.2	10	205	218	1.0	7.1	128	108	1.1	2.4	4108	110	32	10900	–	
3	W	"	1.120	69	7.3	11	220	222	1.5	7.1	154	111	0.9	3.0	4302	90	33	10800	8	
4	T	"	0.987	70	7.1	9	184	201	1.0	7.0	130	97	1.2	1.8	3810	120	33	11200	8	SLUDGE to #1 BED – 16,000 GAL.
5	F	CL.	1.008	68	7.0	7	232	248	1.0	7.0	140	112	0.7	1.9	4005	115	34	10600	8	
6	S	"	1.102	68	7.2	9	211	210	0.75	7.1	138	100	0.8	2.1	4190	120	32	11000	4	
7	S	FAIR	0.974	69	7.3	8	199	215	0.75	7.1	140	101	0.9	2.0	3915	110	32	10800	4	
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28																				
29																				
30																				
31																				
MAX.																				
MIN.																				
AVG.			1.016	69	7.1	9	195	210	1.0	7.1	135	106	0.9	2.0	4154	100	33	10810	5	

SUMMARY DATA

% REMOVAL	BOD	SS
INF. – EFF.	30	49

SLUDGE DATA

% SOLIDS – AVG.	4.8
LBS. DRY SOLIDS / DAY	1663
% VOL. SOLIDS – AVG.	76
LBS. VOL. SOLIDS / DAY	1264
LBS. VOL. SOL. / 1000 FT.³/ DAY	25.3
GAL. SLUDGE TO BEDS	48,000
CU. YDS. CAKE REMOVED	22
FT.³ GAS / LB. VOL. SOLIDS	8.5
FT.³ GAS / MG. FLOW	10,640
CU. YDS. GRIT / MG. FLOW	1.0

COST DATA

MAN DAYS 44 PAYROLL	$ 1250 –
POWER PURCHASED	250 –
OTHER UTILITIES (GAS ETC.)	60 –
GASOLINE, OIL, GREASE	30 –
CHEMICALS & SUPPLIES	60 –
MAINTENANCE	130 –
VEHICLE COSTS	70 –
OTHER	20 –
TOTAL	$ 1870 –
OPERATING COST / MG.	$ 59.37
OPERATING COST / CAPITA / MG	$ 0.19

FLOW METER:
LAST 445237
1st 413749
TOTAL 31.488 MG

ELECTRIC METER:
LAST 5029
1st 4821
MULT. 80 X 208 = 16,640 KWH.

RAW SLUDGE:
LAST 828588
1st 699814
STROKES — SCUM 3100
TOTAL 128,774 X 1.0 = 128,774 GALS.

GAS METER:
LAST 718406
1st 383296
TOTAL 335,110 FT³

CHAPTER 6

TRICKLING FILTERS

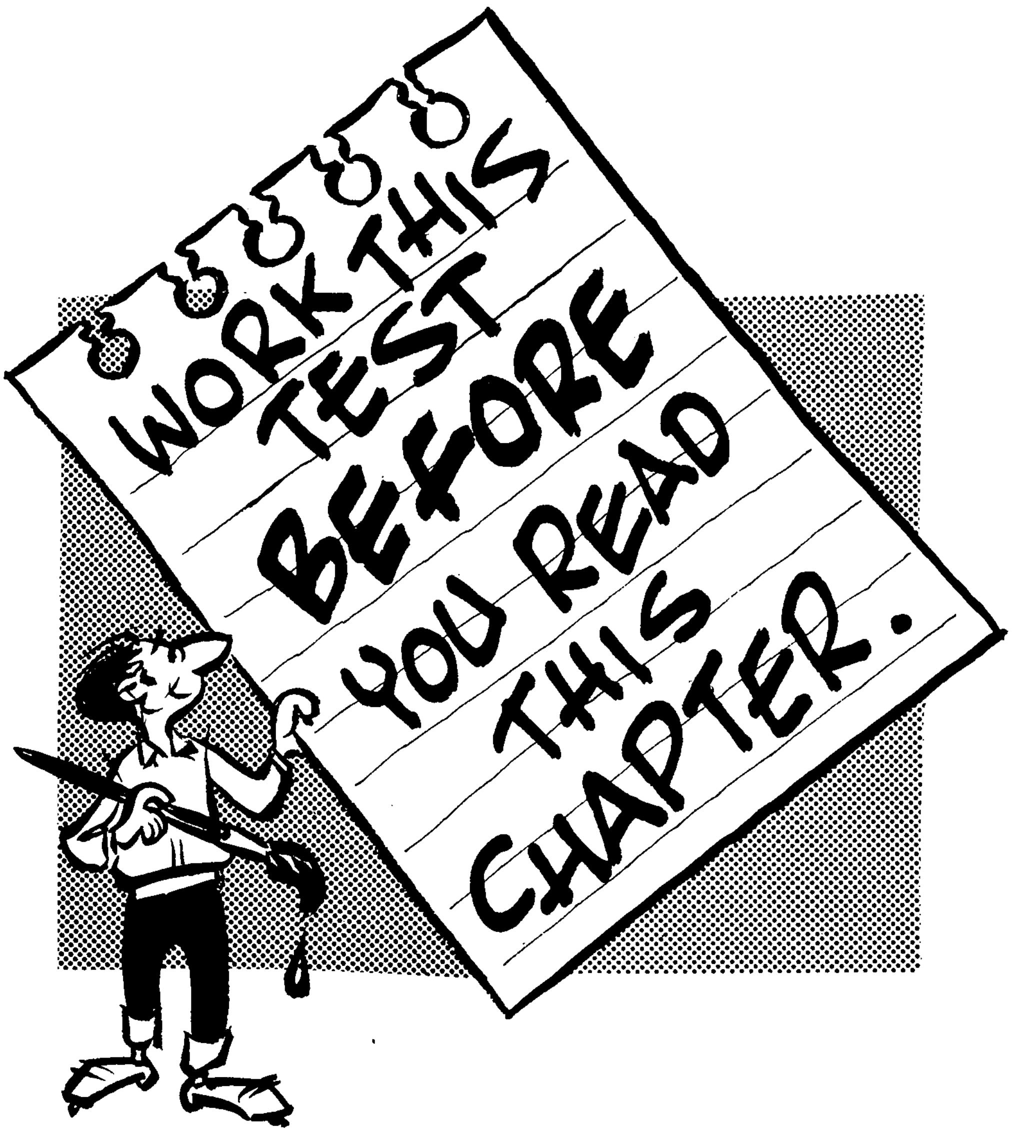
by

Larry Bristow

TABLE OF CONTENTS

Chapter 6. Trickling Filters

EXPLANATION OF PRE-TEST



Write your name and mark your answers on the IBM sheet. The objective of the Pre-Test is to indicate to you the important topics in this chapter, as well as to indicate how well the material was presented to you. It's okay if you don't know many of the answers.

PRE-TEST

Chapter 6. Trickling Filters

Name ______________________ Date __________

Please write your name and mark the correct answers on the IBM answer sheet. There may be more than one answer to each question.

1. Loading on a trickling filter may be expressed as:

   1. lb H_2O/day
   2. lb BOD/day/1000 cu ft
   3. lb H_2O/sq ft/day
   4. gal/day/sq ft
   5. gal/day/1000 cu ft

2. Masking agents:

   1. Cover the filter
   2. Mask the plant
   3. Produce desirable odors
   4. Are sprayed into the air
   5. Tend to make undesirable odors unnoticeable

3. A shock load is:

   1. A heavy blow
   2. A big load in a truck
   3. An unexpected strong waste
   4. An unexpected bump
   5. None of these

4. A flow of 1400 gpm is approximately the same as:

   1. 1 MGD
   2. 2 MGD
   3. 0.5 MGD
   4. 0.33 MGD
   5. 0.75 MGD

5. Physical methods of waste treatment include:

   1. Trickling filters
   2. Disinfection
   3. Sedimentation
   4. Screens
   5. Activated sludge

6. Before starting up a new trickling filter plant the operator should check:

    1. Oil reservoirs for proper amount and type of oil
    2. Rotation of distributor arm
    3. Underdrain system for debris
    4. Zoogleal film on filter media
    5. To be sure there are no voids in the filter media

7. In operating a trickling filter the operator should:

    1. Adjust the process to obtain the best possible results for the least cost
    2. Use the lowest recirculation rates that will yield good results to conserve power
    3. Rotate the distributor as fast as possible to better spray settled wastewater over the media
    4. Maintain aerobic conditions in the filter
    5. Bubble oxygen up through the filter

8. Which test best measures the efficiency of a trickling filter?

    1. Total solids
    2. pH
    3. BOD
    4. Temperature
    5. Sludge age

9. To correct an odor problem in a trickling filter the operator should:

    1. Take corrective action immediately
    2. Shut off flow to the filter
    3. Try to maintain aerobic conditions
    4. Check ventilation in the filter
    5. Increase recirculation rate

10. Maintenance of a distributor moved by hydraulic action includes:

    1. Cleaning the filter media
    2. Cleaning orifices in the distributor arms
    3. Changing the mercury if the distributor arm does not rotate smoothly
    4. Adjusting turnbuckles occasionally on guy rods to keep rotating arms at proper level
    5. Greasing gears that rotate distributor

11. The differences between high-rate filters and standard-rate filters include:

    1. Higher flows per day per square foot of surface area
    2. Higher pounds of BOD per day per cubic foot of media
    3. Higher BOD reductions
    4. Greater depth of filter
    5. Higher rate of odor production

12. The hydraulic loading on a trickling filter 90 feet in diameter with a flow of 0.6 MGD is approximately:

    1. 100 gpd/sq ft
    2. 95 gpd/sq ft
    3. 90 gpd/sq ft
    4. 85 gpd/sq ft
    5. None of these

13. The organic load applied to a trickling filter in pounds of BOD per day for a filter with a diameter of 75 feet, a flow of 0.4 MGD, and a filter influent BOD of 100 mg/1 would be approximately:

    1. 350 lbs/day
    2. 335 lbs/day
    3. 325 lbs/day
    4. 300 lbs/day
    5. None of these

14. Successful trickling filter operation depends on:

    1. Maintenance of a chlorine residual in the effluent
    2. Washing slimes off the filter media
    3. Preventing sludge bulking
    4. Maintenance of a good growth of organisms on the filter media
    5. Filtering the solids out of the wastewater

15. The basic parts of a trickling filter include:

    1. Distribution box
    2. Distribution system
    3. Pumps
    4. Underdrain system
    5. Media

16. Problems associated with trickling filters include:

    1. Bulking
    2. Filter flies
    3. Clogging
    4. Turbid effluent
    5. Snails

17. Trickling filtration is primary treatment process.

    1. True
    2. False

If wastewater recirculation rates are too low, then (18) ______________

18. 1. Aerobic
    2. Anaerobic

conditions may develop in the secondary clarifier; however, if recirculation rates are too high (19) __________

19. 1. Solids will wash out of the secondary clarifier
    2. The effluent will be sparkling clear

GLOSSARY

Chapter 6. Trickling Filters

Aerobic Process (AIR-O-bick): The waste treatment process is conducted under aerobic (in the presence of "free" or dissolved oxygen) conditions.

Anaerobic (AN-air-O-bick): A condition in which "free" or dissolved oxygen is not present.

Colloids (KOL-loids): Very small solids (particulate or insoluble material) in a finely divided form that remain dispersed in a liquid for a long time due to their small size and electrical charge.

Distributor: The rotating mechanism that distributes the wastewater evenly over the surface of a trickling filter or other process unit.

Fixed Spray Nozzle: Cone-shaped spray nozzle used to distribute wastewater over the filter media, similar to a lawn sprinkling system. A deflector or steel ball is mounted within the cone to spread the flow of wastewater through the cone, causing a spraying action.

Loading: Quantity of material applied to a device at one time.

Masking Agents: Liquids which are dripped into the wastewater, sprayed into the air, or evaporated (using heat) with the "fumes" or odors discharged into the air by blowers to make an undesirable odor less noticeable.

Microorganisms (micro-ORGAN-is-zums): Very small organisms that can be seen only through a microscope. Some microorganisms use the wastes in wastewater for food and thus remove or alter much of the undesirable matter.

Orifice (OR-i-fiss): An opening in a plate, wall, or partition. In a trickling filter distributor the wastewater passes through an orifice to the surface of the filter media. An orifice flange set in a pipe consists of a slot or hole smaller than the pipe diameter. The difference in pressure in the pipe above and below the orifice may be related to flow in the pipe.

Physical Waste Treatment Processes: Racks, screens, comminutors, sedimentation, and flotation. Chemical or biological reactions are not an important part of the process.

Ponding: A condition occurring on trickling filters when the voids become plugged to the extent that water passage through the filter is inadequate. Ponding may be the result of excessive slime growths, trash, or media breakdown.

Protozoa (pro-toe-ZOE-ah): A group of microscopic animals, principally of one cell, that sometimes cluster into colonies.

Recirculation: The return of part of the effluent from a treatment process to the incoming flow.

Secondary Treatment: A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated.

Shock Load: The arrival at a plant of waste which is toxic to organisms in sufficient quantity or strength to cause operating problems, such as odors or sloughing off of the growth or slime on the trickling filter media. Organic or hydraulic overloads also can cause a shock load.

Trickling Filter: A treatment process in which the wastewater trickles over media that provide the opportunity for the formation of slimes which clarify and oxidize the wastewater.

Trickling Filter Media: Rocks or other durable materials that make up the body of the filter. Synthetic (manufactured) media have been used successfully.

Two-Stage Filters: Two filters are used. Effluent from the first filter goes to the second filter, either directly or with a clarifier between the two filters.

Zoogleal Film (ZOE-glee-al): A complex population of organisms that form a slime growth on the trickling filter media and break down the organic matter in wastewater. These slimes consist of living organisms feeding on the wastes in wastewater, dead organisms, silt, and other debris. Slime growth is a more common description.

CHAPTER 6. TRICKLING FILTERS

(Lesson 1 of 3 Lessons)

6.0 INTRODUCTION

6.00 General Description

In the initial chapters of this course, you have learned about physical methods of wastewater treatment. In general, these techniques (processes) consist of the screening of large particles, settling of heavy material, and floating of light material by preliminary and primary treatment units (screen, grit chamber, clarifier). Although primary treatment is very efficient for removing settleable solids, it is not capable of removing other, lighter suspended solids or dissolved solids which may exert a strong oxygen demand on the receiving waters.

In order to remove the very small suspended solids (colloids) and dissolved solids, most waste treatment plants now being built include "secondary treatment".[1] This additional process increases overall plant removal of suspended solids and BOD to 90% or more. The two most common secondary treatment processes are trickling filters and activated sludge. This chapter will deal with trickling filters.[2]

---

[1] Secondary treatment. A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated.

[2] Trickling filters are sometimes called biofilters, accelo filters, or aero-filters, depending on the recirculation pattern.

Figures 6.1 and 6.2 show where a trickling filter is usually located in a plant.

More trickling filters, have been built in this country than any other type of secondary treatment device. Most trickling filters are large in diameter, shallow, cylindrical structures filled with stone and having an overhead distributor. (See Fig. 6.3.) Many variations of this design have been built. Square or rectangular filters have been constructed with fixed sprinklers for wastewater distribution.

6.01 Principles of Treatment Process

Trickling filters, or biological oxidation beds, consist of three basic parts:

1. The media (and retaining structure)
2. The underdrain system
3. The distribution system

The media provide a large surface area upon which a biological slime growth develops. This slime growth, sometimes called a zoogleal film,[3] contains the living organisms that break down the organic material. The media may be rock, slag, coal, bricks, redwood blocks, molded plastic (Fig. 6.4), or any other sound, durable material. The media should be of such sizes and stacked in such a fashion to provide voids for air to ventilate the filter and keep conditions aerobic. For rock, the size will usually be from about two inches to four inches. Although actual size is not too critical, it is important that the media be uniform in size to permit adequate ventilation. The depth ranges from about three to eight feet.

The underdrain system has a sloping bottom, leading to a center channel, which collects the filter effluent. It also supports the media and permits air flow. Common methods are the use of spaced redwood stringers, or any of a number of prefabricated blocks of concrete, vitrified clay, or other material.

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[3] Zoogleal Film (ZOE-glee-al). A complex population of organisms that form a slime growth on the trickling filter media and break down the organic matter in the wastewater. These slimes consist of living organisms, silt, and other debris. Slime growth is a more common definition.

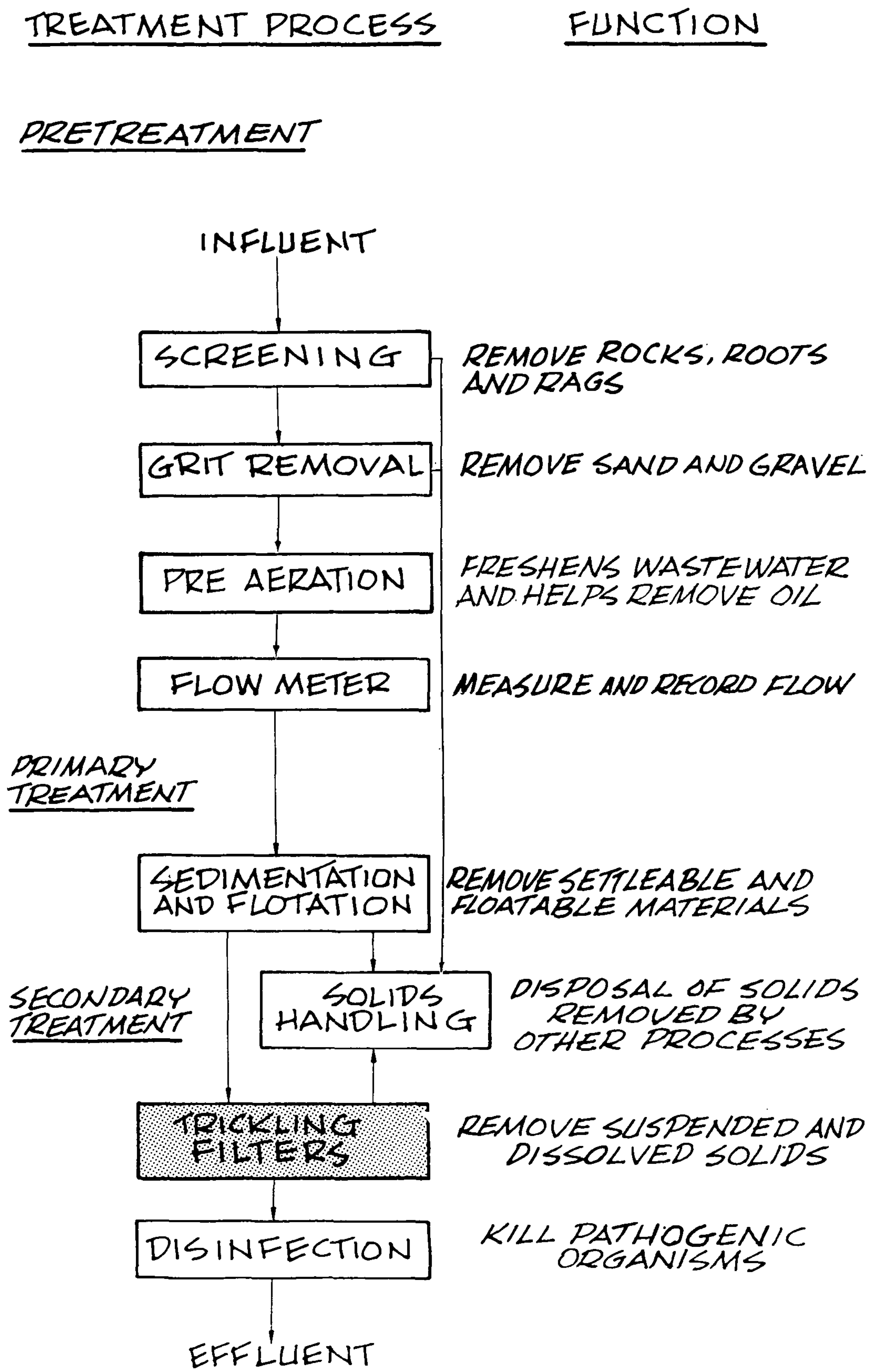

Fig. 6.1 Flow diagram of treatment plant

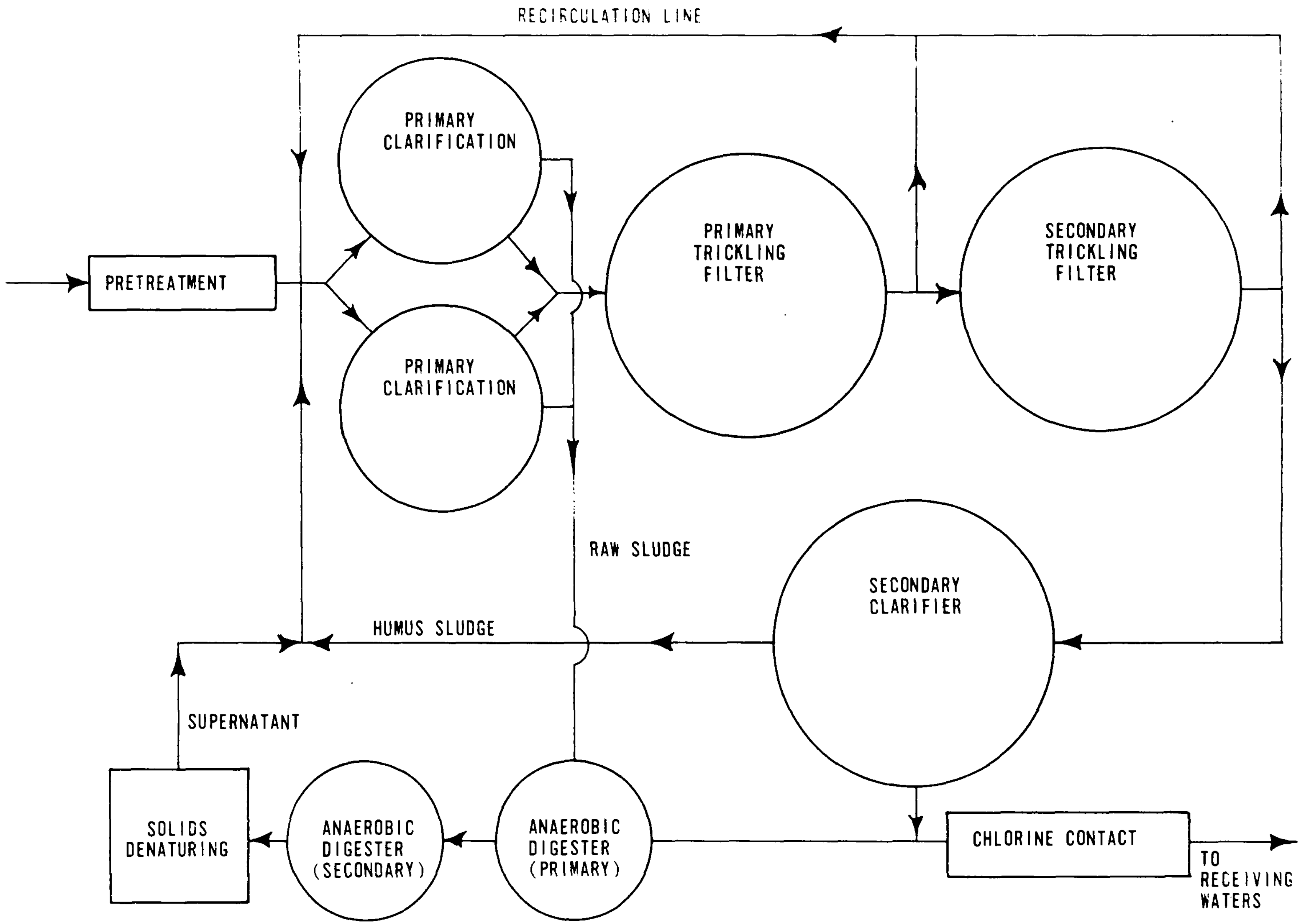

Fig. 6.2 Plan to typical trickling filter plant

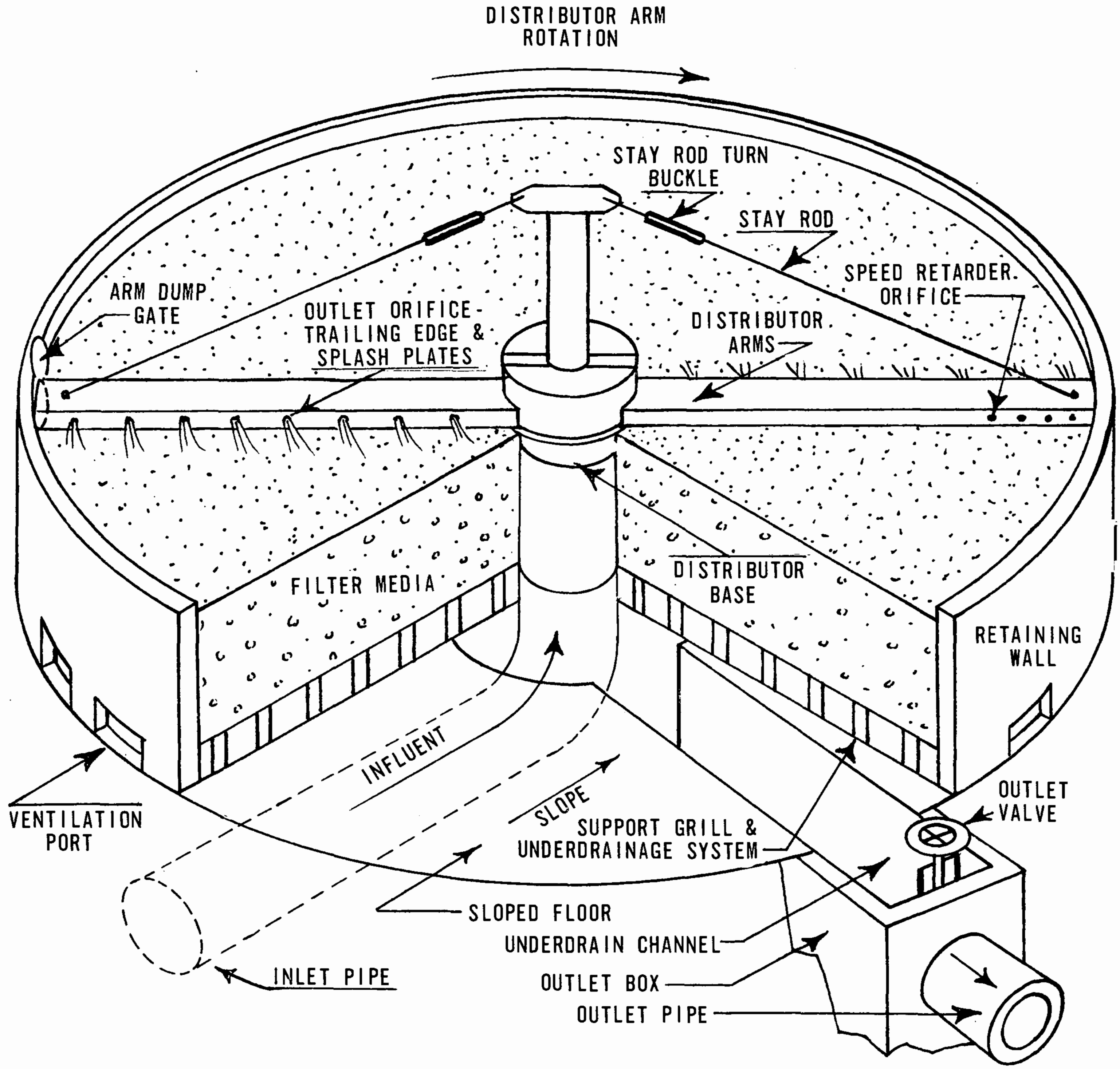

Fig. 6.3 Trickling filter

Fig. 6.4 Installation of synthetic media in trickling filter

(Courtesy of The Dow Chemical Company)

The distribution system, in the vast majority of cases, is a rotary-type distributor which consists of two or more horizontal pipes supported a few inches above the filter media by a central column. The wastewater is fed from the column through the horizontal pipes and is distributed over the media through orifices located along one side of each of these pipes (or arms). Rotation of the arms is due either to the "jet-like" or rotating water sprinkler reaction from wastewater flowing out the orifices or by some mechanical means. The distributors are equipped with a mercury or mechanical type seal at the center column to prevent leakage and protect the bearings, guy rods for seasonal adjustment of the pipes (arms) to maintain them in a horizontal position, and quick-opening gates at the end of each arm to permit easy flushing.

Today the fixed nozzle distribution system is not as common as the rotary type. Each fixed nozzle consists of a circular orifice with an inverted cone-shaped deflector mounted above the center which breaks the flow into a spray. Some types have a steel ball in the inverted cone. (See Fig. 6.5.) The fixed nozzle system requires an elaborate piping system to insure relatively even distribution of the wastewater. Flow is usually intermittent and is controlled by automatic siphons which regulate the flow from dosing tanks. (See Fig. 6.5.) The nozzles extend six to twelve inches above the media and are shaped so that an overlapping spray pattern exists at the start of dosing when the head in the dosing tank is the greatest. The pattern is carefully worked out to provide a relatively even distribution of the wastewater.

6.02 Principles of Operation

The maintenance of a good growth of organisms on the filter media is crucial to successful operation.

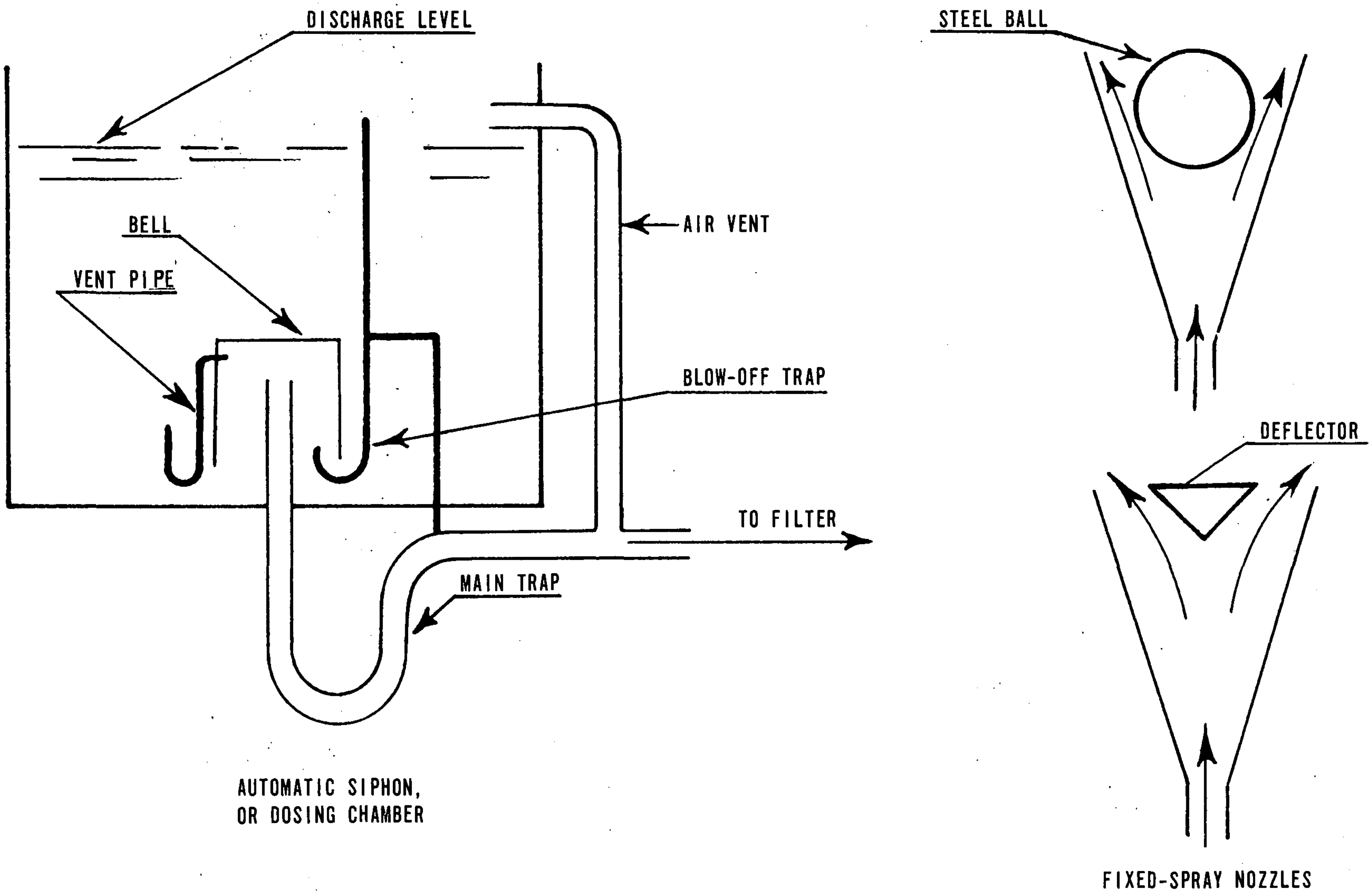

Fig. 6.5 Siphon and nozzle details for fixed spray filters

The term "filter" is rather misleading, indicating that solids are separated from liquid by a straining action, but this is not the case. Passage of wastewater through the filter causes the development of a gelatinous coating of bacteria, protozoa, and other organisms on the media. This growth of organisms absorbs and utilizes much of the suspended colloidal and dissolved organic matter from the wastewater as it passes over the growth in a rather thin film. Part of this material is utilized as food for production of new cells, while another portion is oxidized to carbon dioxide and water. Partially decomposed organic matter together with excess and dead film is continuously or periodically washed (sloughed) off and passes from the filter with the effluent.

For the oxidation (decomposition) processes to be carried out, the biological film requires a continuous supply of dissolved oxygen, which may be absorbed from the air circulating through the filter voids (spaces between the rocks or other media). Adequate ventilation of the filter must be provided; therefore the voids in the filter media must be kept open. Clogged voids can create operational problems, including ponding and reduction in overall filter efficiency.

A method of increasing the efficiency of trickling filters is to add recirculation. Recirculation is a process in which filter effluent is recycled and brought into contact with the biological film more than once. Recycling of filter effluent increases the contact time with the biological film and helps to seed the lower portions of the filter with active organisms. Due to the increased flow rate per unit of area, higher velocities occur which tend to cause more continuous and uniform sloughing of excess growths, thus preventing ponding and restriction of ventilation. This increased hydraulic loading also decreases the opportunity for snail and filter fly breeding. It has been observed that the thickness of the biological growth is directly related to the organic strength of the wastewater (the higher BOD, the thicker the layers of organisms). By the use of recirculation, the strength of wastewater applied to the filter can be diluted, thus preventing excessive build-up.

Recirculation may be constant or intermittent and at a steady or fluctuating rate. Recycling may be practiced only during periods of low flow to keep rotary distributors in motion, to prevent drying of the filter growths, or to prevent freezing. Recirculation in proportion to flow may be utilized to reduce the strength of the wastewater applied to the filter while steady recirculation of a constant amount keeps the distributors in operation and also tends to even out the highs and lows of organic loading, but involves higher pumping costs.

It is generally agreed that any organic waste which can be successfully treated by other aerobic biological processes can be treated on trickling filters. This includes, in addition to domestic wastewater, such wastewaters as might come from food processing, textile and fermentation industries, and certain pharmaceutical processes. Industrial wastewaters which cannot be treated are those which contain excessive concentrations of toxic materials, such as pesticide residues, heavy metals, and highly acidic or alkaline wastes.

For maximum efficiency, the slime growths on the filter media should be kept fairly aerobic. This can be accomplished by proper design of the wastewater collection system and proper operation of primary clarifiers, or by pretreatment of the wastewater by aeration or addition of recycled filter effluent. The air supply to the slimes may be improved by increased air or wastewater recirculation. The thin slime growth may be aerobic on the surface, but anaerobic next to the media. A trickling filter media of rock or slag can accumulate slimes only on the outside surface, but manufactured media provides considerably more surface area per unit of dead space.

The temperature of the wastewater and of the climate also affects filter operation, with temperature of the wastewater being the more important. Of course, temperature of the wastewater will vary with the weather. Within limits, activity of the organisms increases as the temperature rises. Therefore, higher loadings and greater efficiency are possible in warmer climates if aerobic conditions can be reasonably maintained in the filter.

QUESTIONS

6.0A Primary treatment is effective in removing (a) ____________ ____________ and (b) ____________ ____________, but not nearly as effective in removing (c) ____________ ____________.

6.0B What is the purpose of "secondary treatment"?

6.0C How does the trickling filter process work?

6.0D What causes the distributor arms or pipes on a trickling filter to operate?

6.0E How does recirculation increase the efficiency of a trickling filter?

6.1 STARTING AND OPERATING A FILTER[4]

6.10 Pre-Start Up

A new plant is seldom started up without some unexpected, frustrating problems. Some careful checking ahead of time can prevent many of these situations.

If at all possible, you should arrange to be present when your new equipment is serviced. You should see that the correct oil is used in all oil reservoirs. Many contractors will put motor oil in everything and consider it serviced. For future reference, record the amount and type of oil each reservoir holds.

Insist on being present when the mercury is installed in the mercury seal chamber on trickling filter distributors. This is expensive material, and in case wastewater leaks past the seal, you should definitely know whether the recommended amount of mercury was installed.

After the oil and mercury have been installed in a distributor, check the arms for even adjustment and level. Rotate the unit by hand and observe for smooth turning. Any vibration or roughness should be corrected before putting the unit in service.

If the distributor has adjustable orifices, get the erection sheet and a rule and check out the orifice settings. File the erection sheet for future reference.

In a trickling filter plant with fixed spray nozzles, each nozzle should be checked to insure that it is free of foreign objects.

In order to prevent damage to pumps, crawl into the underdrain system of the filter and remove any debris (rocks, pieces of wood, etc.). Check painted surfaces for damaged areas. Touch these up before they get wet to prevent corrosion and further damage. A few nicks and scratches in a distributor arm can seriously affect the life of the original protective coatings.

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[4] Contracts for treatment plant construction often include services of the consultant or contractor to assist in start-up of new facilities. The operator should make full use of these services when available.

Check all valves in the system for smooth operation. On sliding gate valves, see that the gates seat properly. There are adjustable wedges and stops on this type of valve. With the valve adjusted, set the lock nut on the stem to prevent jamming the gate closed too tightly. These small precautions will yield years of trouble-free valve operation.

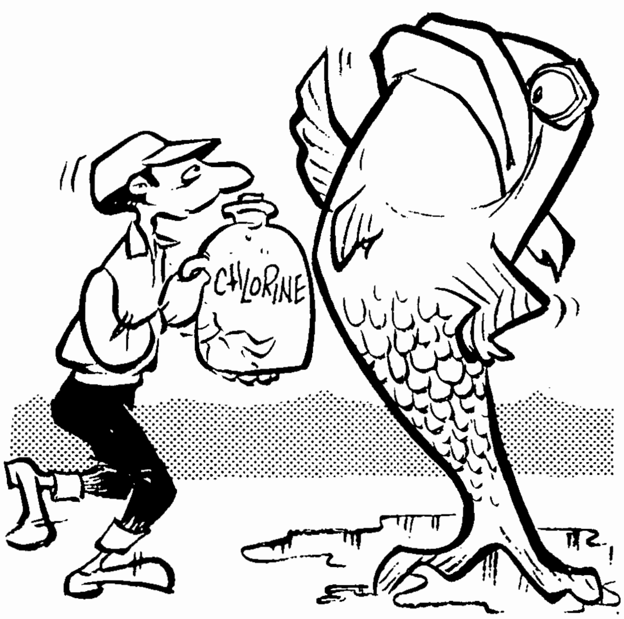
In addition to the general items covered in this section, you should be certain that the correct manufacturer's manual has been furnished for each piece of equipment. Read each manual carefully and follow the given recommendations. Obtain the oils and greases recommended; or, if you buy from one oil company, have their representative furnish you a written list of his company's products that are equivalent to those recommended by the equipment manufacturer.

6.11 Placing Filter in Service

When you have checked out all equipment mechanically, starting up the trickling filter portion of the plant is very simple. Start the wastewater flow to the filters, observing the rotating arms carefully for smooth operation, speed of rotation, and even distribution of the waste over the media. Time the speed of rotation, record the flow rate, and log them for future reference.

For fixed nozzles, observe the spray pattern. Some debris will usually show up to plug some of the nozzles, the amount depending on how thoroughly the plant was checked out previous to start-up. It is important to keep the nozzles clear so that the wastewater is distributed over all of the filter media.

It will take several days for any growth to develop on the filter media, and up to several weeks for full development. Time of year, weather conditions, and strength of the waste are all factors which will affect the time needed for growth development.



During this period of growth development, an unstable effluent will be produced. This effluent will exert a pollutional load on the receiving waters. Heavy chlorination is usually used during this time to reduce the pollutional load and the health hazard to some extent.

In some locations, the use of chlorine in this manner may be restricted, such as where fish are threatened. If an older plant is being phased out, it may be possible to load the new facilities lightly or intermittently until a full growth is established.

Starting up of pumps, clarifiers, and other equipment is covered in other chapters.

6.12 Daily Operation

Once growth on the media has been established and the plant is in "normal operation", very little routine operational control is required. Careful daily observation is important. Items to be checked daily are:

1. Any indication of ponding
2. Filter flies
3. Odors
4. Plugged orifices
5. Roughness or vibration of the distributor arms
6. Leakage past the mercury seal

Occasionally the underdrains should be checked for accumulation of debris in order to prevent stoppages.

Refer to the appropriate paragraphs in the following section on operational problems for procedures to correct these conditions.

Operation of clarifiers is interconnected with trickling filter operation. If the recirculation pattern permits, it is a good idea to return filter effluent to the primary clarifier. This is a very effective odor control measure. In some plants, increasing the recirculation rate will increase the hydraulic loading on the clarifier. Be sure the hydraulic loading remains within the engineering design limits. If the hydraulic loading is too low, septic conditions may develop in the clarifier, while excessively high loadings may wash solids out of the clarifier.

Recirculation during low inflow periods of the day and night may help to keep the slime growths wet, minimize fly development and wash off excessive slime growths. It may be necessary to reduce or stop recirculation during high flow periods to avoid clarifier problems from hydraulic overloading. Recirculation of final clarifier effluent dilutes influent wastewater and recirculated sludge improves slime development on the media.

You should, by evaluating your own operating records, adjust the process to obtain the best possible results for the least cost. Use the lowest recirculation rates that will yield good results (but not cause ponding or other problems) to conserve power. Power costs are a large item in a plant budget. Also, reduced hydraulic loadings mean better settling in the clarifiers, resulting in less chlorine usage in plants which disinfect the final effluent, since organic matter exerts a high chlorine demand. If filter effluent, rather than secondary clarifier effluent, is recirculated, the hydraulic loading on the secondary clarifier is not affected.

QUESTIONS

6.1A Prepare a check list of items that should be inspected before a trickling filter is placed in service.

6.1B During start-up of a trickling filter, why should the plant effluent be heavily chlorinated?

6.1C Prepare a check list of items needing daily inspection during "normal operation".

6.1D What may happen to a clarifier effluent if the clarifier is not operated within design hydraulic loadings?

6.2 SAMPLING AND ANALYSIS

6.20 General

The trickling filter is a biological treatment unit and therefore loadings and efficiencies of the unit are normally determined on the basis of influent characteristics (inflow and biochemical oxygen demand (BOD) test) and required quality of effluent or receiving waters (dissolved oxygen and solids). Detailed procedures for performing the trickling filter control tests are given in Chapter 14, Laboratory Procedures and Chemistry. The frequency of each test and expected ranges will vary from plant to plant. Strength of the wastewater, freshness, characteristics of the water supply, weather, and industrial wastes will all serve to affect the "common" range of the various test results.

6.21 Typical Trickling Filter Plant Lab Results

	Test	Frequency	Location	Common Range
1.	Dissolved Oxygen	Daily	Prim. Effl.	1.0 - 2.0 mg/l
2.	Settleable Solids	Daily	Influent	5 - 15 ml/l
3.	pH	Daily	Influent Final Effl.	6.8 - 8.0 7.0 - 8.5
4.	Temperature	Daily	Influent	---
5.	BOD	Weekly (Minimum)	Influent Prim. Effl. Final Effl.	150 - 400 mg/l 60 - 160 mg/l 15 - 40 mg/l
6.	Suspended Solids	Weekly (Minimum)	Influent Prim. Effl. Final Effl.	150 - 400 mg/l 60 - 150 mg/l 15 - 40 mg/l
7.	Chlorine Residual	Daily	Final Effl.	0.5 - 2.0 mg/l
8.	Coliform Bacteria	Weekly (Minimum)	Final Effl., Chlorinated	50 - 700/100 ml ---
9.	Clarity	Daily	Final Effl.	1 - 3 ft

NOTES: Results of tests listed on the previous page as "Primary Effluent" may vary at different plants due to the many variations in recirculation patterns and activities of the waste dischargers into the collection system.

Settleable solids tests of the effluent may be required by some regulatory agencies. If your plant is operating efficiently, the settleable solids will be so low as to be unreadable. In this case, record as "Trace".

Dissolved Oxygen and Settleable Solids or Clarity Tests on trickling filter effluent are sometimes useful in evaluating problems when they occur. The operator should know what range is "common" for his plant.

An easy test that should be made periodically by the operator is to check the distribution of wastewater over the filter. Pans of the same size are placed level with the rock surface at several points along the radius of a circular filter. The distributor arm should then be run long enough to almost fill the pans. The arm is then stopped and the amount or depth of water in each pan is measured. The amount in each pan should not differ from the average by more than 5%. If the distribution is not uniform, the orifices must be adjusted.

6.22 Response to Poor Trickling Filter Performance

There are several operational procedures an operator can follow to correct deficiencies in plant performance. The ability to make corrections will depend on your alertness and ingenuity, as well as the design of the collection system and treatment plant. In Section 6.21, the common ranges are listed for a number of lab test results. If your plant is not operating within or near the common ranges for your plant, then you may have problems.

Suspended Solids. An effluent that is high in suspended solids may be expected to affect all the other test results listed. Ordinarily this will be due to three principal factors:

1. Heavy sloughing from the filters,
2. High hydraulic loading or short-circuiting through the secondary or final clarifier, and
3. Shock loading caused by toxic wastes or hydraulic or organic overloads.

Heavy sloughing may be due to seasonal weather changes, a period of heavy organic loading on the filters, or corrective action taken to overcome ponding, filter flies, or other problems (see Section 6.3). High hydraulic loading or short-circuiting in the secondary clarifier will carry the light solids from the filters over the weirs. If a plant is not receiving more flow than it was designed to handle, you may be able to adjust recirculation rates or the flow pattern (see Fig. 6.7, Page 6-40) to reduce the clarifier loading. Refer to Chapter 5, Sedimentation and Flotation, for solutions to problems created in clarifiers by short-circuiting and sludge withdrawal.

BOD. The effluent BOD will generally go up or down along with the suspended solids. This is not always the case, however. Anything you can do to assure that the wastewater arrives at the plant in an aerobic condition will reduce the organic load (and odors); consequently, the effluent BOD will be lower. Aeration has been used in force mains with some degree of success when applied properly.

The recirculation rate and flow pattern will affect effluent quality. These can be varied experimentally, keeping in mind that too low a recirculation rate leads to filter flies and ponding, while too high a rate may cause excessive sloughing or overload the clarifiers. Biological systems respond to a change in their environment and establish a balance with the existing conditions, but it takes time. If you change your operation, give your plant a couple of weeks to reach an equilibrium state (level out) before you decide whether or not you have helped the situation.

The shortcomings of the BOD test must be recognized. It is difficult to use as a daily operational tool unless the influent BOD remains fairly constant. If an industry dumped some wastewater with a high BOD, you could not measure the BOD and base your operational adjustments on the test results because they will not be available for five days. You will have to adjust your operation on the basis of your experience and the probable BOD. Use the COD test to estimate rapid changes in the influent load. For control purposes the COD test procedure may be altered and a very short heating time may be acceptable.

Settleable Solids. High settleable solids in the effluent mean that solids are being carried over the clarifier weir. It also means that the suspended solids will be high. Refer to the paragraph in this section on suspended solids for corrective action.

Dissolved Oxygen. One of the principal functions of a trickling filter plant is to stabilize the oxygen demanding substances in the wastewater being treated. This is achieved by the addition of dissolved oxygen to the water. If the suspended solids and BOD are within range, the DO is almost certain to be in range also. Increased recirculation will increase the DO. In plants with very low inflows, excessive detention time in the clarifiers may cause the problem. If this is the case, remember that any agitation of the effluent will cause it to pick up dissolved oxygen. If the elevation is available, a staircase type of effluent discharge will help; otherwise it may be necessary to aerate the effluent, using compressed air or paddle type aerators (see Chapter 7, Activated Sludge).

Chlorine Demand. Difficulty in maintaining a chlorine residual in the effluent (assuming normal detention period) will primarily be due to excessive solids in the effluent. Refer to the paragraph on Suspended Solids.

Clarity. Clarity of the effluent also is primarily related to the amount, size, shape, and characteristics of the suspended solids in the effluent. In some cases, industrial or food processing wastes may cause discoloration. Trickling filter effluents tend to be slightly turbid.

pH. The pH of the effluent should move from whatever value is found in the influent toward neutral (a pH of 7.0). Normally the influent pH will be somewhat acidic (a pH of less than 7.0) and will move up to 7.0 or slightly higher. Other than pH changes caused by industrial waste dumps or other unusual wastes entering the plant, the pH will remain "normal" as long as the suspended solids and BOD are within reasonable limits. Corrective action requires chemical neutralization.

Coliform Count. Where the bacterial count requirement must be met, excessive solids in the effluent are a serious problem. Even with high chlorine residuals, some particles are not penetrated completely by the chlorine, yielding sporadic results. If in-plant corrections do not solve the solids carry-over problem, some type of water treatment plant techniques may have to be employed, such as coagulation and settling, or sand or diatomaceous earth filters. Good disinfection is achieved if the previous treatment processes do their job.

QUESTIONS

6.2A How would you determine if the distribution of wastewater over a trickling filter is even?

6.2B List the laboratory tests used to measure the efficiency of a trickling filter.

6.2C (1) Calculate the efficiency of a trickling filter plant if the suspended solids of the plant influent is 200 mg/l and the plant effluent suspended solids is 20 mg/l.

(2) What is the efficiency of the trickling filter only if the effluent suspended solids from the primary clarifier (wastewater applied to filter) is 140 mg/l?

END OF LESSON 1 OF 3 LESSONS

on

Trickling Filters

DISCUSSION AND REVIEW QUESTIONS

(Lesson 1 of 3 Lessons)

Chapter 6. Trickling Filters

Name ______________________________ Date ______________ .

Write the answers to these questions in your notebook before continuing.

1. Draw a sketch of a trickling filter and label the essential parts.

2. Why is recirculation important in the operation of a trickling filter?

3. Why should a trickling filter be carefully checked before a new one is started or an existing one is placed in service again?

4. Why would the efficiency of waste removal by a new trickling filter be low during the first few days?

5. What would you do if laboratory results or visual inspection indicated a sudden drop in efficiency of a trickling filter?

6. Calculate the suspended solids removal efficiency of a trickling filter plant if the influent suspended solids were 360 mg/l and the effluent suspended solids were 40 mg/l.

7. Why do laboratory test results for trickling filter plants vary from

   a. plant to plant?
   b. month to month within a plant?

6.3 DAILY OPERATION PROBLEMS

In actual operation, the trickling filter is one of the most trouble-free types of secondary treatment. It requires less operating attention and control. Where recirculation is used, difficulties due to shock loads[5] are less frequent and recovery is faster. Suspended solids in the trickling filter effluent tend to make the effluent somewhat turbid; thus, a poorer quality effluent due to shock loads may not be visibly evident. Recirculation is used to maintain a constant load on the filter and thus produce a better quality of effluent. However, there are some problems which include ponding; odors; insects; and, in colder climates, freezing. These problems are all controllable, and in most cases, preventable.

6.30 Ponding

Ponding is normally the result of excessive organic loading without a corresponding high recirculation rate. Another cause of ponding can be the use of media which is too small or not sufficiently uniform in size. In non-uniform media, the smaller pieces fit between the larger ones and thus make it easier for the slimes to plug the filter. If this condition exists, replacement of the media is the most satisfactory solution. Other causes of ponding include a poor or improper media permitting cementing or break up, accumulation of fibers or

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[5] Shock Loads. The arrival at a plant of waste which is toxic to organisms in sufficient quantity or strength to cause operating problems, such as odors or sloughing off of the growth or slime on the trickling filter media. Organic or hydraulic overloads also can cause a shock load.

trash in the filter voids, a high organic growth rate followed by a shock load and rapid uncontrolled sloughing, or an excessive growth of insect larvae or snails which may accumulate in the voids. Ponding results from a loss of open area in the filter. If the voids are filled, flow tends to collect on the surface in ponds.

The cause of ponding must be located since it may increase rapidly and take over large areas of the filter. Increasing the hydraulic loading by increasing the recirculation ratio or adjusting the orifices on the distributor assembly so that it distributes flow more evenly is likely to flush off some of the heavier portions of the biological film and may slowly cure this condition.

Minor ponding, which may occur from time to time, can be eliminated by any of several methods, including the following:

1. Jet filter surface with a high pressure water stream. Sometimes stopping a rotary distributor over the ponded area will flush the growth from the voids. One way to do this is to shut off the flow momentarily, wait for the distributor to stop, move the distributor to the problem area, and then restart the flow while keeping the distributor over the ponded area.

2. Hand turn or stir the filter surface with a rake, fork, or bar. Remove any accumulation of leaves or other debris.

3. Dose the filter with chlorine at about 5 mg/l for several hours. If done during a period of low flow, the amount of chlorine used is held to a minimum.

4. If it is possible to flood the filter, then keeping the media submerged for 24 hours will cause the growth to slough somewhat. Keep the surface of the media covered, but don't let the water rise high enough to get in the distributor bearings. Under these conditions the growths tend to become anaerobic and loosen or liquify. The resulting liquid is a mess to dump.

5. Shut off flow to the filter for several hours. The growth will dry, and part of it will be flushed our when the unit is put back in service.

It is important to keep in mind that your primary purpose is to consistently turn out an effluent of good quality. With this in mind, the corrective actions on the previous page are listed in order, starting with procedures that will least affect the effluent. If at all possible, ponding should be corrected before it becomes serious. Items 4 and 5 are drastic measures. However, the job must be done so that full efficiency of the filter is restored. In cases 4 and 5, where effluent chlorination is used, it is usually a good idea to increase the amount of chlorine in the effluent until the filter has been restored to normal operation.

6.31 Odors

Since operation of trickling filters is an aerobic[6] process, no serious odors should exist. The presence of foul odors indicates that anaerobic[7] conditions are predominant. (Anaerobic conditions are usually present next to the media surface. As long as the surface of the slime growth zoogleal film is aerobic, odors should be nimor.) Corrective measures should be taken immediately. Some things to check:

1. Do everything possible to maintain aerobic conditions in the sewer collection system and in the primary treatment units.

2. Check ventilation in the filter. Heavy biological growths or stoppages in the underdrain system will cut down ventilation. Examine ventilation facilities such as the draft tube or other inlets for stoppages. If necessary, force air into underdrains using mechanical equipment such as fans or compressors. Natural ventilation through a filter will occur if the vents are open and the difference in air temperature and filter temperature is greater than 3°F.

3. Increase the recirculation rate to provide more oxygen to the filter bed and increase sloughing.

4. Keep the wastewater splash from the distributor away from exposed structures, grass, and other surfaces to retain the growth on the media. If slime growths appear on sidewalks and other surfaces, remove the slimes immediately.

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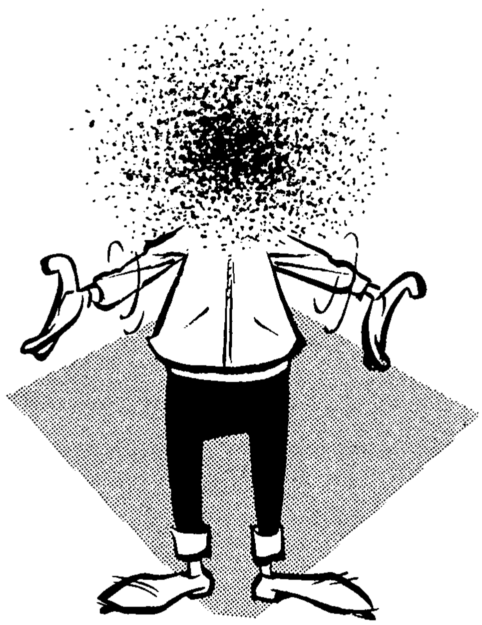
[6] Aerobic (AIR-O-bick). A condition in which "free" or dissolved oxygen is present.

[7] Anaerobic (AN-air-O-bick). A condition in which "free" or dissolved oxygen is not present.

In some cases during hot weather, odors will be noticeable from filters in good condition. If these odors are a serious problem (close neighbors), the situation can sometimes be resolved with one of the commercially available masking agents.[8] This should be a last resort.

6.32 Filter Flies

The tiny, gnat-size filter fly (psychoda) is the primary nuisance insect connected with trickling filter operations. They are occasionally found in great numbers and can be an extremely difficult problem to plant operating personnel as well as nearby neighbors. Preferring an alternate wet and dry environment for development, the flies are found most frequently in low-rate filters and are usually not much of a problem in high-rate filters. Control can usually be accomplished by the use of one or more of the following methods:



1. Increase recirculation. A continuous hydraulic loading of 200 gpd/sq ft or more will keep filter fly larvae washed out of the filter.

2. Apply approved insecticides with caution to filter walls and to other plant structures. If not prohibited by your local control agencies, the surface of the filter (and the walls of the retaining structure) may be sprayed with approved doses of an insecticide.

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[8] Masking Agents. Liquids which are dripped into the wastewater, sprayed into the air, or evaporated (using heat) with the "fumes" or odors discharged into the air by blowers to make an undesirable odor less noticeable.

3. Flood filter for 24 hours at intervals frequent enough to prevent completion of the life cycle. This cycle is as short as seven days in hot weather. A poor effluent will result from this practice and should be accurately monitored.

4. A low dosage of chlorine applied weekly may do the job.

5. Shrubbery, weeds, and tall grass provide a natural sanctuary for filter flies. Good grounds maintenance and cleanup practices will help to minimize fly problems.

6.33 Weather Problems

Cold weather usually does not offer much of a problem to wastewater flowing in a pipe or through a clarifier. Occasionally, however, wastewater sprayed from distributor nozzles or exposed in thin layers on the media may reach the freezing point and cause a build-up of ice on the filter. Several measures can be taken to reduce ice problems on the filter:

1. Decrease the amount of recirculation, provided sufficient flow will remain to keep the filter working properly.

2. Operate two-stage filters[9] in parallel rather than in series.

3. Adjust orifices and splash plates to reduce the spray effect.

4. Construct wind screens, covers, or canopies to reduce heat losses.

5. Break up and remove the larger areas of build-up.

6. Partially open end gates to provide a stream rather than a spray along the retaining wall.

7. Add hot water or steam to the influent if necessary.

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[9] Two-Stage Filters. Two filters are used. Effluent from the first filter goes to the second filter, either directly or with a clarifier in between the two filters. (See Fig. 6.7, page 6-40.)

Although the efficiency of the filter unit is reduced during periods of icing, it is important to keep this unit running. Taking the unit out of service will not only reduce the quality of the effluent but may lead to additional maintenance problems, such as ice forming, with the possibility of structural damage. Also, moisture may condense in the oil and damage the bearings.

QUESTIONS

6.3A What are some of the causes of ponding?

6.3B How would you correct a ponding problem?

6.3C How would you control odor problems in a trickling filter?

6.3D Trickling filter flies can be controlled by what methods?

6.3E Why should a trickling filter not be taken out of service during icing conditions?

6.4 MAINTENANCE

6.40 Bearings and Seals

The mercury seal in the base of the distributor keeps the wastewater from leaking out of the center column and possibly into the bearings. (See Fig. 6.6.) The bearings ride in removable races, immersed in oil. A good grade of turbine oil with oxidation and corrosion inhibiting agents is recommended. Your manufacturer's manual will contain oil specifications. Check the oil weekly. To check, drain out about a pint into a clean container and, if the oil is clean and free of moisture, return it to the unit. Droplets of water and oil are easily distinguished. Maintain the correct oil level. If the oil is dirty, drain the oil, refill with a mixture of approximately 1/4 oil and 3/4 solvent (such as kerosene), and operate the distributor for a few minutes. Drain again, and refill with the correct oil.

If water is found in the oil, check the mercury seal. Drain the mercury from the seal and from the overflow pockets (Fig. 6.6), and weigh it. If necessary, add mercury to maintain the amount specified by the manufacturer.

WARNING

MERCURY IS POISONOUS.
SEE SECTION 4.4 ON COMMINUTORS IN CHAPTER 4 FOR PRECAUTIONARY MEASURES.
MERCURY POISONING IS OFTEN FATAL.

6.41 Distributor Arms

Work on distributor orifices only after the arms have stopped moving, unless you are using a pressure hose for cleaning and stand outside the filter wall. The distributor arms should be flushed weekly by opening the end dump gates one at a time. Clean debris out of the orifices at this time, also. Observe operation of the filter each day, cleaning the orifices as often as needed. When there is considerable plugging, you should install a coarse hardware cloth or similar type screen if possible, ahead of the filters. Screens are easier to clean and good distribution is maintained over the filter media. Observe the distributor daily for smooth operation. If it becomes jumpy or seems to vibrate, or slows down with the same amount of wastewater passing through it, the bearings and races are probably damaged and will require replacement. A thorough oil check each week will probably keep this from happening.

The speed of rotation of the distributor should not be excessive. On larger distributors, approximately 1 rpm is normal. The manufacturer's literature will state the maximum allowable speed. Rotation of the distributor is due to the reaction of the water flowing through the orifices. This is similar to the reaction of a fire hose or of some types of lawn sprinklers. To reduce the speed of rotation, provision is usually made on the front of each arm for orifices which are easily installed (Fig. 6.3). The reaction of the water flowing through these orifices cancels some of the thrust of the regular orifices. If the speed of rotation is too slow, check for mechanical problems and, if none, increase flow to distributor.

Since most distributors appear rather large and bulky, most operators are surprised to find that they are delicately balanced. As soon as wastewater begins to flow from the orifices, the distributor arm should start to move. The fan-like pattern as the wastewater leaves the deflecting plates should be uniform. If the plates have developed a slime growth that is affecting uniform distribution, the slime should be brushed off.

6.42 Maintenance of Fixed Nozzles

Fixed nozzles should be observed frequently and cleaned often if plugging is persistent. If frequent plugging is a problem, screens may be used ahead of the filter to remove debris.

QUESTIONS

6.4A What is the purpose of the mercury seal in a rotary distributor?

6.4B Why should you drain some of the oil from the distributor each time it is checked?

6.4C How would you slow down the rotational speed of a distributor?

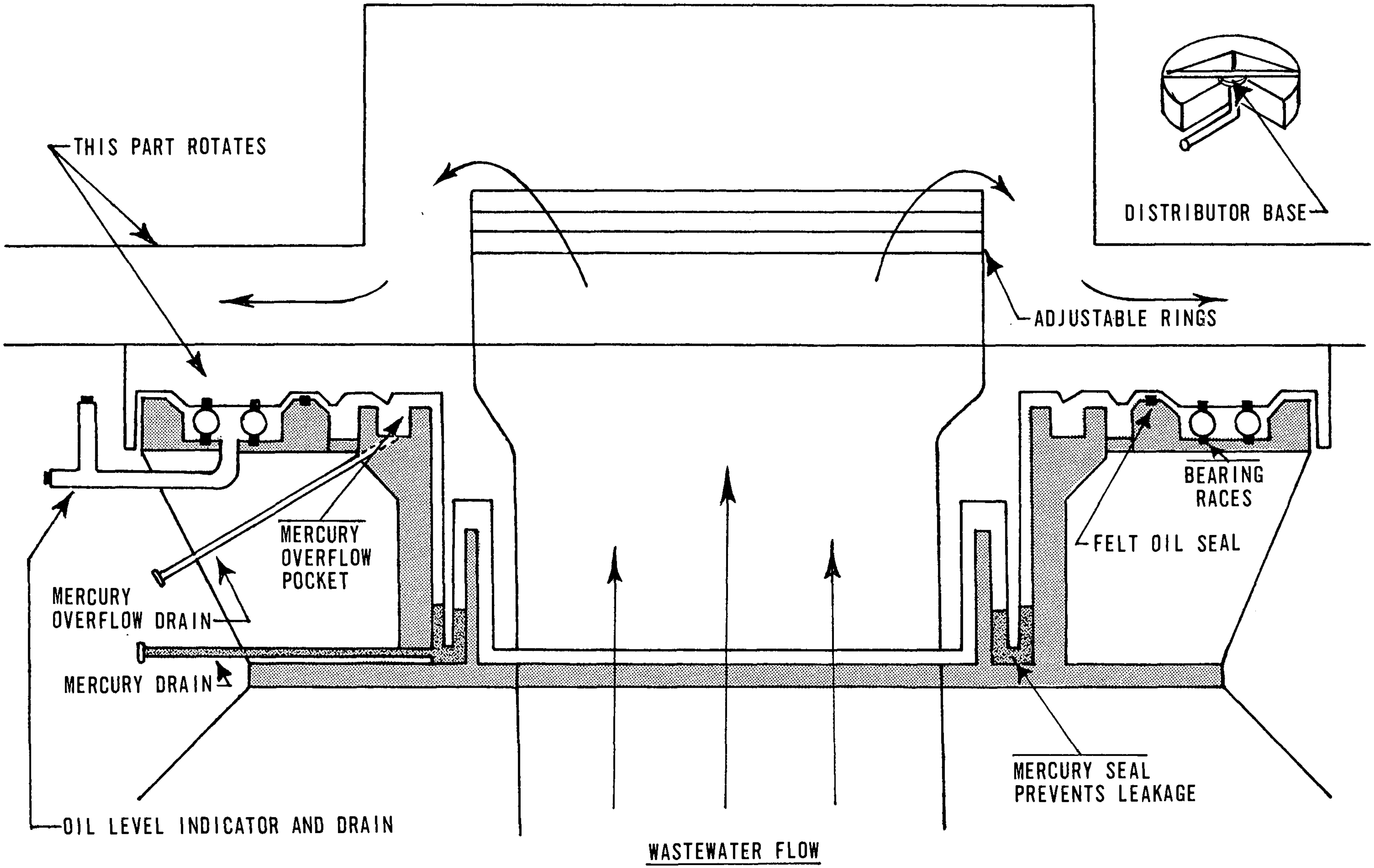


Fig. 6.6 Distributor base

6.5 SAFETY

In order to work around a trickling filter safely, several precautions should be taken. First, shut off the flow to the filter and allow the distributor to stop rotating before attempting to work on it. On all but the very small units, the force of the rotating distributor arms is about the equivalent of a good-sized truck. A man just can't reach out and stop one without endangering himself. Serious injuries can result.

The slime growth on a filter is very slippery. Extreme care should be taken when walking on the filter media. Do not carry oil in glass containers. Rubber boots with deeply ridged soles will help your footing.

QUESTION

6.5A Why should the flow to a trickling filter be shut off before attempting to work on the filter?

END OF LESSON 2 OF 3 LESSONS

on

Trickling Filters

DISCUSSION AND REVIEW QUESTIONS

(Lesson 2 of 3 Lessons)

Chapter 6. Trickling Filters

Name ____________________ Date __________

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 1.

8. Define the term shock load.

9. How would you correct a ponding problem?

10. Why should a ponding problem be corrected as soon as possible?

11. What action would you take to prevent odor problems from developing in a trickling filter?

12. Why should wastewater be kept from leaking into the bearings of the distributor base?

13. Why should the flow to a trickling filter be shut off before attempting to work on the filter?

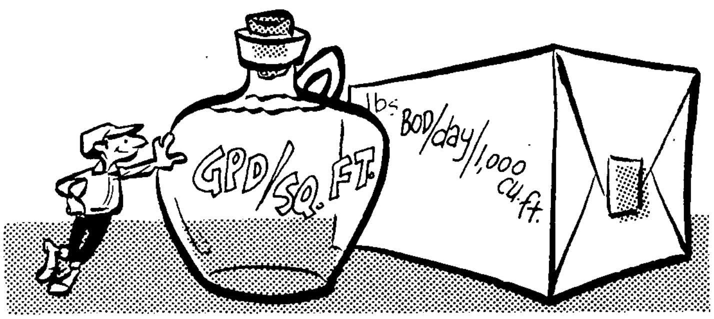
CHAPTER 6. TRICKLING FILTERS

(Lesson 3 of 3 Lessons)

6.6 CLASSIFICATION OF FILTERS

6.60 General

Depending upon the hydraulic and organic loadings applied, filters are classified as standard-rate, high-rate, or roughing filters. Further designations, such as single-stage, two-stage, series or parallel, and others are used to indicate the flow pattern of the plant. The hydraulic loading applied to a filter is the total volume of liquid, including recirculation, expressed as gallons per day per square foot of filter surface area (gpd/sq ft). The organic loading is expressed as the pounds of BOD applied per day per 1000 cubic feet of filter media (lbs BOD/day/1000 cu ft). Where recirculation is used, an additional organic loading will be placed on the filter; however, this added loading is omitted in most calculations because it was included in the influent load.



6.61 Standard-Rate Filters

The standard-rate filter is operated with hydraulic loading range of 25 to 100 gals/day/sq ft, and an organic BOD loading of 5 to 25 lbs/day/1000 cu ft. The filter media is usually 6 to 8 feet in depth, with application to the filter by a rotating distributor, although many are equipped to provide some recirculation during low flow periods.

The filter growth is often heavy and in addition to the bacteria and protozoa[10] many types of worms, snails, and insect larvae can be found.

---

[10] Protozoa (pro-toe-ZOE-ah). A group of microscopic animals, principally of one cell, that sometimes cluster into colonies.

The growth usually sloughs off at intervals, noticeably in spring and fall. The effluent from a standard-rate filter treating municipal wastewater is usually quite stable with BODs as low as 20 to 25 mg/l.

6.62 High-Rate Filters

High-rate filters were the result of trying to reduce costs associated with standard-rate filters or attempting to treat increased wasteloads with the same facility. Studies indicated that essentially the same BOD reductions could be obtained at the higher design loadings.

High-rate filters are normally 3 to 5 feet deep with recommended loadings being 100 to 1000 gal/day/sq ft and 25 to 300 lbs BOD/day/1000 cu ft. These filters are designed to receive wastewater continually, and practically all high-rate installations utilize recirculation.

Due to the heavy flow of wastewater over the media, more uniform sloughing of the filter growths occurs. This sloughed material is somewhat lighter than from a standard-rate unit and therefore more difficult to settle. Effluent with BODs as low as 20 to 50 mg/l is sometimes produced by plants treating municipal wastewater.

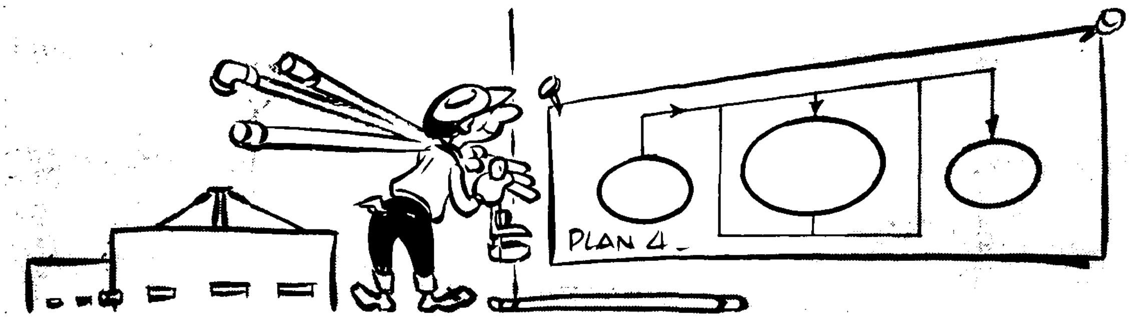
6.63 Roughing Filter

A roughing filter is actually a high-rate filter receiving a very high organic loading. Any filter receiving an organic loading of over 300 lbs of BOD/day/1000 cu ft of media is considered to be in this class. This type of filter is used primarily to reduce the organic load on subsequent oxidation processes such as a second-stage filter or activated sludge process. Many times they are used in plants which receive strong organic industrial wastes. They are also used where an intermediate (50-70% BOD removal) degree of treatment is satisfactory.

Operation of the filter is basically the same as for the high-rate filters with recirculation. Overall BOD reductions are much lower, but reductions per unit volume of filter media are greater.

6.64 Filter Staging

Fig. 6.7 shows various filter and clarifier layouts. The decision as to the number of filters (or stages) required is one of design rather than operation. In general, however, at smaller plants



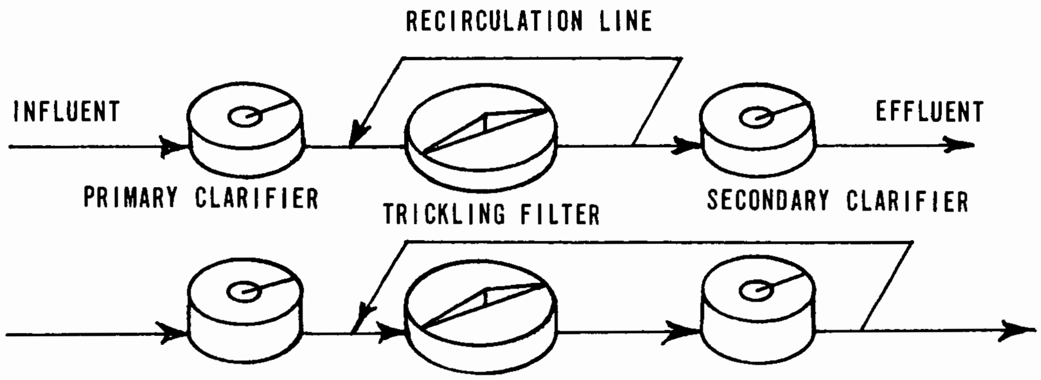
where the flow is fairly low, the strength of the raw wastewater is average, and effluent quality requirements are not too strict, a single-stage plant (one filter) is often sufficient and most economical. In slightly overloaded plants the addition of some recirculation capability can sometimes improve the effluent quality enough to meet receiving water standards without the necessity of adding more stages.

In two-stage filter plants, two filters are operated in a series. Sometimes a secondary clarifier is installed between the two filters. Recirculation is almost universally practiced at two-stage plants with many different arrangements being possible. Choice of recirculation scheme used is based on consideration of which arrangement produces the best effluent under the particular conditions of wastewater strength and other characteristics. (See Fig. 6.7.)

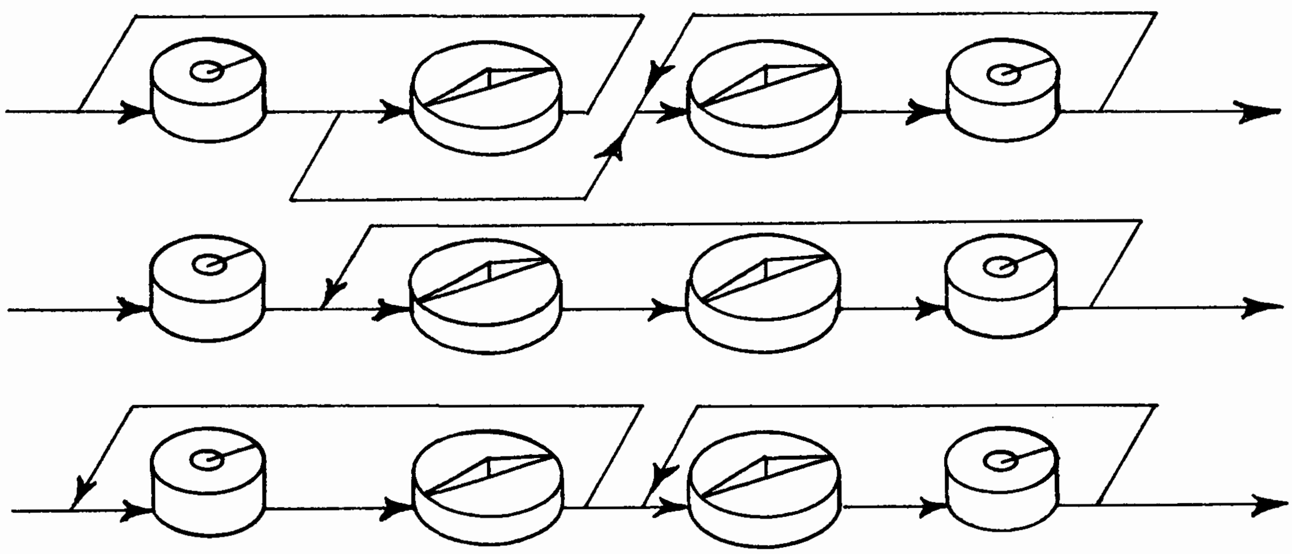
QUESTIONS

6.6A What are the three general classifications of trickling filters?

6.6B What are the principal differences between standard-rate and high-rate filters?



Typical Single-Stage Recirculation Patterns



Typical Two-Stage Recirculation Patterns

Fig. 6.7 Trickling filter recirculation patterns

6.7 LOADING PARAMETERS

6.70 Typical Loading Rates

STANDARD-RATE FILTER:

Media	- 6 to 8 ft depth, growth sloughs periodically
Hydraulic Loading	- 25 to 100 gal/day/sq ft
Organic (BOD) Loading	- 5 to 25 lbs BOD/1000 cu ft

HIGH-RATE FILTER:

Media	- 3 to 5 ft depth, growth sloughs continually
Hydraulic Loading	- 100 to 1000 gal/day/sq ft
Organic (BOD) Loading	- 25 to 300 lbs BOD/1000 cu ft

6.71 Computing Hydraulic Loading

In computing hydraulic loadings, several bits of information must be gathered. To figure the hydraulic loading, we must know:

1. The gallons per day applied to the filter, and
2. The surface area of the filter.

NOTE: Hydraulic loadings are expressed as:

gal/sq ft/day,[11] or

gal/day/sq ft = gpd/sq ft.[11]

Both expressions mean the same. The hydraulic rate indicates the number of gallons of wastewater per day applied to each square foot of surface area or the gallons of water applied to each square foot each day.

---

[11] Loadings as well as test results should always be presented using the same units. Theoretically a rate should have the time unit last (gal/sq ft/day); however, because flows are calculated as gal/day, it is easier to understand if loadings are reported as gal/day/sq ft. The Water Pollution Control Federation's MOP No. 6, *Units of Expression for Wastes and Waste Treatment*, uses both terms.

Suppose we have a high-rate filter that is fed by a pump rated at 2100 gpm, and the filter diameter is 100 feet.

$$\text{Hydraulic Loading, gpd/sq ft} = \frac{\text{Flow Rate, gpd}}{\text{Surface Area, sq ft}}$$

For our problem, we must obtain the flow rate in gpd and surface area[12] in square feet or ft^2.

(a) Flow Rate, gpd

$$= 2100\ \frac{\text{gal}}{\text{min}} \times \frac{60\ \text{min}}{\text{hr}} \times \frac{24\ \text{hrs}}{\text{day}}$$

$$= 3{,}024{,}000\ \text{gal/day}$$

(b) Surface Area, sq ft

$$= 0.785 \times (\text{Diameter, ft})^2$$

$$= 0.785 \times 100\ \text{ft} \times 100\ \text{ft}$$

$$= 7850\ \text{sq ft}$$

(c) Hydraulic Loading, gpd/sq ft

$$= \frac{\text{Flow Rate, gpd}}{\text{Surface Area, sq ft}}$$

$$= \frac{3{,}024{,}000\ \text{gpd}}{7850\ \text{sq ft}}$$

$$= 385\ \text{gpd/sq ft}$$

```
           385
7850 / 3,024,000.
       2 355 0
         669 00
         628 00
          41 000
          39 250
           1 750
```

---

[12] Area of a Circle, sq ft $= \underline{0.785} \times \underline{\text{Diameter, ft}} \times \underline{\text{Diameter, ft}}$, or

$$= 0.785\ D^2$$

It is important to note in computing hydraulic loadings that when filter effluent is recirculated to the filter influent, recirculated flow must be added to the primary clarifier effluent flow in order to calculate the total hydraulic loading. When filter effluent is recirculated to the primary clarifier influent, recirculated flow must be added to the clarifier influent flow.

6.72 Computing Organic (BOD) Loading

Using the same filter as in the above example of hydraulic loading, assume that the laboratory test results show that the wastewater being applied to the filter has a BOD of 100 mg/l. We need to know the pounds of BOD applied per day and the volume of the media in cu ft.

> NOTE: Organic (BOD) loadings are expressed as:
>
> lbs BOD/1000 cu ft/day, or
>
> lbs BOD/day/1000 cu ft.
>
> Both expressions mean the same. The organic loading indicates the pounds of BOD applied per day to the volume of filter media for treatment.

$$\text{Organic (BOD) Loading, lbs BOD/day/1000 cu ft} = \frac{\text{BOD Applied, lbs/day}}{\text{Volume of Media in 1000 cu ft}}$$

To solve this problem we must first calculate the BOD applied in lbs/day and volume of media in cu ft.

$$\begin{aligned}\text{Volume of Media, cu ft} &= (\text{Surface Area, sq ft})\ (\text{Depth, ft})\\ &= (7850\text{ sq ft})\ (3\text{ ft})\\ &= 23{,}550\text{ cu ft}\end{aligned}$$

$$\begin{aligned}\text{Volume of Media, in 1000 cu ft} &= 23.5\ (\text{1000 cu ft units})\\ &= 23.5\text{ thousand cubic feet}\end{aligned}$$

BOD Applied, lbs/day $= (\text{BOD, mg/l})\ (\text{Flow, MGD})\ (8.34\ \text{lb/gal})$[13]

$$= \frac{100\ \text{mg}}{\text{M mg}} \times 3.024\ \frac{\text{M gal}}{\text{day}} \times \frac{8.34\ \text{lb}}{\text{gal}}$$

$$= 2522\ \text{lbs BOD/day}$$

$$\begin{array}{r} 3.024 \\ \underline{8.34} \\ 12096 \\ 9072 \\ \underline{24192} \\ 25.22016 \end{array}$$

Organic BOD Loading, lbs BOD/day/1000 cu ft $= \dfrac{\text{BOD Applied, lbs BOD/day}}{\text{Volume of Media (in 1000 cu ft)}}$

$$= \frac{2522\ \text{lbs BOD/day}}{23.5\ (1000\ \text{cu ft})}$$

$$\begin{array}{r} 107. \\ 23.5\ \overline{)\,2522.0} \\ \underline{235} \\ 172\ 0 \\ 164\ 5 \end{array}$$

$$= 107\ \text{lbs BOD/day/1000 cu ft}$$

In computing BOD loadings, it is standard practice to ignore the BOD of the recirculated effluent, where recirculation is used. To attempt to perform this calculation (using the recirculated load) is complicated and makes it difficult to compare your loadings and resulting effluent quality with other plants.

---

[13] The units of this formula can be proved by remembering that one liter equals one million milligrams.

$$\frac{\text{mg}}{\text{L}} = \frac{\text{mg}}{1{,}000{,}000\ \text{mg}} = \frac{\text{mg}}{\text{M mg}}$$

Therefore,

$$\frac{\text{mg}}{\text{L}}\ \text{BOD} \times \text{MGD} \times 8.34\ \frac{\text{lb}}{\text{gal}} = \frac{\text{mg BOD}}{\text{M mg}} \times \frac{\text{M gal}}{\text{day}} \times \frac{\text{lb}}{\text{gal}} = \text{lb BOD/day.}$$

<u>QUESTIONS</u>

6.7A What is hydraulic loading of a trickling filter and how is it expressed?

6.7B What information must be available to figure the hydraulic loading on a trickling filter?

6.7C What is the hydraulic loading on a trickling filter 80 feet in diameter that is receiving a flow of 3200 gpm?

6.7D Is the filter in Problem 6.7C within the normal hydraulic loading range for high-rate filters?

6.7E What information is needed to figure the BOD loading on a trickling filter?

6.7F Compute the BOD loading on a standard-rate trickling filter with a diameter of 100 feet, media depth 8 feet, which is receiving 350 gpm of wastewater with a BOD of 100 mg/l.

6.7G Is the filter in Problem 6.7F loaded within normal limits for a standard-rate filter?

6.8 ADDITIONAL READING

a. MOP 11, pages 98-107

b. New York Manual, pages 47-58

c. Texas Manual, pages 202-235

d. Sewage Treatment Practices, pages 47-54

END OF LESSON 3 OF 3 LESSONS

on

Trickling Filters

DISCUSSION AND REVIEW QUESTIONS

(Lesson 3 of 3 Lessons)

Chapter 6. Trickling Filters

Name ______________________________ Date ____________

Write the answers to the questions before continuing. The problem numbering continues from Lesson 2.

A trickling filter is 70 feet in diameter and the depth of the media is 5 feet. The average daily flow is 2450 gpm and the BOD of the influent to the filter is 100 mg/l. Show your work and calculate:

14. Flow in gallons per day.

15. Surface area of filter.

16. Hydraulic loading.

17. BOD applied in pounds per day.

18. Volume of filter media.

19. Organic loading.

SUGGESTED ANSWERS

Chapter 6. Trickling Filters

6.0A (a) and (b) Settleable solids and scum or floatable solids. (c) BOD or organic or oxygen demanding material.

6.0B The purpose of secondary treatment is to remove soluble and nonsettleable or nonfloating oxygen demanding substances.

6.0C The trickling filter process works by distributing settled wastewater over the filter media. Microorganisms grow on the filter media and convert colloidal and soluble oxygen demanding substances to forms that will separate from the wastewater being treated.

6.0D The distributor arms or pipes on a trickling filter rotate because of the reaction from the force of the water leaving the arms (as with a lawn sprinkler or fire hose), or by mechanical means (a motor and gears).

6.0E Recirculation increases the efficiency of a trickling filter by increasing the time of contact of the wastewater with the biological slime growth on the filter media, and by washing off excess growths (sloughing). Sloughing keeps the biological film in an aerobic condition and seeds the lower regions of the filter with active organisms. Sometimes recirculation is used to prevent intermittent drying of slimes on the filter media.

6.1A Items that should be checked before placing a filter in service:

- x Check type and amount of oil used in all oil reservoirs.
- x Be present when mercury seal in distributor base is filled.
- x Record amount of mercury used.
- x Check distributor arms for rotation and level.
- x Check distributor orifices.
- x Remove debris from underdrain system.
- x Touch up any damage to painted surfaces.
- x Examine valves for seating and smooth operation.
- x Remove any trash on or in the media.

6.1B During start-up heavy chlorination is necessary to reduce the health hazard and the pollutional load in the receiving waters because the slime growths have not developed on the filter media.

6.1C Items requiring daily checking:

- x Ponding
- x Filter Flies
- x Odors
- x Plugged Orifices
- x Roughness or Vibration of Distributor Arms
- x Leakage Past the Mercury Seal
- x Splash beyond the Filter Media
- x Cleanup of Slimes not on Media

6.1D If a clarifier is operated below design hydraulic loading, the solids in the clarifier will become septic and cause a poor effluent. When the hydraulic loading is too high, some solids may be washed out of the clarifier.

6.2A To determine if the distribution of wastewater over the trickling filter is even, place pans of the same size in the media at several points along the radius of the filter. Run the distributor until the pans are almost full. The amount of water in each pan should not vary by more than 5%.

6.2B Laboratory tests used to measure the efficiency of a trickling filter include BOD, suspended solids, and coliform group bacteria.

6.2C (1) Plant Efficiency:

$$\text{BOD Efficiency, \%} = \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

$$= \frac{(200 \text{ mg/l} - 20 \text{ mg/l})}{200 \text{ mg/l}} \times 100\%$$

$$= 90\%$$

(2) Trickling Filter Efficiency:

$$\text{Trickling Filter Efficiency, \%} = \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

$$= \frac{(140 \text{ mg/l} - 20 \text{ mg/l})}{140 \text{ mg/l}} \times 100\%$$

$$= 85.7\%$$

END OF ANSWERS TO LESSON 1 AND START OF ANSWERS TO LESSON 2

6.3A Causes of ponding include excessive organic loadings without corresponding high recirculation rate, media too small or not sufficiently uniform in size, accumulation of debris in filter voids, or an excessive growth of insect larvae or snails.

6.3B To correct a ponding problem:

(a) Locate cause.

(b) Increase hydraulic loading by increasing recirculation.

(c) Adjust distributor so it will rotate more slowly and flush off some of the slime.

(d) If media is non-uniform, it should be replaced.

(e) Jet filter surface with a high pressure water stream or step distributor and allow it to flush problem area.

(f) Rake or turn ponding area.

(g) Shut off filter for a few hours and allow growth to dry so part of it may be flushed out.

(h) Flood filter.

(i) Dose filter with chlorine.

There are many possible ways to correct ponding. The approach for a particular problem should be aimed at the cause and the quickest and easiest way to correct the situation. You are not expected to have listed all the answers, but to know some of them.

6.3C To correct an odor problem in a trickling filter:

(a) Maintain aerobic conditions in collection system and primary units.

(b) Maintain ventilation in filter.

(c) Increase recirculation rate if odor problems develop.

6.3D Trickling filter flies can be controlled by:

(a) Increasing recirculation.

(b) Flooding filter weekly.

(c) Carefully applying insecticides.

(d) Cleaning around the filter, including grass and shrubbery.

6.3E A trickling filter should not be taken out of service during icing conditions because the quality of the effluent will be reduced and additional maintenance problems could develop.

6.4A The purpose of the mercury seal is to prevent wastewater leakage from the center column before the wastewater is distributed over the media.

6.4B Some oil should be drained from the distributor each time it is checked to examine the condition of the oil and to be sure the oil line is not plugged.

6.4C The rotational speed of a distributor can be reduced by opening orifices on the front side of the distributor arms.

6.5A Flow to a trickling filter should be shut off before attempting to work on a filter because the rotating arms can cause serious injury.

END OF ANSWERS TO LESSON 2 AND START OF ANSWERS TO LESSON 3

6.6A The three general classifications of trickling filters are standard-rate, high-rate, and roughing filters.

6.6B The principal differences between standard-rate and high-rate filters include BOD loadings, hydraulic loadings, and depth of the media.

6.7A The hydraulic loading on a trickling filter is the amount of wastewater applied per day over the surface area, expressed as gallons/day/sq ft, or gpd/sq ft.

6.7B Gallons/day applied to the filter and surface area of the filter in sq ft. These two items are all that are needed. However, it is necessary to convert the other data into the proper form (gpm to gal/day, surface area in sq ft).

6.7C <u>Given</u>: Diameter = 80 ft
Flow = 3200 gpm

<u>Required</u>: Hydraulic Loading

$$\text{Hydraulic Loading, gpd/sq ft} = \frac{\text{Flow Rate, gpd}}{\text{Surface Area, sq ft}}$$

Find <u>flow rate</u>, gpd, and <u>surface area</u> in sq ft.

$$\text{Flow Rate, gpd} = 3200 \frac{\text{gal}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hrs}}{\text{day}}$$

$$= 4{,}608{,}000 \text{ gal/day}$$

$$\text{Surface Area, sq ft} = 0.785 \times (\text{Diameter, ft})^2$$

$$= 0.785 \times 80 \text{ ft} \times 80 \text{ ft}$$

$$= 5025 \text{ sq ft (rounded off)}$$

$$\text{Hydraulic Loading, gpd/sq ft} = \frac{\text{Flow Rate, gpd}}{\text{Surface Area, sq ft}}$$

$$= \frac{4{,}608{,}000 \text{ gpd}}{5025 \text{ sq ft}}$$

$$= 917 \text{ gpd/sq ft}$$

6.7D Yes. The hydraulic loading range for high-rate filters is 200 to 1000 gpd/sq ft.

6.7E To calculate the BOD loading on a trickling filter, the pounds of BOD applied per day and the volume of filter media in thousands of cu ft are needed. Since BOD is reported in mg/l, the standard formula for converting mg/l to pounds per day is needed (mg/l x MGD x 8.34), and usually gpm will have to be converted to MGD (700 gpm = 1 MGD). There are many conversion factors that can be used to obtain the correct answers, and you should use the ones you are familiar with and understand.

6.7F Given: Diameter = 100 ft
Depth = 8 ft
Flow = 350 gpm
BOD = 100 mg/1

Required: Organic (BOD) Loading

$$\text{Organic (BOD) Loading, lbs BOD/day/1000 cu ft} = \frac{\text{BOD Applied, lbs BOD/day}}{\text{Volume of Media, 1000 cu ft}}$$

Find surface area, media volume, and BOD applied.

$$\begin{aligned}
\text{Surface Area, sq ft} &= 0.785 \times (\text{Diameter, ft})^2 \\
&= 0.785 \times 100 \text{ ft} \times 100 \text{ ft} \\
&= 7{,}850 \text{ sq ft}
\end{aligned}$$

$$\begin{aligned}
\text{Volume of Media, cu ft} &= (\text{Surface Area, sq ft})\ (\text{Depth, ft}) \\
&= (7{,}850 \text{ sq ft})\ (8 \text{ ft}) \\
&= 62{,}800 \text{ cu ft} \\
&= 62.8\ (1000 \text{ cu ft})
\end{aligned}$$

$$\begin{aligned}
\text{Flow Rate, MGD} &= \frac{(350 \text{ gpm})}{700 \text{ gpm/MGD}} \\
&= 0.5 \text{ MGD}
\end{aligned}$$

$$\begin{aligned}
\text{BOD Applied, lbs/day} &= (\text{BOD, mg/1})\ (\text{Flow, MGD})\ (8.34 \text{ lg/gal}) \\
&= 100 \frac{\text{mg}}{\text{M mg}} \times 0.5 \frac{\text{M gal}}{\text{day}} \times 8.34 \frac{\text{lb}}{\text{gal}} \\
&= 417 \text{ lbs BOD/day}
\end{aligned}$$

$$\begin{aligned}
\text{Organic (BOD) Loading, lbs/day/1000 cu ft} &= \frac{\text{BOD Applied, lbs/day}}{\text{Volume of Media, 1000 cu ft}} \\
&= \frac{417 \text{ lbs/day}}{62.8\ (1000 \text{ cu ft})} \\
&= 6.6 \text{ lbs BOD/day/1000 cu ft}
\end{aligned}$$

6.7G Yes. The BOD loading range for standard-rate filters is 5 to 25 pounds of BOD per day per 1000 cu ft.

END OF ANSWERS TO LESSON 3.

<u>OBJECTIVE TEST</u>

Chapter 6. Trickling Filters

Name ______________________________ Date __________

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one answer to each question.

1. Loadings on a trickling filter may be expressed as:

    1. lb H_2O/day
    2. lb BOD/day/1000 cu ft
    3. lb H_2O/sq ft/day
    4. gal/day/sq ft
    5. gal/day/1000 cu ft

2. Masking agents:

    1. Cover the filter
    2. Mask the plant
    3. Produce desirable odors
    4. Are sprayed into the air
    5. Tend to make undesirable odors unnoticeable

3. A shock load is:

    1. A heavy blow
    2. A big load in a truck
    3. An unexpected strong waste
    4. An unexpected bump
    5. None of these

4. A flow of 1400 gpm is approximately the same as:

    1. 1 MGD
    2. 2 MGD
    3. 0.5 MGD
    4. 0.33 MGD
    5. 0.75 MGD

5. Physical methods of waste treatment include:

    1. Trickling filters
    2. Disinfection
    3. Sedimentation
    4. Screens
    5. Activated sludge

6. Before starting up a new trickling filter plant the operator should check:

   1. Oil reservoirs for proper amount and type of oil
   2. Rotation of distributor arm
   3. Underdrain system for debris
   4. Zoogleal film on filter media
   5. To be sure there are no voids in the filter media

7. In operating a trickling filter the operator should:

   1. Adjust the process to obtain the best possible results for the least cost
   2. Use the lowest recirculation rates that will yield good results to conserve power
   3. Rotate the distributor as fast as possible to better spray settled wastewater over the media
   4. Maintain aerobic conditions in the filter
   5. Bubble oxygen up through the filter

8. Which test best measures the efficiency of a trickling filter?

   1. Total solids
   2. pH
   3. BOD
   4. Temperature
   5. Sludge age

9. To correct an odor problem in a trickling filter the operator should:

   1. Take corrective action immediately
   2. Shut off flow to the filter
   3. Try to maintain aerobic conditions
   4. Check ventilation in the filter
   5. Increase recirculation rate

10. Maintenance of a distributor moved by hydraulic action includes:

    1. Cleaning the filter media
    2. Cleaning orifices in the distributor arms
    3. Changing the mercury if the distributor arm does not rotate smoothly
    4. Adjusting turnbuckles occasionally on guy rods to keep rotating arms at proper level
    5. Greasing gears that rotate distributor

11. The differences between high-rate filters and standard-rate filters include:

    1. Higher flows per day per square foot of surface area
    2. Higher pounds of BOD per day per cubic foot of media
    3. Higher BOD reductions
    4. Greater depth of filter
    5. Higher rate of odor production

12. The hydraulic loading on a trickling filter 90 feet in diameter with a flow of 0.6 MGD is approximately:

    1. 100 gpd/sq ft
    2. 95 gpd/sq ft
    3. 90 gpd/sq ft
    4. 85 gpd/sq ft
    5. None of these

13. The organic load applied to a trickling filter in pounds of BOD per day for a filter with a diameter of 75 feet, a flow of 0.4 MGD, and a filter influent BOD of 100 mg/l would be approximately:

    1. 350 lbs/day
    2. 335 lbs/day
    3. 325 lbs/day
    4. 300 lbs/day
    5. None of these

14. Successful trickling filter operation depends on:

    1. Maintenance of a chlorine residual in the effluent
    2. Washing slimes off the filter media
    3. Preventing sludge bulking
    4. Maintenance of a good growth of organisms on the filter media
    5. Filtering the solids out of the wastewater

15. The basic parts of a trickling filter include:

    1. Distribution box
    2. Distribution system
    3. Pumps
    4. Underdrain system
    5. Media

16. Problems associated with trickling filters include:

    1. Bulking
    2. Filter flies
    3. Clogging
    4. Turbid effluent
    5. Snails

17. Trickling filtration is a primary treatment process.

    1. True
    2. False

    If wastewater recirculation rates are too low, then (18)________

18. 1. Aerobic
    2. Anaerobic

    conditions may develop in the secondary clarifier; however, if recirculation rates are too high (19) ________________

19. 1. Solids will wash out of the secondary clarifier
    2. The effluent will be sparkling clear

Please write on your IBM answer sheet the total time required to work all three lessons and this objective test.

APPENDIX

(Monthly Data Sheet)

CLEANWATER, U.S.A.

WATER POLLUTION CONTROL PLANT

MONTHLY RECORD __________ 19 ____ OPERATOR: ____________________

				RAW WASTEWATER					PRIM. EFF.			FINAL EFFLUENT					DIGESTION					REMARKS
DATE	DAY	WEATHER	FLOW MGD	TEMP.	pH	SETT. SOLIDS	BOD	SUSP. SOLIDS	BOD	SUSP. SOLIDS	D. O.	pH	BOD	SUSP. SOLIDS	D. O.	CL_2 RES.	RAW SLUDGE GALS/DAY	SCUM GALS/DAY	% CO_2	GAS PROD. FT^3/DAY	MIXING HRS.	
1	M	FAIR	1.200	70	7.3	8	190	208	132	95	2.3	7.6	29	21	7.0	2.1	5940	100	32	10800	4	
2	T	"	1.051	69	7.2	10	205	218	143	101	1.9	7.4	31	24	6.8	2.4	5135	110	32	11450	–	
3	W	"	1.120	69	7.3	11	220	222	153	108	2.0	7.0	23	26	5.9	3.0	5380	90	33	11220	8	
4	T	"	0.987	70	7.1	9	184	201	127	92	2.1	7.2	28	32	6.3	1.8	4765	120	33	11570	8	SLUDGE TO #1 BED – 16,000 GAL.
5	F	CLDY	1.008	68	7.0	7	232	248	162	120	2.0	7.3	31	25	8.1	1.9	5010	115	34	10990	8	
6	S	"	1.102	68	7.2	9	211	210	147	105	2.2	7.3	30	30	7.8	2.1	5240	120	32	11200	4	
7	S	FAIR	0.974	69	7.3	8	199	215	139	98	2.1	7.2	26	29	7.4	2.0	4895	110	32	12100	4	
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30																						
31																						
MAX.																						
MIN.																						
AVG.			1.016	69	7.1	9	195	210	130	100	2.0	7.3	30	27	6.4	2.0	4980	100	33	11,000	4	

SUMMARY DATA

% REMOVAL	BOD	SS
INF–PRI	30.0	52.4
INF–EFF	84.6	87.2

SLUDGE DATA

% SOLIDS — AVG.	4.4
LBS. DRY SOLIDS / DAY	1,827
% VOL. SOLIDS — AVG.	76
LBS. VOL. SOLIDS / DAY	1,388
LBS. VOL. SOLIDS / 1000 FT^3/DAY	27.7
GALS. SLUDGE TO BEDS	48,000
CU. YDS. CAKE REMOVED	22
FT^3 GAS / LB. VOL. SOLIDS	8.0
FT^3 GAS / MG FLOW	10,800

COST DATA

MAN DAYS 44 PAYROLL	$ 1,250—
POWER PURCHASED	450—
OTHER UTILITIES (GAS, H_2O)	60—
GASOLINE, OIL, GREASE	30—
CHEMICALS AND SUPPLIES	95—
MAINTENANCE	140—
VEHICLE COSTS	70—
OTHER	20—
TOTAL	$ 2,105—
OPERATING COST/MG TREATED	$ 66.83
OPERATING COST/CAPITA / MO.	$ 0.21

FLOW METER:
LAST 445237
1st 413749
TOTAL: 31,488 MG

ELECTRIC METER:
LAST 5196
1st 4821
MULT. 80 X 375 = 30,000 KWH

RAW SLUDGE:
LAST 857,314
1st 699,814
STROKES — SCUM 3,100
TOTAL: 154,000 X 1.0 = 154,000 GALS

GAS METER:
LAST 724296
1st 383296
TOTAL: 341,000 FT^3

CHAPTER 7

ACTIVATED SLUDGE

by

John Brady

TABLE OF CONTENTS

Chapter 7. Activated Sludge

GLOSSARY

Chapter 7. Activated Sludge

Absorption (ab-SORP-shun): Taking in or reception of one substance into the body of another by physical or chemical action, and distributed throughout the absorber.

Activated Sludge (ACK-ta-VATE-ed): Sludge particles produced in raw or settled wastewater (primary effluent) by the growth of organisms (including zoogleal bacteria) in aeration tanks in the presence of dissolved oxygen. The term "activated" comes from the fact that the particles are teaming with bacteria, fungi, and protozoa.

Activated Sludge Process: A biological wastewater treatment process in which a mixture of wastewater and activated sludge is aerated and agitated. The activated sludge is subsequently separated from the treated wastewater (mixed liquor) by sedimentation, and wasted or returned to the process as needed.

Adsorption (add-SORP-shun): To gather (a gas, liquid, or dissolved substance) on the surface or interface zone of another substance.

Aeration Tank (air-A-shun): The same a aerator. The tank where raw or settled wastewater is mixed with return sludge and aerated.

Aeration Liquor: Mixed liquor. The contents of the aeration tank, which is composed of living organisms plus material carried into the tank by the untreated wastewater or primary effluent.

Aerobes: Bacteria that must have molecular (dissolved) oxygen (DO) to survive.

Agglomeration (a-GLOM-er-A-shun): The growing or coming together of dispersed suspended matter into larger flocs or particles which settle rapidly.

Aliquot (AL-li-kwot): Portion of a sample.

Bacterial Culture (back-TEAR-e-al): In the case of activated sludge, the bacterial culture refers to the group of bacteria classed as aerobes and facultative organisms which covers a wide range of organisms. Most treatment processes in the United States grow facultative organisms which utilize the carbonaceous (carbon compounds) BOD. Facultative organisms can live when oxygen resources are low. When "nitrification" is required the nitrifying organisms are obligate aerobes (require oxygen) and may require from 0.5 to 4.0 mg/l of dissolved oxygen throughout the whole system to function properly.

Batch Process: A batch process is a treatment process in which a tank or reactor is filled, the waste is treated, and the tank contents are released. The tank may then be filled and the process repeated.

Bulking (BULK-ing): Bulking occurs in activated sludge plants when the sludge becomes too light and will not settle properly.

Cathodic Protection (ca-THOD-ick): An electrical system for prevention of rust, corrosion, and pitting of steel and iron surfaces in contact with water or wastewater.

Composite (Proportional) Samples (com-POZ-it): Samples collected at regular intervals in proportion to the existing flow and then combined to form a sample representative of the entire period of flow over a given period of time.

Coning (CONE-ing): A condition that may be established in a sludge hopper during sludge withdrawal when part of the sludge moves toward the outlet while the remainder tends to stay in place. Development of a cone or channel of moving liquid surrounded by relatively stationary sludge.

Diffused-Air Aeration: A diffused air activated sludge plant takes air, compresses it, and then discharges the air below the water surface of the aerator through some type of air diffusion device.

Diffuser: A diffuser is a device (porous plate, tube, bag) used to break the air stream from the blower system into fine bubbles in the mixed liquor.

Endogenous (en-DODGE-en-us): A diminished level of respiration in which materials previously stored by the cell are oxidized.

Facultative (FACK-ul-tay-tive): Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food materials. In other words, facultative bacteria can live under aerobic or anaerobic conditions.

Filamentous Bacteria (FILL-a-men-tuss): Organisms that grow in a thread or filamentous form.

Flights: Scraper boards, made from redwood or other rot-resistant woods, used to collect and move settled sludge or floating scum.

Floc: Groups or "clumps" of bacteria that have come together and formed a cluster. Found in aeration tanks and secondary clarifiers.

Mechanical Aeration: The surface of the aeration tank is agitated to cause spray and waves by a paddle wheel, mixers, rotating brushes, or some other method of splashing water into the air or air into the water where the oxygen can be absorbed.

Microorganisms: Very small organisms that can be seen only through a microscope. Some microorganisms use the wastes in wastewater for food and thus remove or alter much of the undesirable matter.

Mixed Liquor: The mixture of primary effluent or raw wastewater and return sludge undergoing activated sludge treatment in an aeration tank.

Nitrification: The biochemical conversion of unoxidized nitrogenous matter (ammonia and organic nitrogen) to oxidized nitrogen (usually nitrate). The second-stage BOD is sometimes referred to as the nitrification stage. First-stage BOD is called the carbonaceous stage (carbon compounds oxidized to CO_2)

Protozoa (pro-toe-ZOE-ah): A group of microscopic animals, principally of one cell, that sometimes cluster into colonies.

Rising Sludge: Rising sludge occurs in the secondary clarifiers of activated sludge plants when the sludge settles to the bottom of the clarifier, is compacted, and then starts to rise to the surface.

Supernatant (sue-per-NAY-tent): Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the scum on the surface of an anaerobic digester. This liquid is usually returned to the influent wet well or the primary clarifier.

Volute (vol-LOOT): The spiral-shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

Zoogleal Mass (ZOE-glee-al): Jelly-like masses of bacteria found in both the trickling filter and activated sludge processes. These masses may be formed for or function as the protection against predators for the storage of food supplies.

PRE-TEST

Chapter 7. Activated Sludge

PLEASE WORK THIS PRE-TEST BEFORE READING THE CHAPTER. You are not expected to know many of the answers. Write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to each question.

Match the word with the correct definition by marking the number of the definition on the answer sheet opposite the number of the word.

EXAMPLE

Word	*Definition*
1. Plant Operator	*1. Women's Liberation advocate*
	2. Hard-working water quality protector
	3. Uneducated individual
	4. Town clown
	5. None of these

	1	*2*	*3*	*4*	*5*
1.		■			

Word	Definition
1. Aliquot	1. Airline schedule
2. Coning	2. Bacteria that have come together and formed a cluster
3. Flights	3. Portion of a sample
4. Floc	4. Scraper boards used to remove settled sludge to collection hoppers
	5. Caused by sludge when removed too quickly
5. Meniscus	1. A thin plate with a hole in the middle used to measure flow
6. Orifice	2. Membranes in the nose and throat
	3. Jelly-like substances of bacteria
7. Protozoa	4. The curved top of a column of liquid in a tube
8. Zoogleal Mass	5. A group of microscopic animals found in treatment processes

9. The activated sludge process:

   1. Requires aeration
   2. Requires activated carbon
   3. Is a biological process
   4. Usually follows primary sedimentation
   5. Is an anaerobic process

10. Before starting a new plant, the operator should check:

    1. The blower system
    2. Control gates and mud valves
    3. The aeration equipment
    4. For chips and scrapes on painted gates
    5. Effluent weirs for level

11. The hoist used to lift the air headers in the aeration tank must be properly anchored or it:

    1. Will float away
    2. Could fall into the aerator
    3. Won't allow even distribution of the air
    4. Could hurt someone
    5. Could not lift the aerator.

12. How many pounds of solids are in a 400,000-gallon aeration tank if the suspended solids concentration is 1200 mg/l? Select the closest answer.

    1. 3600
    2. 4000
    3. 4400
    4. 4800
    5. 5200

13. When the return sludge rate is too low, what happens?

    1. The tank will not fill.
    2. There will be insufficient organisms to meet the waste load entering the aerator.
    3. The activated sludge in the aerator will starve.
    4. The activated sludge in the secondary clarifier could become septic.
    5. The sludge blanket in the secondary clarifier could become too high.

14. When operating an activated sludge plant, which is the most important suspended solids test for operational control?

    1. Primary effluent
    2. Aerator mixed liquor
    3. Return sludge
    4. Final clarifier effluent
    5. Plant influent

15. The main operational process controls available to an operator include:

    1. Air rates
    2. Pounds of solids under aeration
    3. Maintenance
    4. Return sludge rate
    5. BOD test

16. What should be the waste sludge pumping rate if a plant should be wasting 2000 pounds per day and the concentration of return sludge is 5000 mg/l? Select the closest answer.

    1. 30 gpm
    2. 33 gpm
    3. 35 gpm
    4. 36 gpm
    5. 40 gpm

17. What items would you check if an activated sludge plant becomes upset?

    1. Influent temperature
    2. Daily flow rates
    3. BOD loadings
    4. Digester operation
    5. Chlorinator

18. How long would you allow an activated sludge process to react and stabilize after a change?

    1. 3 hours
    2. 12 hours
    3. 1 day
    4. 2 days
    5. 1 week

19. Causes of sludge bulking include:

    1. Bulk of sludge too large
    2. Air supply too low
    3. Loading rate too high
    4. Aeration period too short
    5. Sludge going septic in secondary clarifier

20. Package plants usually:

    1. Operate the aeration device continuously
    2. Have an operator at the plant 24 hours a day
    3. Waste sludge out the effluent, but shouldn't when operated properly
    4. Have an extensive lab testing program
    5. None of these

21. The effectiveness of the organisms in the aerator depends on the:

   1. Temperature
   2. pH
   3. Presence of inhibiting substances
   4. Characteristics of food supply
   5. Time of reaction or time available for the reaction

22. What is the food/organism loading ratio in an activated sludge plant with a flow of 1 MGD? The average BOD to the aerator is 140 mg/l, the aeration tank contains 250,000 gallons, and the mixed liquor suspended solids concentration is 2000 mg/l. Select the closest answer.

   1. 25 lbs BOD per day/100 lbs MLSS
   2. 28 lbs BOD per day/100 lbs MLSS
   3. 30 lbs BOD per day/100 lbs MLSS
   4. 32 lbs BOD per day/100 lbs MLSS
   5. 35 lbs BOD per day/100 lbs MLSS

23. Why is the COD test a better operational control test than the BOD test?

   1. It isn't better.
   2. The oxygen demand is not caused by biological organisms
   3. Everyone uses it.
   4. The results are available sooner.
   5. This chapter says so.

24. Why should all of the diffusers in an aeration tank be cleaned at once?

   1. To get the job done in a hurry
   2. So the air will flow evenly out all of the diffusers
   3. To improve step-feed aeration
   4. So the plant won't use too much air
   5. None of these

CHAPTER 7. ACTIVATED SLUDGE

(Lesson 1 of 8 Lessons)

7.0 INTRODUCTION

7.00 General

When wastewater enters an activated sludge plant, the pretreatment processes (Chapter 4) remove the coarse or heavy solids (grit) and other debris, such as roots, rags, and boards. Primary clarifiers (Chapter 5) remove much of the floatable and settleable material. Normally settled wastewater is treated by the activated sludge process, but in some plants the raw wastewater flows from the pre-treatment processes directly to the activated sludge process.

7.01 Definitions

ACTIVATED SLUDGE (Fig. 7.1). Activated sludge consists of sludge particles produced in raw or settled wastewater (primary effluent) by the growth of organisms in aeration tanks in the presence of dissolved oxygen. The term "activated" comes from the fact that the particles are teaming with bacteria, fungi, and protozoa.

ACTIVATED SLUDGE PROCESS (Fig. 7.1). The term activated sludge process refers to a method or process of wastewater treatment. In this treatment process there is maintained a biological culture consisting of a large number of organisms. All of them require food (wastewater or substrate) and oxygen to make the process work. The bacterial population is maintained at some mass (solids concentration)[1] to balance the food available from the wastewater for the microorganisms[2] (food/microorganism ratio) with the oxygen input capability of the plant equipment.

---

[1] Solids Concentration. The solids in the aeration tank carry bacteria that feed on wastewater.

[2] Microorganisms. Very small organisms that can be seen only through a microscope. Some microorganisms use the wastes in wastewater for food and thus remove or alter much of the undesirable matter.

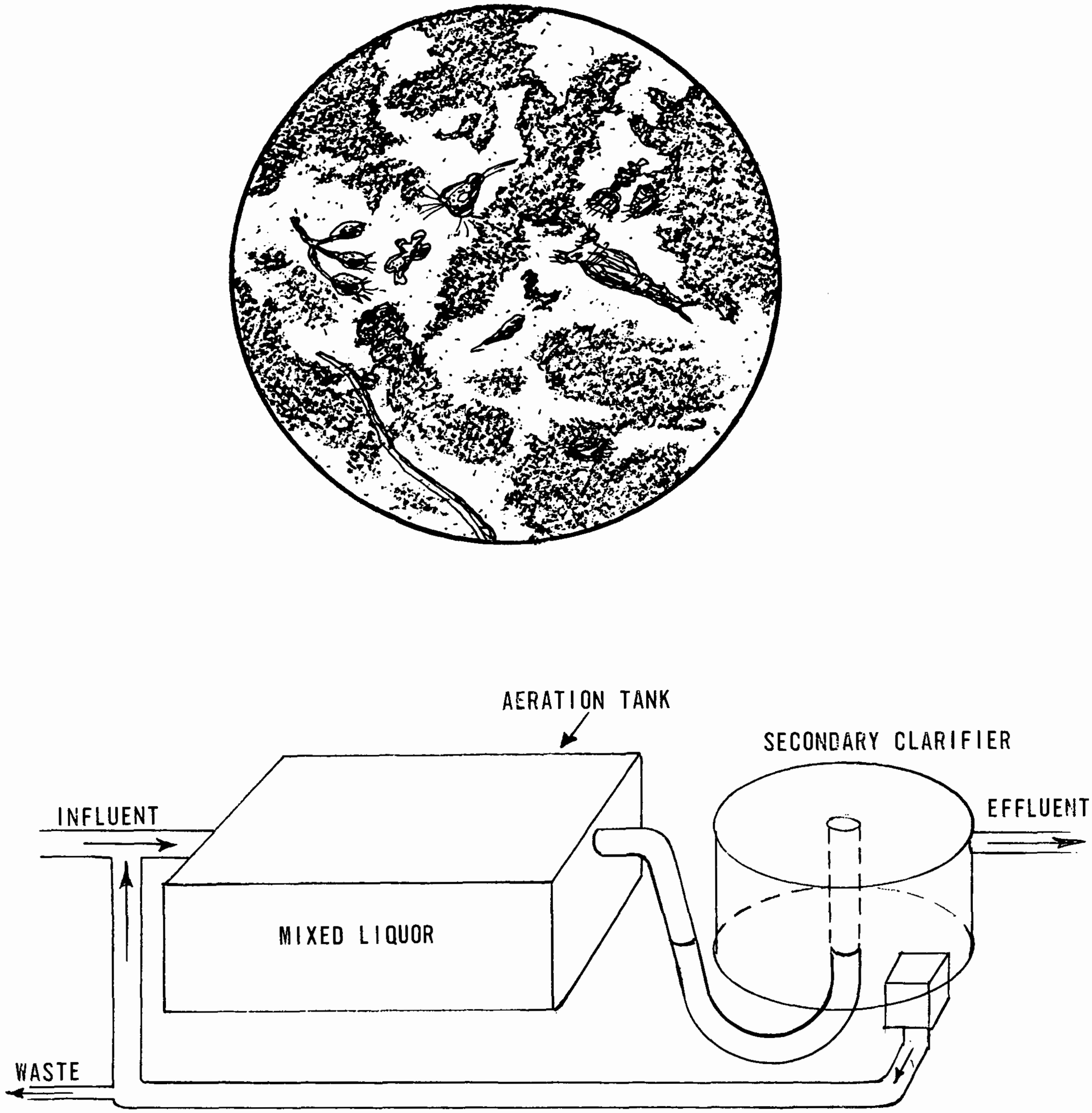
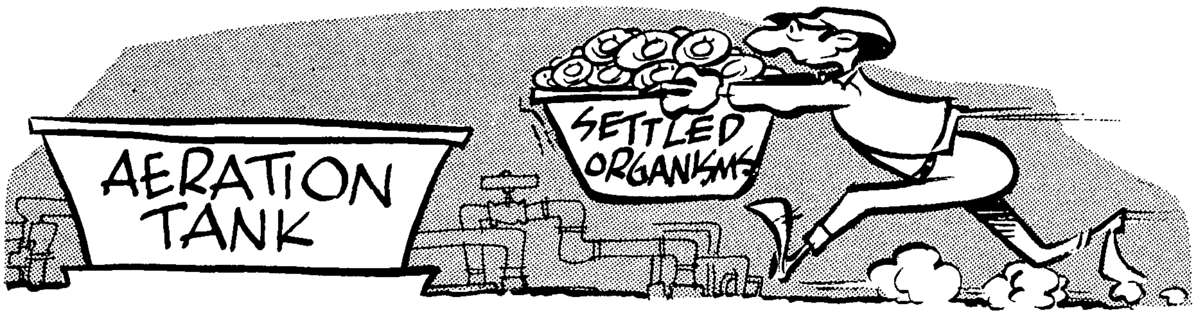


Fig. 7.1 Activated sludge and activated sludge process

7.02 Process Description

Secondary treatment in the form of the activated sludge process (Figs. 7.2 and 7.3) is aimed at oxidation and removal of soluble or finely divided suspended materials that were not removed by previous treatment. This is accomplished in an aeration tank by aerobic organisms within a few hours when the water is being treated while it flows through the tank. Soluble or finely divided suspended solids are intended to be stabilized[3] in the aeration tank by partial oxidation to form carbon dioxide, water, sulfates, and nitrates. Remaining solids are intended to be converted to a form where they can be settled and removed as sludge during clarification.



After the aeration period the wastewater is routed to a secondary settling tank for a liquid-organism (water-solids) separation. Settled organisms are quickly returned back to the aeration tank. The resultant clarifier effluent is usually chlorinated and discharged from the plant.

Conversion of dissolved and suspended material to settleable solids is the main objective of high-rate activated sludge processes, while low-rate processes stress oxidation. The oxidation may be by chemical or biological processes. In the activated sludge process, the biochemical oxidation carried out by living organisms is stressed. The same organisms also are effective in conversion of substances to settleable solids if the plant is operated properly.

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[3] Stabilized Waste. A waste that has been treated or decomposed to the extent that, if discharged or released, its rate and state of decomposition would be such that the waste would not cause a nuisance or odors.

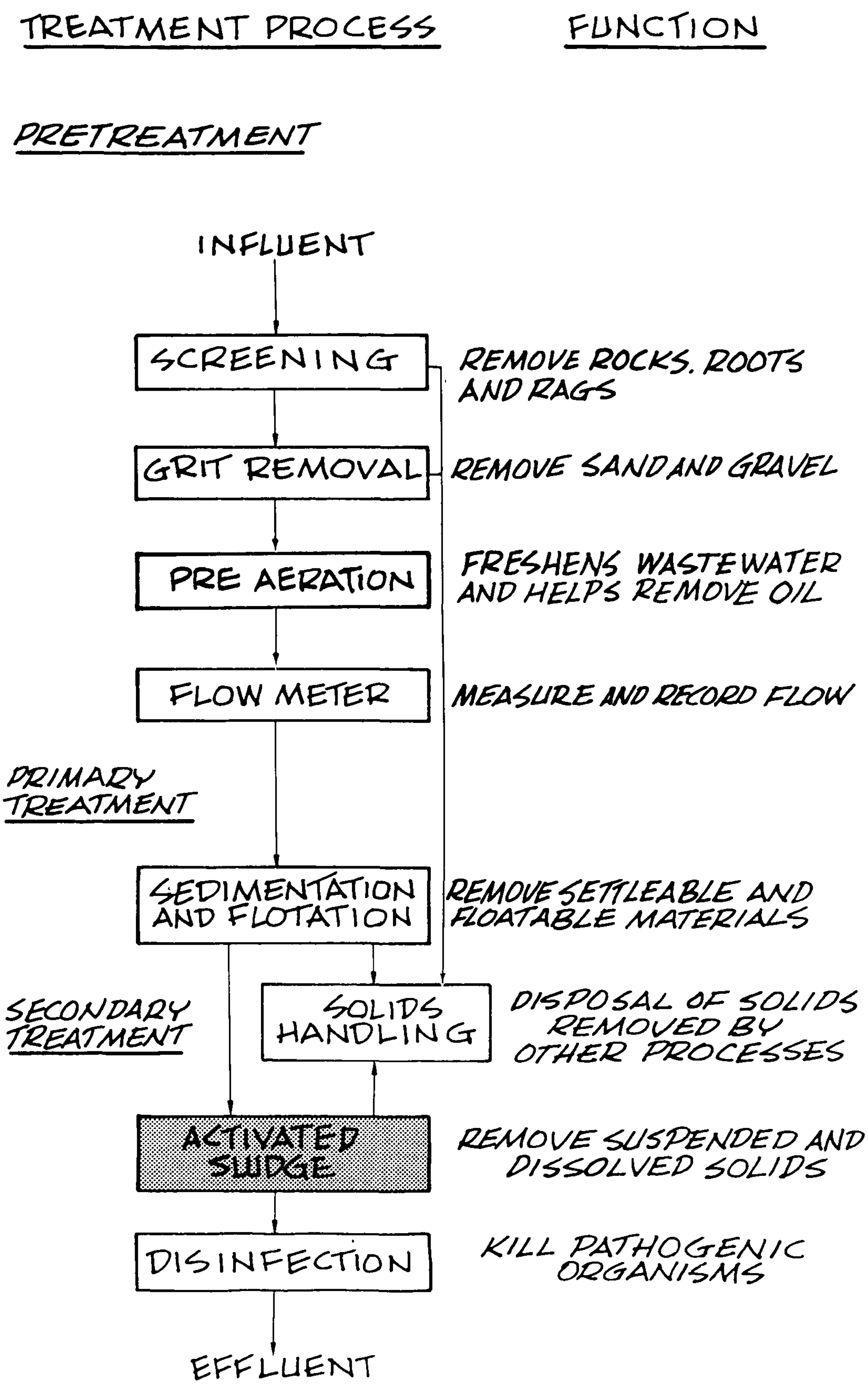

Fig. 7.2 Flow diagram of a typical plant

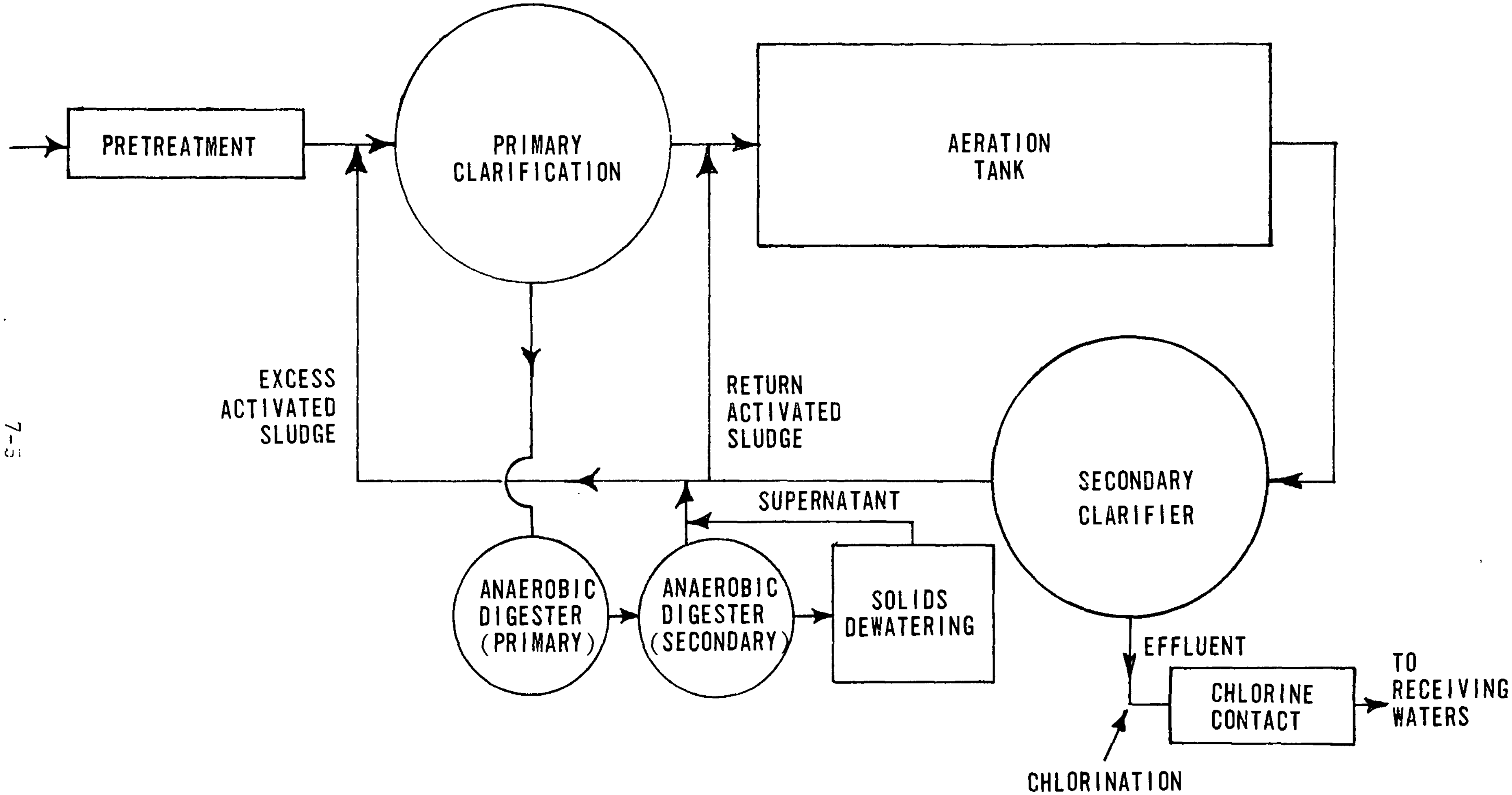

Fig. 7.3 Plan layout of a typical activated sludge plant

QUESTIONS

7.0A What is the purpose of the activated sludge process in treating wastewater?

7.0B What is a stabilized waste?

7.1 REQUIREMENTS FOR CONTROL

Control of the activated sludge process is based on evaluation of and action upon several interrelated factors to favor effective treatment of the influent wastewater. These factors include:

1. Effluent quality requirements.

2. Wastewater flow, concentration, and characteristics of the wastewater received.

3. Amount of activated sludge (containing the working organisms) to be maintained in the process relative to inflow.

4. Amount of oxygen required to stabilize wastewater oxygen demands and to maintain a satisfactory level of dissolved oxygen to meet organism requirements.

5. Equal division of plant flow and waste load between duplicate treatment units (two or more clarifiers or aeration tanks).

6. Transfer of the pollutional material (food) from the wastewater to the floc mass (solids or workers) and separation of the solids from the treated wastewater.

7. Effective control and disposal of inplant residues (solids, scums, and supernatants) to accomplish ultimate disposal in a nonpollutional manner.

8. Provisions for maintaining a suitable environment for the work force of living organisms treating the wastes. Keep them healthy and happy.

Effluent quality requirements may be stated by your regularoty agency in terms of percentage removal of wastes. Current regulations frequently specify allowable quantities of wastes that may be discharged. These quantities are based upon flow and concentrations of significant items such as solids, oxygen demand, coliform bacteria, nitrogen, and oil as specified by your regulatory agencies.

The effluent quality requirements largely determine the mode of activated sludge operation and the degree of control required. For example, if an effluent containing 50 mg/l of suspended solids and BOD (refers to five-day BOD) is satisfactory, a high-rate activated sludge process is likely to be applicable. If the limit is 10 mg/l, the high-rate process would not be suitable. If a high degree of treatment is required, very close process control and additional treatment after the activated sludge process may be needed.

Flow concentrations and characteristics of the influent are subject to limited control by the operator. Municipal ordinances may prohibit discharge to the collection system of materials significantly damaging to treatment structures or safety. Control over wastes dumped into the collection system requires inspection to insure compliance. It may be necessary to require alternate means of disposal, pretreatment, or controlled discharge of significantly damaging items to permit dilution to an acceptable level by the time the waste arrives at the treatment plant.

The material entering the aeration tanks is mixed with the activated sludge to form a mixture of sludge, carrier water, and influent solids. These solids come from roofs or streets in combined sewer systems and also from the discharges from homes, factories, and businesses. Included in the return sludge solids are many different types of helpful living organisms that were grown during previous contact with wastewater. These organisms are the workers in the treatment process. They use the incoming wastes for food and as a source of energy for their life processes and for the reproduction of more organisms. These organisms will use more food contained in the wastewater in treating the wastes. The activated sludge also forms a lacy mass that entraps many materials not used as food.

Some organisms (workers) will require a long time to use the available food in the wastewater at a given waste concentration. Many organisms will compete with each other in the use of available food (waste) to shorten the time factor and increase the portion of waste stabilized. The ratio of food to organisms is a primary control in the activated sludge process. Organisms tend to increase with waste (food) load and time spent in the aeration tank. Under favorable conditions the operator will remove (sludge wasting) the excess organisms to maintain the required number of workers for effective waste treatment. Therefore, removal of organisms from the treatment process (sludge wasting) is a very important control technique.

Oxygen, usually supplied from air, is necessary to sustain the living organisms and for oxidation of wastes to obtain energy for growth. Insufficient oxygen will inactivate aerobic organisms, make facultative[4] organisms work less efficiently, and favor production of foul-smelling intermediate products of decomposition and incomplete reactions.

An increase in organisms in an aeration tank will require greater amounts of oxygen. More food in the influent encourages more organism activity and more oxidation; consequently, more oxygen is required in the aeration tank. An excess of oxygen is required for complete waste stabilization. Therefore, the dissolved oxygen (DO) content in the aeration tank is an essential control test. Some minimum level of oxygen must be maintained to favor the desired type or organism activity to achieve the necessary treatment efficiency.

Flows must be distributed evenly among two or more similar treatment units. If your plant is equipped with a splitter box or a series of boxes, it will be necessary to periodically check and estimate whether the flow is being split as intended.

Activated sludge solids concentrations in the aerator and the secondary clarifier should be determined by the operator for process control purposes. Solids are in a deteriorating condition as long as they remain in the secondary clarifier. Depth of sludge blanket in the secondary clarifier and concentrations of solids in the aerator are very important for successful wastewater treatment. Centrifuge tests will give a quick estimate of solids concentrations and locations in the units. Precise solids tests should be made periodically for comparison with centrifuge solids tests. Before any changes are made in the mode of operation, precise solids measurements should be obtained. Settleability tests show the degree and volume of solids settling that may be obtained in a secondary clarifier; however, visual plant checks show what is actually happening.

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[4] Facultative (FACK-ul-tay-tive). Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food materials.

Primary clarifiers remove easily settleable or floatable material. Activated sludge tends to convert soluble solids to suspended cell mass material and to gather and agglomerate[5] particles too fine to settle rapidly into readily separated material. If the soluble solids transfer fails, then the process fails to provide a satisfactory effluent.

There must be organisms, oxidizing conditions, and suitable time to cause the conversion of soluble solids and to agglomerate the fine particles to form a floc mass.

This floc mass consists of millions of organisms (10^{12} to 10^{18}/100 ml in a good activated sludge), including bacteria, fungi, yeast, protozoa, and worms. When a floc mass is returned to the aerator from the final clarifier, the organisms grow as a result of taking food from the inflowing wastewater. The surface of the floc mass is irregular and promotes the transfer of wastewater pollutants into the solids by means of mechanical entrapment, absorption, adsorption, or adhesion. Many substances not used as food also are transferred to the floc mass, thus improving the quality of the plant effluent.

Material taken into the floc mass is partially oxidized to form cell mass and oxidation products. Ash or inorganic material (silt and sand) taken in by the floc mass increases the density of the mass. Mixing in the aerator promotes collisions and thus produces larger floc masses. The net effect after the aeration period is to form a floc mass which will separate from the wastewater and settle to the bottom of the secondary clarifier. This sludge contains most of the residual contaminants and organisms.

Growth of organisms and accumulated residues produce solids for disposal (waste activated sludge). Certain materials are converted and removed from the wastewater to the atmosphere in the form of stripped gases (carbon dioxide or other volatile gases), and also as water and as solids (sludge). To produce a good effluent the operator must strive to minimize the return of these solids (other than as return sludge) to the process. They must be removed from the wastewater being treated and disposed of in the plant by a manner which prevents any material from returning to the plant flow. For example, maintain as high a concentration of solids in the return sludge as possible to reduce the amount of water needed to return these solids back to the aerator. Don't pump waste activated sludge

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[5] Agglomerate. To cause the growing or coming together of dispersed suspended matter into larger flocs or particles which settle rapidly.

directly to an anaerobic digester because it will return to the aeration tank as supernatant with an added load on the organisms. The organisms have already attempted to treat the solids once and won't be too effective next time. If screenings are removed at the headworks, don't grind them up and return them to the plant flow. Once material is removed from the wastewater, keep it out, except as necessary to maintain the process.

To maintain the working organisms in the activated sludge, you must provide a suitable environment. Intolerable concentrations of acids, bases, and other toxic substances are undesirable and may kill the working organisms. Unduly fluctuating loads may cause overfeeding, starvation, and other factors that are all capable of upsetting the activated sludge process. Insufficient oxygen can cause an unfavorable environment which results in decreased organism activity.

An outstanding example of a toxic substance added by operators is the uninhibited use of chlorine for odor control (prechlorination). Chlorination is for disinfection. Chlorine is a toxicant and should not be allowed to enter the activated sludge process because it is not selective with respect to type of organisms damaged. It may kill the organisms that you should be retaining as workers. Chlorine is effective in disinfecting the plant effluent after treatment by the activated sludge process.

The successful operation of an activated sludge plant requires the operator to be aware of the many factors influencing the process and to check them repeatedly. The actual control of the process as outlined in this section is relatively simple. Control consists of maintaining the proper solids (floc mass) concentration in the aerator for the waste (food) inflow by adjusting the waste sludge pumping rate and regulating the oxygen supply to maintain a satisfactory level of dissolved oxygen in the process.

QUESTIONS

7.1A Why is air added to the aeration tank in the activated sludge process?

7.1B What happens to the air requirement in the aeration tank when the strength (BOD) of the incoming water increases?

7.1C What factors could cause an unsuitable environment for the activated sludge process in an aeration tank?

END OF LESSON 1 OF 8 LESSONS

on

ACTIVATED SLUDGE

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. Activated Sludge

(Lesson 1 of 8 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing.

1. Sketch the activated sludge process.

2. Define activated sludge.

3. Define facultative bacteria.

4. Some activated sludge plants do not have a primary clarifier. True or False?

5. Why must the activated sludge retention time not be too long in the final clarifier?

6. How can the operator control the activated sludge process?

CHAPTER 7. ACTIVATED SLUDGE

(Lesson 2 of 8 Lessons)

7.2 BASIC VARIABLES AND RECORD KEEPING

7.20 General

Wastewater flows and constituents fluctuate daily. The activated sludge plant operator attempts to maintain the process at some balanced state that will be capable of handling the minor variations in flows or wastewater characteristics and produce the desired quality of effluent. To accomplish this goal he must establish his process on known data and knowledge obtained at other plants and relate them to his plant. After his plant becomes operational, he then must relate his control procedures to his own experience. The variations that affect his operation are derived from two sources: (1) the dischargers to the collection system and (2) inplant operational variables.

7.21 Variables in Collection System

7.210 Combined Sewer Systems

During storms the treatment plant will receive an increase in flow which may cause the following problems:

1. Reduced wastewater time in treatment units (hydraulic overload).

2. Increased amounts of grit and silt which lower the volatile (food) content of the solids.

3. Increased organic load during initial washout of accumulated sewer deposits.

4. Rapid changes in wastewater temperature and solids content.

7.211 Waste Dischargers to the System

Various industries and businesses can cause considerable fluctuation in flows and waste characteristics entering a plant. You should become

acquainted with the managers of plants whose discharges could upset your treatment processes. Convince these men in a friendly manner how vital it is to your plant processes and the receiving waters for you to be notified of any potentially harmful discharges. Try to obtain their cooperation and request them to notify you whenever an accidental spill, a process change, or a cleaning operation occurs which could cause undesirable waste discharges. This requires diplomacy to obtain cooperation from dischargers to regulate their own discharges and to reduce the number of midnight dumps.

7.212 Maintenance of the Collection System

Advance notice of collection system maintenance crew activities can be very helpful. If a lift station has been out of service for a period of time, large volumes of septic wastewater could cause a shock load on your treatment processes. Similar problems could be created when a blockage in a line is cleared or a new line is connected to the system. Analysis of inflow quantities and characteristics when these flows reach a treatment plant can indicate whether or not they will cause a serious problem.

7.22 Operational Variables

Continual review of laboratory test results is essential in determining whether a treatment plant is discharging effluent of the required quality in terms of such water quality indicators as COD, suspended solids, and nitrogen. If the desired quality of the plant effluent is not achieved, the operator must determine what factor or factors have changed to upset plant performance and thus reduce efficiency.

Important factors that could have changed include:

1. Higher COD or BOD load applied to the aerator (influent load).

2. More difficult to treat wastes have adversely changed influent characteristics.

3. Unsuitable mixed liquor suspended solids concentration in the aerator.

4. Lower or higher rate of wasting activated sludge.

5. Unsuitable rate of returning sludge to the aerator could adversely influence mixed liquor suspended solids.

6. Higher solids concentrations in digester supernatant[6] returned to the plant flow, or return too rapid.

7. Dropping of oxygen concentration in the aerator below desirable levels.

Examination of plant records should reveal the items which have changed that could have upset the treatment process.

QUESTIONS

7.2A What two major variables affect the way an activated sludge plant is operated?

7.2B What variables in the collection system can affect the operation of an activated sludge plant?

7.2C What problems can be caused in an activated sludge plant when excessive storm water flows through the process?

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[6] Supernatant (sue-per-NAY-tent). Liquid removed from settled sludge. Commonly refers to the liquid between the sludge on the bottom and the scum on the surface of an anaerobic digester. This liquid is usually returned to the influent wet well or the primary clarifier.

7.23 Plant Records

Accurate daily plant and laboratory records on the items listed below can help the operator determine the best operating ranges for operational controls on the basis of plant performance. Records also are capable of indicating when problems develop and identifying the source of the problem. Record the following data on a daily basis. (Also see Monthly Data Sheet in the Appendix.)

1. Suspended Solids and Volatile Content
   a. Primary effluent
   b. Aerator mixed liquor
   c. Return sludge
   d. Final clarifier effluent

2. BOD, COD, or TOC
   a. Plant influent
   b. Primary effluent
   c. Final clarifier effluent

   NOTE: COD is recommended to determine the strength of influent wastewater because the results are available within four hours and can be used to control the activated sludge process. For many years operators attempted to use the BOD test for operational control, but the test has the following disadvantages:

   (1) Procedural errors can cause a large variation in results.

   (2) Five days of waiting are required before results are available.

   (3) Only a portion of the load on the activated sludge process is measured by the test.

3. Dissolved Oxygen
   a. Aerator
   b. Final clarifier (inside the effluent weir)
   c. Final effluent

4. Settleable Solids
   a. Influent
   b. Mixed liquor settleability test
   c. Digester supernatant
   d. Final effluent

5. Temperature

   a. Influent
   b. Aerator
   c. Final effluent

6. pH

   a. Influent
   b. Primary effluent
   c. Aerator[7]
   d. Final effluent

7. Clarity or Turbidity (Secchi Disc)[8]

   a. Final clarifier

8. Chlorine Demand

   a. Final clarifier effluent

9. Coliform Group Bacteria[9]

   a. Plant effluent

10. Meter Readings and Calculations

    a. Daily flow
    b. Pounds of solids under aeration
    c. Pounds of COD or BOD to aerators
    d. Pounds of activated sludge solids to waste
    e. Pounds of solids in effluent
    f. Return sludge rate
    g. Waste sludge rate
    h. Air to aerators (diffused air system); hours operated at various speeds (mechanical aeration)
    i. Sludge age

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[7] Measure aerator pH in the aerator or immediately after sample is collected, because the pH can change very rapidly once the sample is out of the aerator. Do not take sample to the lab.

[8] Secchi Disc (SECK-key). A flat, white disc lowered into the water by a nylon rope until it is just distinguishable. At this point, the depth of the disc from the water surface is the recorded secchi disc reading.

[9] Check with your regulatory agency for test and procedures. Tests approved by agencies include MPN, membrane filter, and fecal coliform.

j. Pounds of solids in sludge to digester
k. Pounds of solids in digester supernatant
l. Power cost

Accurate records will indicate when the proper operational procedures have been determined that produce the best effluent. This effluent will be low in COD (or BOD) and suspended solids, and the effluent clarity will be good. Waste loadings and operational procedures will vary continuously due to seasonal changes which require the operator to constantly review his records for changes and to make appropriate changes to maintain the best possible effluent quality. Process control consists not only of maintaining the equipment, but of making a constant daily review of process conditions to determine when adjustments must be made to compensate for the many variables that can influence effluent quality. Remember that the sight, smell, and touch observations often are your first indications that problems are developing and frequently offer indications of appropriate corrective action.

QUESTIONS

7.2D Why should the strength or waste load of the influent to the activated sludge process be measured by the COD test instead of the BOD test?

7.2E Why should the aerator pH be measured in the aerator?

7.2F Sight and smell observations are often the operator's first indication that process problems are developing. True or False?

7.24 Typical Lab Results for an Activated Sludge Plant

Typical results of lab tests for an activated sludge plant are provided to assist in the evaluation of lab results and plant performance. Remember that every plant is different and is influenced by different conditions.

Test	Location	Common Range	
COD	Influent	300 - 700	mg/l
	Primary Effl.	200 - 400	mg/l
	Final Effl. (Conv. Act. Sl.)	30 - 70	mg/l
BOD	Influent	150 - 400	mg/l
	Primary Effl.	100 - 280	mg/l
	Final Effl. (Conv. Act. Sl.)	10 - 20	mg/l
SUSPENDED SOLIDS	Influent	150 - 400	mg/l
	Primary Effl.	60 - 160	mg/l
	Mixed Liquor	1000 - 4500	mg/l
	Return Sludge	2000 - 10,000	mg/l
	Final Effl. (Conv. Act. Sl.)	10 - 20	mg/l
DISSOLVED OXYGEN	Mixed Liquor	2 - 4	mg/l
	Final Effl. (Outfall)	2 - 6	mg/l
CHLORINE RESIDUAL (30 min.)	Final Effl.	0.5 - 2.0	mg/l*
COLIFORM GROUP BACTERIA, MPN	Final Effl. (Chlorinated)	23 - 700/100	ml
CLARITY (Secchi Disc)	Final Effl.	3 - 8	ft
pH	Influent	6.8 - 8.0	
	Effluent	7.0 - 8.5	

* Regulatory agencies normally specify a chlorine residual remaining after a certain time period.

7.25 Design Variables

Several different types of activated sludge plants have been built using various flow arrangements, tank configurations, or oxygen application equipment. However, all of these variations are essentially modifications of the basic concept of conventional activated sludge.

7.250 Aeration Methods

Two methods are commonly used to supply oxygen from the air to the bacteria--mechanical aeration and diffused aeration. Both methods are mechanical processes with the difference being whether the mechanisms are at or in the aerator or at a remote location.

Mechanical aeration devices agitate the water surface in the aerator to cause spray and waves by paddle wheels (Fig. 7.4), mixers, rotating brushes, or some other method of splashing water into the air or air into the water where the oxygen can be absorbed.

Mechanical aerators in the tank tend to be lower in installation and maintenance costs. Usually they are more versatile in terms of mixing, production of surface area of bubbles, and oxygen transfer per unit of applied power.

Diffused air systems use a device called a diffuser (Fig. 7.5) which is used to break up the air stream from the blower system into fine bubbles in the mixed liquor. The smaller the bubble, the greater the oxygen transfer due to the greater surface area of rising air bubbles surrounded by water. Unfortunately, fine bubbles will tend to regroup into larger bubbles while rising unless broken up by suitable mixing energy and turbulence.

Fig. 7.4 Mechanical Aeration Device

(Courtesy INFILCO INC.)

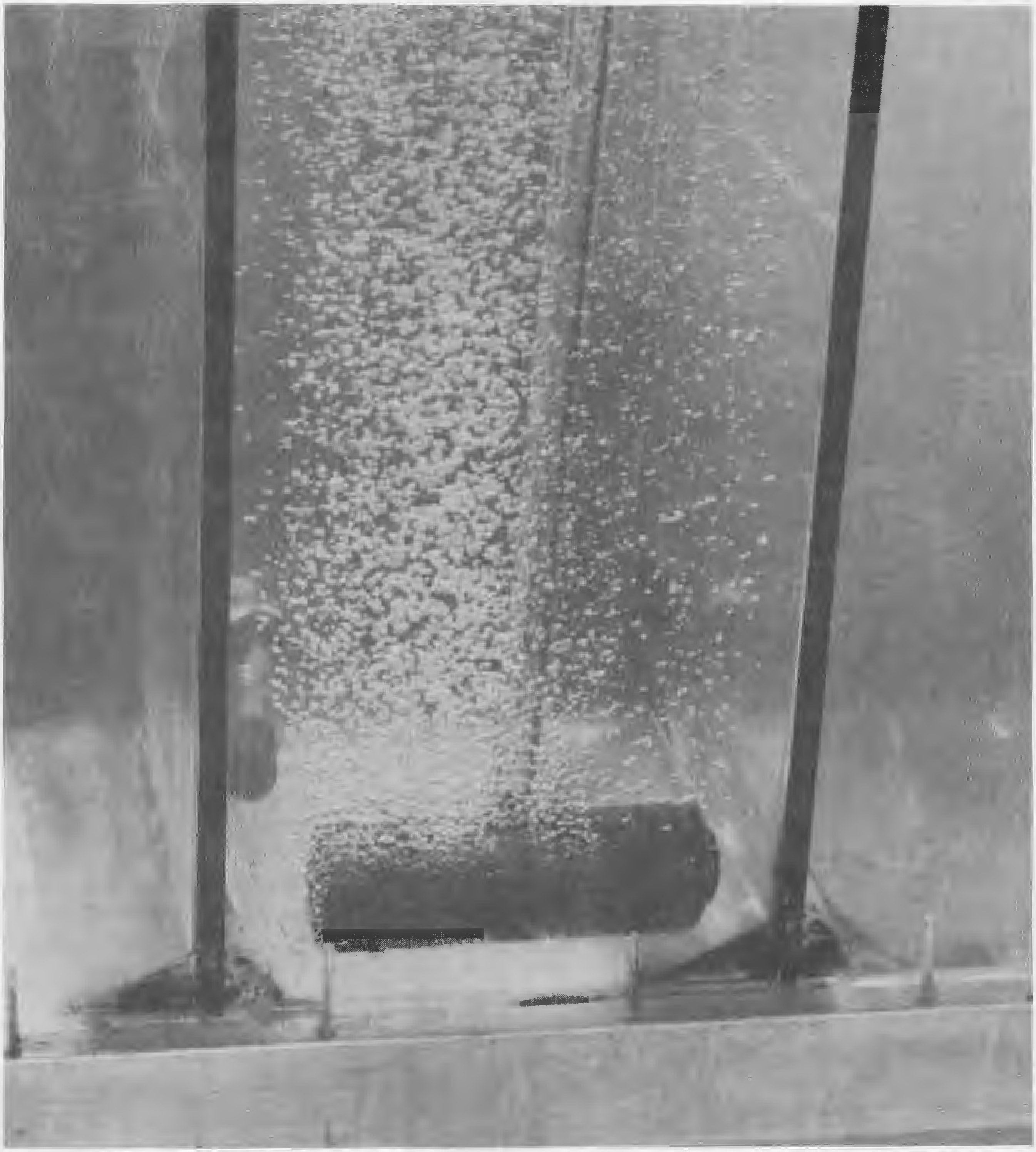

Fig. 7.5 Air diffuser

(Courtesy Paul Hallbach, National Training Center, Water Quality Office/EPA)

7.251 Variation of Activated Sludge Process

The activated sludge plant may be operated in any one of three operational zones on the basis of "sludge age"[10] which is an expression of pounds of organic loading added per day per pound of organisms maintained in the particular process. Sludge age is a control guide that is widely used and is an indicator of the length of time a pound of solids is maintained under aeration in the system. If the amount of solids under aeration remains fairly constant, then an increase in the influent solids load will decrease the sludge age. Use of this measure of sludge age is recommended for the new activated sludge plant operator because of the ease in understanding this approach. The experienced operator may not accept this method of control because it ignores the soluble COD that is related to the solids production but not measured by suspended solids tests on the influent.

The following values are typical sludge ages for different types of municipal activated sludge plants with negligible industrial wastes. Actual loadings must be related to the type of waste and local situation.

1. High-Rate. A high-rate activated sludge plant operates at the highest loading of food to microorganisms; the sludge age ranges from 0.5 to 2.0 days. Due to this higher loading the system produces a lower quality of effluent than the other types of activated sludge plants. This system requires greater operational surveillance and control and is more easily upset.

2. Conventional. Conventional activated sludge plants are the most common type in use today. The loading of food to microorganisms is approximately 50% lower than in a high-rate plant, and the sludge age ranges from 3.5 to 7.0 days. This method of operation produces a high quality of effluent and is capable of absorbing some shock loads without effluent quality being adversely affected.

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[10] Sludge Age, days =

$$\frac{\text{(Suspended Sol. in Mixed Liq., mg/l) (Aerator Vol., MG) (8.34 lbs/gal)}}{\text{(Suspended Sol. in Primary Effl., mg/l) (Flow, MGD) (8.34 lbs/gal)}}$$

$$= \frac{\text{Suspended Solids Under Aeration, lbs}}{\text{Suspended Solids Added, lbs/day}}$$

3. Extended Aeration. Extended aeration is commonly employed in smaller package-type plants or so-called complete oxidation systems. These are the most stable of the three processes due to the light loading of food to microorganisms, and the sludge age is commonly greater than ten days. Effluent suspended solids commonly are higher than found under conventional loadings.

For a summary of the loadings for different types of activated sludge processes, see Table 7-1.

There are other variations of activated sludge processes such as contact stabilization, step-feed, Kraus and complete mix which are discussed in Section 7.9.

QUESTIONS

7.2G List two methods of supplying oxygen from air to bacteria in the activated sludge process.

7.2H Write the formula for calculating sludge age.

END OF LESSON 2 OF 8 LESSONS

on

ACTIVATED SLUDGE

TABLE 7-1

AERATION TANK CAPACITIES AND PERMISSIBLE LOADINGS*

PROCESS	PLANT DESIGN FLOW, MGD	AERATION RETENTION PERIOD, HOURS BASED ON DESIGN FLOW	PLANT DESIGN LOAD 1b BOD/day	AERATOR LOADING 1b BOD per day/1b MLSS	SLUDGE AGE, DAYS
Modified or "HIGH-RATE"	All	2.5 up	2000 up	1/1 (or less)	0.5 - 2.0
Conventional	To 0.5 0.5 to 1.5 1.5 up	7.5 6.0 to 7.5 6.0	To 1000 1000 to 3000 3000 up	1/2 to 1/4	3.5 - 7.0
Extended Aeration	All	24	All	As high as 1/10 to As low as 1/20	10 or Longer

* Recommended Standards for Sewage Works (10 State Standards), Great Lakes-Upper Mississippi River Board of State Sanitary Engineers, 1968 Edition, published by Health Education Service, P. O. Box 7283, Albany, New York 12224. Price, $1.00.

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. Activated Sludge

(Lesson 2 of 8 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 1. Write the numbers for the correct answers to question 7 on your answer sheet in your notebook.

7. During storms an activated sludge plant will receive an increased inflow which may cause the following problems:

    1. Dilution of wastes which makes them easy to treat
    2. Reduced wastewater time in treatment units
    3. Increased amounts of grit and silt
    4. Increased organic loading
    5. Fluctuating wastewater temperatures

8. How can the operator attempt to reduce problems caused by waste discharges into the collection system?

9. How can maintenance activities in a collection system cause operational problems in an activated sludge treatment plant?

10. What can the operator determine from laboratory test results on the plant effluent?

11. What are some of the disadvantages of using the BOD test for operational control?

12. The operator of an activated sludge plant must constantly review his records and make appropriate changes to account for seasonal changes. True or False?

13. What is the difference between mechanical aeration and diffused aeration?

CHAPTER 7. ACTIVATED SLUDGE

(Lesson 3 of 8 Lessons)

7.3 CHECKING OUT A NEW PLANT

This section outlines the steps you should follow when checking out a new plant. The descriptions are based on a particular typical type of plant layout (Fig. 7.3). Your plant may vary from this plant; but by following this outline and obtaining assistance during checkout from the design engineer and representatives of the equipment manufacturers, many initial operating problems can be eliminated.

7.30 A New Activated Sludge Plant: Description

Imagine that your primary treatment plant has just been expanded to a diffused air activated sludge plant. You will continue to use your old screens, grit chamber, and primary clarifiers. The new aeration tank is 100 feet long, 45 feet wide, and 16.5 feet deep, and has a "Y" wall dividing it down the center. Air headers[11] are located along the full length of the tank on each side of the "Y" and spaced approximately 10 feet apart. Air bubbles come out at the bottom of the tank through the headers equipped with diffusers (Fig. 7.5). Drawings of the aeration tank and secondary clarifier are provided in Fig. 7.6.

The new secondary clarifier is circular with an 80-foot inside diameter and a 12-foot side wall depth sloping from the wall to the center of the tank. The tank is equipped with a sweep mechanism fitted with suction devices to collect the sludge after it has settled.

The resident engineer informs you that the contractor has completed his work and the new system may be put into service. First item on the agenda is to completely recheck the equipment and structures. Normally the contractor and the construction inspector are charged with this responsibility; but many times important items are overlooked, due to time schedules, negligence, or oversight.

There is nothing more disappointing than starting a new plant and having to shut down after two or three days because of some small

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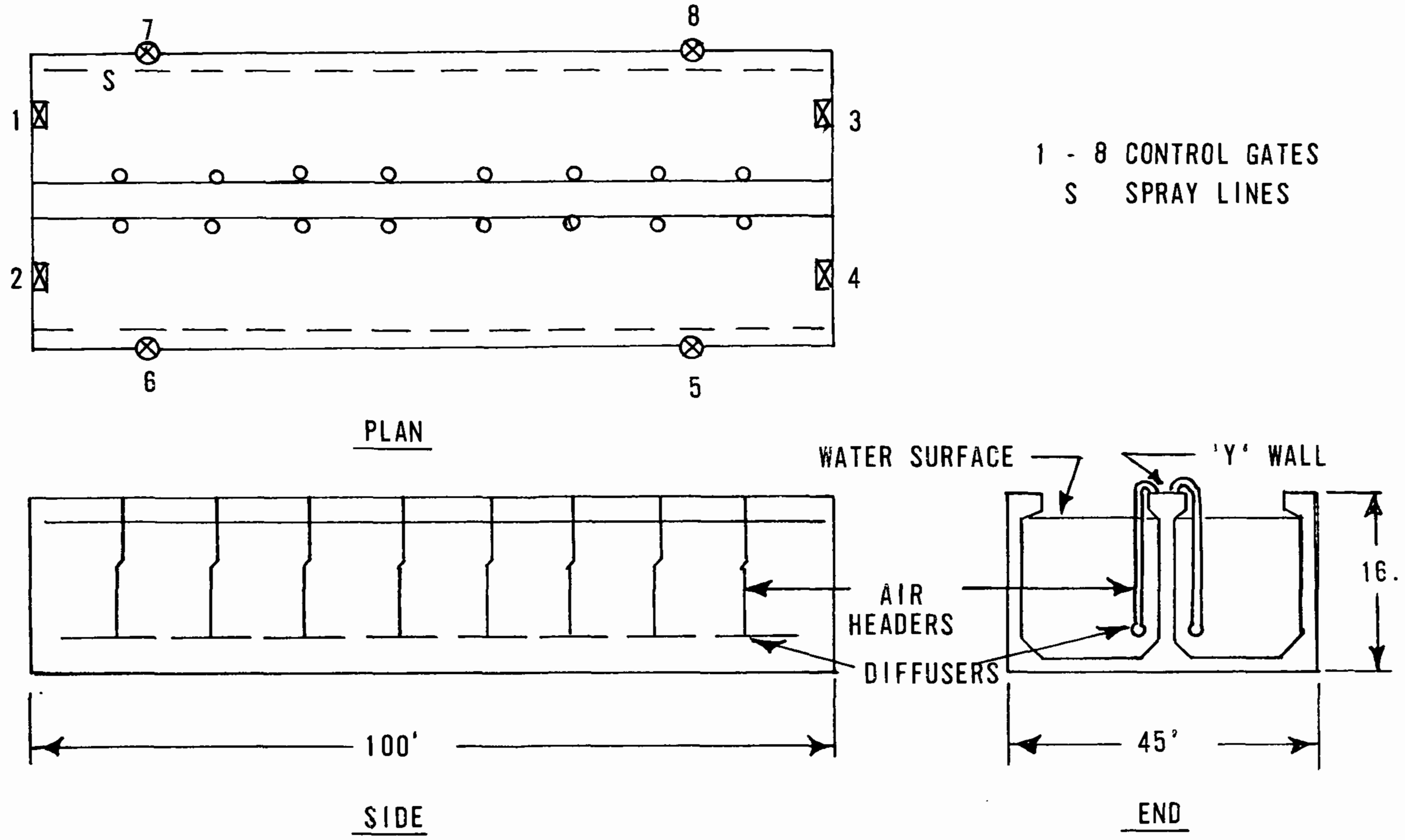
[11] Air Headers. Pipes carrying air from the main line in the "Y" wall to the air diffusers near the bottom of the aeration tank.



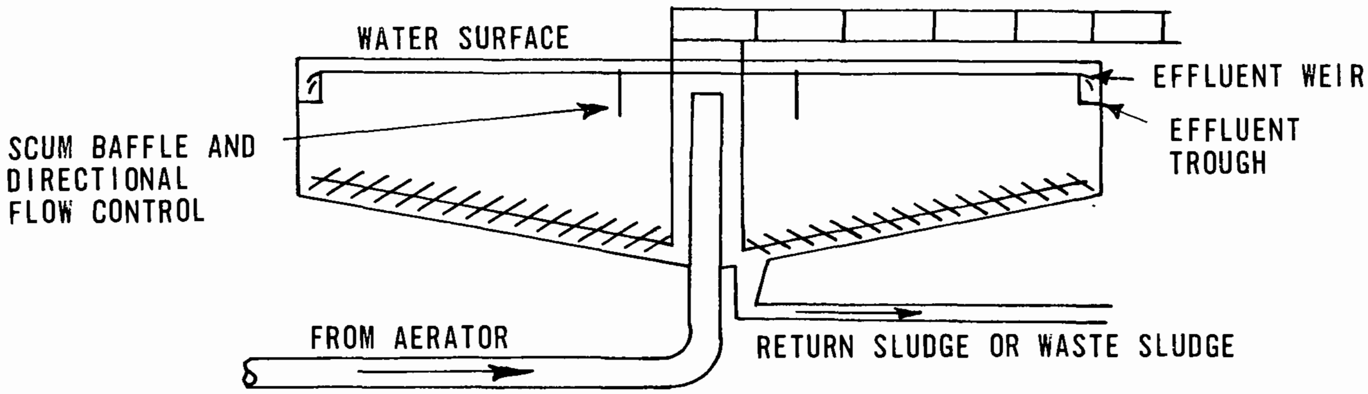


Fig. 7.6 Activated sludge process units

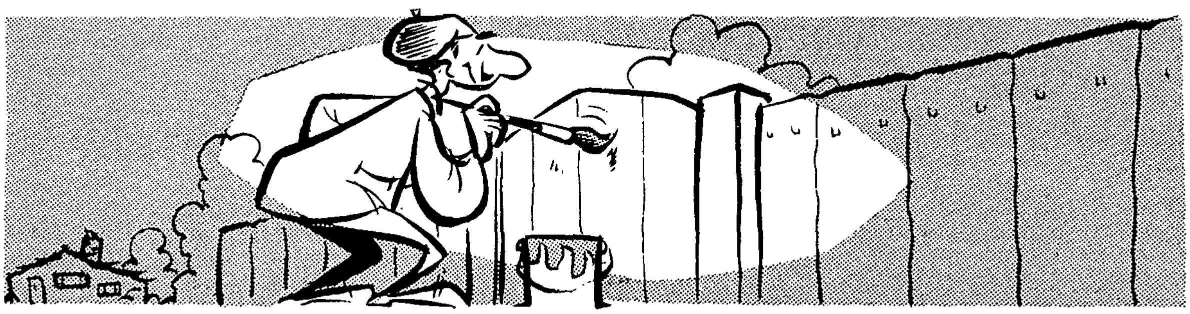
item that would have required only an hour or so to correct on a preliminary checkout. When each item is checked, be sure that you know what it is supposed to do, how it is done, how to service it correctly and safely. If possible, have a contractor or manufacturer's representative present during checkout and start-up. When each item of equipment is examined, check your manual of instructions to be sure your equipment is discussed. Start NOW with an orderly file on each piece of equipment.

7.31 Aerator

7.310 Control Gates

In Fig. 7.6 (Plan) there are eight gates or mud valves indicated by "X". The gates are marked by rectangles and the mud valves by circles. Open and close the gates even if it does permit the entry of some wastewater and check them for ease of operation and access. They must travel smoothly with no binding or jumping during opening and closing. Now is the time to check your means of noting the gate or valve location in the open, closed, or partially opened position. If you don't have a rising stem or otherwise visible indicator of valve position, count the valve turns and record.

When you have the gates open, check the aerator influent line or channel for debris such as rocks, sand, timber, waste concrete, or other foreign material. Short pieces of 2 x 4 boards and other form-lumber can suddenly appear during initial flow, and this material can jam a pump or stall a clarifier mechanism. After the line or channel is clean, close the gate, making sure there is no foreign material along the side guides and dogs.[12] When the gate closes, be sure it is properly seated.



[12] Dogs. Wedges attached to a slide gate and frame that force the gate to seal tightly.

The gate should have been painted for rust and corrosion protection, and now is an excellent time to touch up any chips or scrapes. Remove the housing protecting the threaded stem and check to be sure there is lubricant on the stem threads, and see if there is a stop-nut at the top of the stem. If there is not a stop-nut, insert one, because the gate could fall into the aeration tank when you or some other operator opens it just a little bit too far, or the stem could be bent attempting to close it farther than necessary.

7.311 Mud Valves (Shear Gates)

These valves may be used for tank drainage or for step-feed aeration.[13] Open and close each valve, checking for ease of operation and proper seating. Give each stem a generous coat of heavy-duty waterproof grease because the stems are normally exposed directly to the wastewater.

QUESTIONS

7.3A Why should the operator completely check the equipment and structures before start-up?

7.3B Why should lines and channels be cleaned before start-up?

7.3C Why should chips and scrapes on gates be painted before a tank is filled?

7.3D What is the purpose of stop-nuts on the stems of valves?

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[13] Step-Feed Aeration. Step-feed aeration is a modification of the conventional activated sludge process. In step aeration, primary effluent enters the aeration tank at several points along the length of the tank, rather than all of the primary effluent entering at the beginning or head of the tank and flowing through the entire tank.

7.312 Weirs

Weirs are used to control flow at the outlet or effluent end of the aeration tank. Check these with a surveyor's level to be sure one end is not higher than the other. Recheck after tank is filled. If they are not level, the effluent will not be evenly distributed over the weir, which could cause short circuiting and an uneven distribution of solids in the effluent. The weirs should have an adequate protective paint coating, unless they are made of a corrosion-resistant material.

7.313 Movable Gates

Check the guide slots of bulkheads for nicks or rocks and make sure the gate seats and operates properly.

7.314 Water Sprays for Froth Control

Check to see if there is a nozzle in each water spray head which will form a fan of water. The fan of water should have an angle to the tank surface of approximately 45°. Turn the water on for a few minutes and check to be sure the spray properly covers the desired area.

> The nozzles must be properly installed to cover the intended area of the aerator or they will be ineffective, spraying the rails and walks. This creates a hazardous condition of algae growths in the summer, or ice conditions in the winter, and also does not dissipate much foam.

There should be no leakage in the piping system, and the water fans should overlap one another for effective control. At the dead-end of each pipeline, check the operation of the valve that allows flushing the whole line when opened. A "Y" strainer should be installed at the inlet end of the system to filter out large material, thus saving time in the future on maintenance.

QUESTIONS

7.3E Why should an effluent weir be level?

7.3F What dangers are created if a foam spray nozzle sprays on a rail or walk?

7.315 Air System

Check the air system by following it through in the direction of air flow to the aeration tank.

A. Air Filters

Filters remove dust and dirt from the air before it is compressed and sent to the aeration tank.

First check the access doors or hatches to the filter chamber. These should be lined around the edges with rubber or some other material to form a tight seal. If there is a gap or torn place, repair it. Check the inside of the filter chamber floors for cleanliness and debris--remove any sand, dirt, paper, or other debris.

Check the filter bags for proper coating of filter media. The main check is to be sure that they are securely installed and that one of the workmen did not leave a tool or some item that could go directly into one of the blowers.

A manometer is installed to read the difference in pressure between the inlet side of the filters and the outlet side. The "U" tube manometer is mounted on the outside of the filter housing with two small copper lines running to the intake and outlet side of the filters.

To check the manometer, remove the glass "U" tube from the manometer housing, taking care not to break it. Blow air through each line back to the manometer, checking to see that the lines are clear and not plugged or accidentally crimped during installation. If the lines are equipped with fittings, check for tightness and leakage. If the lines are okay, fill the manometer "U" tube with the required fluid. This could be a specified oil, or water may be acceptable. Fill the "U" tube approximately half the distance from the top of the tubes to the bottom of the "U"; both columns should be the same height. If water is permissible to use, a drop or two of red or blue chart ink added to the tube before the water is added gives a good color and an easy indicator for reading the manometer.

See Chapter 16, Section 16.2, for instructions on how to read manometers.

The difference in pressure recorded by the manometers will be small when the filters are clean, but as they become dirtier, the manometer reading will increase and each column will move farther away from the manometer zero mark. When this difference reaches approximately two to three inches of water column more than the initial difference, it is probably time to clean or change the filters. The manufacturer's operating manual should be reviewed for the recommended maximum allowable pressure differential as well as the procedure for cleaning the screens.

Check the air duct valving from the filters to the inlet side of the air blowers (compressor) for proper installation. Also check these ducts or pipes for dirt and debris.

QUESTIONS

7.3G Why and how is air cleaned before being compressed and sent to the aeration tank?

7.3H How can you determine when the air filters need cleaning?

B. Blowers (Compressors)

The blowers are of the positive displacement type. Read the manufacturer's manual and thoroughly understand it before the blowers are ever started. This manual should be provided by the manufacturer and can be obtained by writing to the company indicated on the equipment name plate.

Special attention must be directed towards starting and stopping procedures. Prepare a list of items to be checked before the start button is pushed. Check switches, indicators, and pump connectors with drawings. Check the type of oil and oil level. Start the oil circulation pump and check the circulation system and oil level before the blowers are started.

Check inlet and discharge valves by opening and closing them and noting ease of operation. These units are to be started under no load (the discharge air is vented to atmosphere until the unit is running properly), and then valved in slowly to put the air into the system and load the unit. When the unit is shut down, the reverse of the starting procedure is followed. Be absolutely positive of the correct procedure for starting and stopping the unit, including procedures for starting and stopping one unit while the others are operating. Improper procedures can shorten the life of the equipment considerably. Your supervisor will not be happy if he finds out that equipment has broken or worn out because of improper procedures.

Next, check the driver (electric motor), the blower base plates, and the <u>coupling</u> for alignment. Usually the contractor's millwright sets the equipment and aligns the couplings with a dial indicator. Request the dial readings from him and file them with the rest of the equipment data. These readings are invaluable in case of equipment failure, or for future checks on proper alignment. These should be no more than 0.005 of an inch off, and larger equipment calls for even closer tolerances. Check for base plate bolts or nuts because if one corner is loose, the whole alignment will be thrown out on start-up. Do not attempt to tighten base plate nuts or bolts because this also will cause misalignment. If one nut is loose or there is a gap between the equipment mount and the base plate, the coupling must be realigned and the equipment mounts shimmed.

If the blower and driver are securely anchored and all lubrication points are in good condition, coupling alignments are satisfactory, motor and compressor will turn with a reasonable pull on the outside pulleys, and all safety guards are installed and well clear of the moving parts, then you are ready to check the main air lines or "air mains".

On both the inlet and discharge sides of the blower, air mains (air lines) are connected through a flexible coupling in order to keep vibration at a minimum and allow for heat expansion because, when air is compressed, heat is generated, thus increasing the discharge temperature as much as 100°F or more. Check to be certain there is sufficient room for movement in flexible couplings.

The discharge air line from the blower is equipped with an air relief valve which protects the blower from excessive back pressure and overload. It is adjusted by weights or springs to open when air pressure exceeds a point above normal operating range, around 7.5 to 10 psi. Check this valve to insure its free operation by manually lifting the valve off the seat.

Between the air relief valve and the discharge side of the blower is a pressure gauge to read discharge pressure. Check the gauge for proper installation by looking for air leaks and for easy accessibility to read.

A metering device should be located in a straight section of the air main on the discharge side of the blower. This device consists of an orifice plate inserted between two specially made pipe flanges. The orifice plate is made of stainless steel with a precision hole cut through the center of it which will vary in diameter according to the flow rates to be measured. The plate is made of 1/8-inch thick material and is slightly larger than the inside diameter of the pipe. A rectangular shaped handle is attached to the plate. The plate is installed between the flanges, blocking the pipeline except for the hole in the center of the plate. One side is bevelled, leaving a sharp edge on the opposite side. The handle of the orifice plate will have numbers stamped into it giving the orifice size. These numbers on the handle are stamped on the same side as the sharp edge of the orifice opening. When viewing the plate to read the numbers, the blower should be behind you. <u>The sharp edge of the plate and the numbers must be on the side toward the blower for it to read properly</u>.

On top of each pipe flange holding the orifice plate will be a hole tapped and connected to tubing leading to the instruments which indicate the rate of air flow. Check these to see that there are no air leaks. The instruments themselves should have been installed and calibrated correctly, but occasionally an orifice plate is installed backwards or an instrument line is left disconnected. When the meter is properly connected to a dial or totalizer, a zero reading should be recorded when the pump is off.

Check the condensate trap or drain located near the aeration tank at the lowest point of the air main. Open and close the drain line and remove any dirt or sand in the air main at this location.

Inspect the air main from the blowers to the air headers for leaks, tightness, and expansion allowances.

QUESTIONS

7.3I Why is it important to read the blower or compressor manufacturer's manual before starting the equipment?

7.3J If your plant does not have a manufacturer's manual, how would you obtain one?

7.3K Why should proper procedures be followed when starting, operating, and stopping equipment?

7.3L How should the sharp edge of a metering orifice be placed in a pipe?

C. Air Headers

The air main runs down the center "Y" wall of the aeration tank, distributing air to the headers along the tank. This plant is equipped with "swing headers". A swing header is merely a pipe with movable couplings so the header may be raised from the tank with a hoist to service the diffusers.

Take the hoist that is to be used to raise and lower the air headers out to the center "Y" wall and make sure it properly fits each air header. The hoist is anchored by the air header opposite the one to be lifted. Sometimes the correct spacing is missed and the hoist is either too short or too long. In either case, you would not be able to lift those two headers, for there is no other safe way to anchor the hoist. If you attempted to lift a header without the hoist anchored, it could catapult into the tank, possibly taking the operator with it and surely damaging the hoist (and probably the diffusers and headers too).

Each header is equipped with a valve to shut the air off when removing it from the tank to replace or clean the diffusers. Consequently, the other headers may be kept in service, thus not disrupting the air supply to the tank contents. Inspect each air header valve for proper operation, and determine which position of the stem indicates open and which position indicates closed.

> The center "Y" wall is a hazardous area and caution is required when working here. If the aeration tank is empty, a 16-foot fall could be fatal. When the tank is in service you could drown if you fell into it. A good policy is that <u>any work on the center "Y" wall calls for TWO MEN AND LIFE PRESERVERS AND/OR LIFE LINES</u>.

Other safety precautions that should be observed at all times when working on center "Y" walls include:

1. Wear shoes with soles that retard slipping. Ccre inserted composition soles provide the best traction for all-around use.

2. Slippery algal growths should be scrubbed and washed down whenever they appear.

3. Keep the area clear of spilled oil or grease.

4. Do not leave tools, equipment, and materials where they could create a safety hazard.

5. Adequate lighting should be permanently installed for night work.

6. Ice conditions in winter may require spiked shoes and sanding icy areas if ice cannot be thawed away with wash water.

7. Remove only sections of removable handrails necessary for immediate job. Removed sections should be properly stored out of the way and secured against falling.

Since the aeration tank is empty or nearly empty, place a ladder in the tank and continue the check-out.

First, remove any debris, including sand or dirt, from the bottom of the tank.

Next, check the air headers. This is the continuation of the air system to the bottom of the tank with the pipes creating an inverted "T". The horizontal run of pipe forming the cross-bar on the top of the "T" should be perfectly level. If one end is 1/2-inch higher than the other end, then more air will escape through the high end, causing poor air distribution. The contractor should have set them with a surveyor's level to insure that they are all at the same elevation, but it is advisable to check them again. Be sure diffusers are secure and header or diffuser plugs are in place; replace damaged or defective items.

The pipe should have been flushed with water to remove dirt, dust, and scale.

QUESTIONS

7.3M Why must the hoist used to lift the air headers be properly anchored?

7.3N What precautions would you take when working on the center "Y" wall?

7.3O Why must the horizontal pipes containing the air diffusers all be at the same elevation (level)?

D. Diffusers

Thread-type diffusers are installed in our example plant. Before the diffusers were installed, the pipe should have been flushed clean with water. Inspect the diffusers. A light application of grease on the threads (taking care that none of the lubricant touches the opening into the diffuser) should have been applied for ease in removing the diffusers when they need cleaning. Do not use a wrench when installing threaded diffusers; normal "hand tight" is sufficient, and even this can create a problem when the time arrives to remove them.

E. Blower Testing

After you have inspected the air headers and diffusers in the aeration tank, check the blower operation.

Start with the blowers discharging air directly to the atmosphere. Review the stop and start procedure for the blowers and turn them on. If at all possible, let them run for three or four hours to check on any heating problems or vibrations. Check temperatures, amperage readings from the electric motors, and air flow rates and differential pressures across the filter system, and record them.

Repeat these checks after the process tanks are filled. Now is the time to check the air relief valves for correct settings by closing several valves out on the headers until the air relief valves open. Also take another set of amperage readings on the blower motor to see if it is overloaded under operating conditions. If everything functions properly for four hours, you can feel fairly certain that you will not have any immediate problems from the blowers.

QUESTIONS

7.3P While the blowers are running, what items should be checked, and why?

7.3Q Why should a light application of grease be applied to the threads of a diffuser?

7.32 Secondary Clarifiers

CIRCULAR CLARIFIERS - check items:

1. Control gates for operation
2. Clarifier tank for sand and debris
3. Collector drive mechanism for lubrication, drive alignment, and complete assembly
4. Squeegee blades on the collector plows for proper distance from the floor of the tank
5. Connecting lines or channels between aerator and clarifier for debris
6. Pump suction line assembly and controls
7. Inlet baffles and discharge weirs for level
8. Scum control mechanism

Once the collectors are started in a new tank, each flight should be checked for a clearance of one to two inches between the wall and the end of the flight. If a flight is too long, it may rub the tank wall and break the flight, jamming other flights and breaking them. Once a broken flight is detected, it should be replaced or removed from the support structure.

7.33 Return Sludge and Waste Sludge Pumps

Since these two items are identical except for size, the same checks may be used.

Clean out trash in all sludge hoppers, lines, valves, gates, sweeps, and drive mechanisms before checking pumps.

> To check out pumps, FIRST lock out the pump motor at the power panel so it cannot be started.

Remove the handhole cover, clean out the pump casing or volute,[14] and check the impeller for debris and secure fit to the pump shaft. Replace the handhole cover. Install or check pressure gages on the suction and discharge lines of the pump. Check inlet and outlet valve operation and connecting lines for clearance.

Check pump and motor bearings for lubrication. Inspect coupling alignment, and base plate anchor bolts. Turn on the seal water to the pump. Since the pump has not operated, back off the packing gland nuts and rotate the pump shaft by hand through several revolutions. Leave the packing nuts loose and adjust them properly after start-up. If everything checks out satisfactorily, then run some water into the final clarifier hopper or return sludge well where the pump suction is located so it may be operated for a few minutes. While the water is filling the hopper or wet well, check the suction and discharge valves and check (flap) valves on the system. Check the other valves on the return sludge line for proper operation. Open both inlet and discharge valves before starting the pump so the water may flow during the pump test.

There should be several hundred gallons of water available in the final clarifier for the pump test. Prime the pump if necessary and, if everything has checked out properly, unlock the controls at the power panel and turn the pump on. First check pump rotation and the packing gland for water, but let it flow freely for now. Read both pressure gages on suction and discharge and the level of the water in the clarifier or wet well; record all three measurements in order that the operational characteristics and efficiency of the pumps may be checked. Take an amperage reading on the motor and record. If possible, make sure that the meter is functioning, and record a flow meter reading too. The water available will not afford a very long run, but it will indicate any major problems. When the pump is shut off, make sure the check valve closes and seats.

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[14] Volute. The spiral-shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

To check the waste sludge pump, the return sludge pump also must be running. Run the waste sludge pump now to be sure it will operate properly when you are ready to start wasting activated sludge.

QUESTION

7.3R List all the information which should be recorded for future reference when you test the return sludge and waste sludge pumps.

END OF LESSON 3 OF 8 LESSONS

on

ACTIVATED SLUDGE

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. Activated Sludge

(Lesson 3 of 8 Lessons)

Write the answers to these questions in your notebook before continuing . The problem numbering continues from Lesson 2.

14. What should the operator look for when checking out control gates and mud valves?

15. What happens when spray nozzles are not installed properly and spray falls on rails and walks?

16. Why should proper procedures be followed when checking equipment?

17. What safety precaution should be exercised before checking the impeller of a return sludge pump?

18. Why should the equipment manufacturer's manual be thoroughly read and understood before any equipment is started?

7.4 PROCESS START-UP PROCEDURES

7.40 General

Procedures for starting the activated sludge process are outlined in this lesson. Procedures and example calculations will be for the plant checked out in the previous lesson. An initial average daily flow of 4.0 MGD will be assumed, and the plant will be operated as a conventional activated sludge plant.

Start-up help should be available from the design engineer, vendors, nearby operators, or other specialists. The equipment manufacturers or contractor should be under contract for start-up instruction and assistance. During start-up they should be present to be sure that any equipment breakdowns are not caused by improper start-up procedures.

The operator may have several options in the choice of start-up procedures with regard to number of tanks used and procedures to establish a suitable working culture in the aeration tanks. The method described in this lesson is recommended because it provides the longest possible aeration time, reduces chances of solids washout, and provides the opportunity to use most of the equipment for a good test of its acceptability and workability before the end of the warranty.

7.41 First Day

First, start the air blowers and have air passing through the diffusers before primary effluent is admitted to the aeration tanks. This prevents diffuser clogging from material in the primary effluent.

Fill both aeration tanks to the normal operating water depth, thus allowing the aeration equipment to operate at maximum efficiency. Employing all of the aeration tanks will provide the longest possible aeration time. You are trying to build up a population with a minimum amount of seed organisms, and you will need all the aeration capacity available to give the organisms a chance to reach the settling stage.

When both aeration tanks have been filled, begin filling the two secondary clarifiers. Use of all the secondary clarifiers will provide the longest possible detention time to reduce washout of light solids containing rapidly growing organisms and will help enhance solids build-up.

When the secondary clarifiers are approximately three-fourths full, start the clarifier collector mechanism and return sludge pumps. Return sludge pumping rates must be adjusted to rapidly return the solids (organisms) back to the aeration tanks. The solids should never remain in the secondary clarifiers longer than 1.5 hours. Trouble also may develop if the return sludge pumping rate is too high (greater than 50% of the raw wastewater flow), because the high flows through the clarifier may not allow sufficient time for solids to settle to the bottom of the clarifier. A conventional activated sludge plant usually operates satisfactorily at return sludge rates of 20 to 30 percent of raw wastewater flow, but the rate selected should be based upon returning organisms back to the aerator where they can treat the incoming wastes. A thin sludge will require a higher return percentage than a thick one. Addition of a coagulant or coagulant aid at the end of the aeration tank will hasten solids build-up and improve effluent during start-up.

When the secondary clarifiers become full and begin to overflow, start effluent chlorination to disinfect the plant effluent.

Filling the aeration tanks and aerating the wastewater starts the activated sludge process. The aerobes in the aeration tank have food and are now being supplied with oxygen; consequently, this worker population will begin to increase.

After two or three hours of aeration you should check the dissolved oxygen (DO) of the aeration tanks, to determine if sufficient air is being supplied. (See Chapter 14, Laboratory Procedures and Chemistry, for procedure to run DO test.)

Check the DO at each end and at the middle of the aerator. Oxygen must be available for the aerobes throughout the tank. If the DO is less than 2.0 mg/l, increase the air supply. If the DO is greater than 2.0 mg/l the air supply may be decreased, but not to the point where the tank would stop mixing. There will probably be an excess amount of DO at first due to the limited number of organisms initially present to use it.

After a biological culture of aerobes is established in the aeration tanks, sufficient oxygen must be supplied to the aeration tank to overcome the following demands:

1. DO usually is low in both influent wastewater and return sludge to the aerator.

2. Influent wastewater may be septic, thus creating an immediate oxygen demand.

3. Organisms in the presence of sufficient food create a high demand for oxygen.

The effluent end of the aerator should have a dissolved oxygen level of 2.0 mg/l. DO in the aerator should be checked every two hours until a pattern is established. Thereafter, DO should be checked as frequently as needed to maintain the desired DO level. Daily flow variations will create different oxygen demands; and until these patterns are established, it is not known whether sufficient or excess air is being delivered to the aeration tanks. Frequently excess air is provided during early mornings when the inflow waste load is low. Air supply may be too low during the afternoon and evening hours because the waste load tends to increase during the day.

7.42 Second Day

Collect a sample from the aeration tank and run a 60-minute settleability test using a 1000 ml graduated cylinder. If possible, use a 2000 ml cylinder with a five-inch diameter[15] in order to obtain better results. Observe the sludge settling in the sample for approximately one hour. It will probably have the same color as the primary effluent during the first few days. After a few minutes in the cylinder, very fine particles will start forming with a light buff color. The particles remain suspended, not settling, similar to fine particles of dust in a light beam. After an hour, a small amount of these particles may have settled to the bottom of the cylinder to a depth of 10 or 20 ml, but most are still in suspension. This indicates that you are making a start toward establishing a good condition in the aeration tank, but many more particles are needed for effective wastewater treatment.

7.43 Third through Fifth Days

During this period of operation the only controls applied to the system usually consist of maintaining DO concentrations in the system and maintaining proper sludge return rates. A sampling program should be started in accordance with Section 7.23, Plant Records, to develop and record the necessary data required for future plant control.

Aeration of wastewater to maintain DO will require some time before settling will produce a clear liquid over the settled solids. Time

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[15] Mallory Direct Reading Settleometer (a 2 liter graduated cylinder approximately 5 inches in diameter and 7 inches high). Obtain from Scientific Glass Apparatus Co., Inc., 735 Broad Street, Bloomfield, New Jersey. Catalog No. JS-1035. Price $16.50 each.

is required for organisms to grow to the point where there are sufficient numbers to perform the work needed--to produce an activated sludge. Usually within 24 to 72 hours of aeration you will note that the settleable solids do not fall through the liquid quite so rapidly, but the liquid remaining above the solids is clearer.

The active solids (organisms) are light and may wash out of the clarifier to some extent. Hopefully you can retain most of them, because a rapid solids build-up will not occur unless they are retained. A good garden soil will add organisms and solids particles for start-up. Mix the soil with water and hose in the lighter slurry, but try to avoid a lot of grit. A truck-load of activated sludge from a neighboring treatment plant also will help to start the process. Hopefully you will not have to treat design flows during plant start-up. More time is needed both for aeration and clarification until you have collected enough organisms in your return sludge to enable you to produce a clear effluent after a short period of mixing with the influent followed by settling.

QUESTIONS

7.4A Why should chlorination equipment be put in service when effluent starts leaving the plant?

7.4B How is the return sludge rate selected during initial start-up?

7.4C Why should the blowers be started before primary effluent is admitted to the aeration tanks?

7.4D At what locations in the aeration tank would you check the DO, and why?

7.44 Sixth Day

A reasonably clear effluent should be produced by the sixth day. Solids build-up in the aeration tank should be closely checked using the 60-minute settleable solids test during the first week. Results of this test indicate the flocculating, settling, and compacting characteristics of the sludge. Suspended solids build-up is very slow at first but increases as the waste removal efficiency improves. This build-up should be carefully measured and evaluated each day.

Microorganisms in the system are so varied and small that it is impossible to count them. To obtain an indication of the size of the organism population in the aeration tank, the solids are measured either in mg/l or in pounds of dry solids. Suspended solids determinations for aerator mixed liquor will give the desired information in mg/l, and the total pounds of solids may be calculated on the basis of the size of the aerator.

$$\text{Total Susp. Solids, lbs} = \text{Suspended Solids, mg/l} \times \text{Aerator Volume, MG} \times 8.34\ \text{lbs/gal}$$

The suspended solids test (see Chapter 14, Laboratory Procedures and Chemistry) conducted on activated sludge plant mixed liquor is normally a grab sample obtained at the effluent end of the aerator. The sample should be collected at the same time every day, preferably during peak flows, in order to make day-to-day comparisons of the results. Collect the mixed liquor sample approximately five feet from the effluent end of the aeration tank and 1.5 to 2 feet below the water surface to insure a good sample. A return sludge sample also should be collected at this time every day to determine its concentration.

With information from the lab tests, estimates of the organism mass (weight) in the aerator can be calculated.

Information needed:

1. Aeration Tank Dimensions

   100 ft long, 45 ft wide, and 16.5 ft deep

2. Results of Laboratory Tests

   Mixed Liquor Suspended Solids, 780 mg/l

Steps to calculate pounds of solids in aeration tank:

1. Determine aeration tank volume.

$$\text{Aerator Volume, cu ft} = \text{Length, ft} \times \text{Width, ft} \times \text{Depth, ft}$$

$$= 100 \text{ ft} \times 45 \text{ ft} \times 16.5 \text{ ft}$$

$$= 74{,}250 \text{ cu ft}$$

2. Convert cu ft to gallons.

$$\text{Aerator Volume, gals} = 74{,}250 \text{ cu ft} \times 7.48 \text{ gals/cu ft}$$

$$= 555{,}390 \text{ gals}$$

or $= 555{,}000$ gals (approximately)

or $= 0.55$ MG

3. Calculate pounds of solids under aeration.

Formula:

$$\text{Solids, lbs} = \text{Mixed Liquor Suspended Solids, mg/l} \times \text{Aerator Volume, MG} \times 8.34 \text{ lbs/gal}$$

$$= \frac{780 \text{ mg}}{1{,}000{,}000 \text{ mg}} \times 0.55 \text{ M Gals} \times 8.34 \text{ lbs/gal}$$

$$= \frac{780 \text{ mg}}{\text{M mg}} \times 0.55 \text{ M Gals} \times 8.34 \text{ lbs/gal}$$

$$= 780 \times 4.6^{*} \text{ lbs}$$

$$= 3588 \text{ lbs}$$

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* The factor 4.6 lbs is equivalent to 0.55 x 8.34, a constant for your plant. You will use this value every day as long as you use the same aeration tank capacity. Only a change in the suspended solids concentration will cause a change in the pounds of solids in the aeration tank.

Close observation of the suspended solids build-up and results from the 60-minute settleability test will indicate the solids growth rate, condition of solids in aerator, and how much sludge should be returned to insure proper return of the organisms to the aerator. It will be necessary to return all of the sludge for 10 to 15 days or longer if the wastewater is weak.

Results from the 60-minute settleability test can be used to estimate if the return sludge rate is too high or too low. If the volume of settled sludge in the cylinder is indicative of amount of sludge settling in the secondary clarifier, the volume of return sludge should be equal to or slightly greater than the percentage of settling sludge in the cylinder multiplied by the sum of the primary effluent and the return sludge flows.

Estimate the return sludge pumping rate.

Information needed:

1. Flow to Aerator from Primary Clarifier, 4.0 MGD
2. Return Sludge Flow, 1.0 MGD
3. Volume of Mixed Liquor Solids Settled in 60 Minutes, 360 ml in 2 liters, or 18%

Example:

Flow to Aerator from Primary Clarifier	=	4.0 MGD
Return Sludge Flow to Aerator	=	1.0 MGD
Total Flow through Aerator	=	5.0 MGD

Return Sludge Rate, MGD = Aerator Flow, MGD x Settleable Solids, %

= 5.0 MGD x 0.18

= 0.9 MGD or 900,000 gals/day

$$\text{Return Sludge Rate, GPM} = \frac{900{,}000 \text{ GPD}}{1440 \text{ min/day}}$$

= 625 GPM

Therefore, the initially selected 700 GPM return sludge rate is acceptable at this time. It insures that most solids are being returned to the aeration tank. A return sludge pumping rate slightly higher than calculated is recommended to return the organisms as fast as possible to the aerator. Too high a return sludge rate must be avoided because the resulting high flows reduce the detention time in the aerator and secondary clarifier.

If the return sludge rate is too low, the following undesirable conditions may develop:

1. Insufficient organisms will be in the aerator to treat the influent waste (food) load. This normally occurs during the first week or two of start-up.

2. Too long a detention time in the secondary clarifier could allow the sludge to become septic.

3. Accumulation of sludge in the clarifier creates a deep sludge blanket which will allow solids to escape in the effluent.

QUESTIONS

7.4E When and where should solids samples be collected to provide the operator with a record of solids build-up in the aeration tank?

7.4F Determine the pounds of solids in an aeration tank with a volume of 0.25 MG and a Mixed Liquor Suspended Solids (MLSS) concentration of 640 mg/l.

7.4G Estimate the return sludge pumping rate (GPM) if the plant inflow is 2.0 MGD and the return sludge flow is 0.5 MGD. The results of the 60-minute settleability test indicate the volume of solids settled to be 340 ml in 2 liters, or 17%.

END OF LESSON 4 OF 8 LESSONS

on

ACTIVATED SLUDGE

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. Activated Sludge

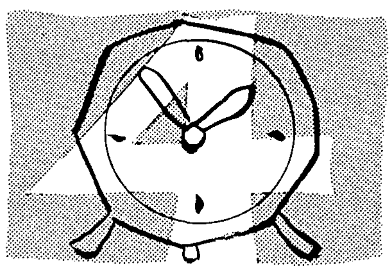
(Lesson 4 of 8 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 3.

19. When starting a new activated sludge plant, who might the operator contact for assistance and advice?

20. When starting the activated sludge process, why should you use all of the aerators and all of the secondary clarifiers?

21. What are the essential laboratory tests for starting the activated sludge process, and why?



7.5 ROUTINE OPERATIONAL CONTROL

7.50 General

Effectiveness of the activated sludge treatment process in reducing the waste load depends upon the amount of activated sludge solids in the system and the health of the organisms which are a part of the solids. To successfully maintain control of the solids and health of the organisms requires continuous (seven days a week) observation and checking by the plant operators. Sludge age[16] is one of the methods used by operators to determine and maintain the desired amount of activated sludge solids in the aeration tank. Sludge age is recommended for operational control because suspended solids are relatively easy to measure. In addition, sludge age considers two factors vital to successful operation: (1) solids (food) entering the treatment process and (2) solids (organisms) available to treat the incoming waste (food). A critical point to recognize is that the solids test is capable of indicating both the amount of food carried by the inflow to the process and the number of organisms available to treat the waste.

Operation of a conventional activated sludge plant is illustrated in this section because the example plant selected to indicate start-up procedures has an allowable effluent BOD of 20 mg/l. A sludge age of five days (See Table 7-1, Section 7.25) will serve as a satisfactory loading target during start-up for this plant. After the plant is in operation, various sludge ages may be tried in an effort to improve the quality of the plant effluent.

Always remember that you must maintain the DO in the aerator and more air will be required when aeration tank solids increase in concentration and activity.

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[16] $$\text{Sludge Age, days} = \frac{\text{Mixed Liquor Suspended Solids in Aerator, lbs}}{\text{Suspended Solids in Primary Effluent, lbs/day}}$$

7.51 Determination of Sludge Age

Whether a new plant is being started or the operation of an existing plant is being checked, the sludge age is used to indicate when activated sludge should be wasted and, if necessary, the waste sludge pumping rate.

Information needed to determine sludge age:

1. Mixed Liquor Suspended Solids = 2380 mg/l
2. Primary Effluent Composite Suspended Solids = 72 mg/l (average of daily values for past week)
3. Average Daily Influent Flow = 4.0 MGD

1. Determine pounds of mixed liquor suspended solids in aerator.

Solids in Aerator, lbs = Mix. Liq. Susp. Sol., mg/l x Aerator Vol., MG x 8.34 lbs/gal

= 2380 mg/l x 4.6 (factor from Section 7.44, Page 7-54)

= 10,948 lbs, or approximately 11,000 lbs

2. Determine pounds of solids added per day to system by primary effluent.

Solids Added by Primary Effluent, lbs/day = Prim. Effl. Susp. Sol., mg/l x Flow, MGD x 8.34 lbs/gal

= 72 mg/l x 4.0 MGD x 8.34 lbs/gal

= 72 x 33.4 lbs/day

= 2404 lbs/day, or approximately 2400 lbs/day

3. Calculate sludge age in days.

$$\text{Sludge Age, days} = \frac{\text{Suspended Solids in Aerator, lbs}}{\text{Suspended Solids in Primary Effluent, lbs/day}}$$

$$= \frac{11{,}000 \text{ lbs}}{2400 \text{ lbs/day}}$$

$$= 4.5 \text{ days}$$

If the results of lab tests and calculations indicate a sludge age of 4.5 days when the target sludge age is five days, no sludge should be wasted. If a sludge age of 4.5 days was obtained during the start-up of the example plant, the operator should continue to allow the solids to increase in the aerator. In an existing plant, if the sludge age is below the desired level, any sludge wasting should be stopped.

A simple way to find the desired pounds of aerator solids to be maintained is to multiply the average daily pounds of primary effluent solids added per day by the desired sludge age.

<u>Example</u>:

Find the desired pounds of solids to be maintained in the aerator.

Information needed:

Desired Sludge Age, days = 5 days

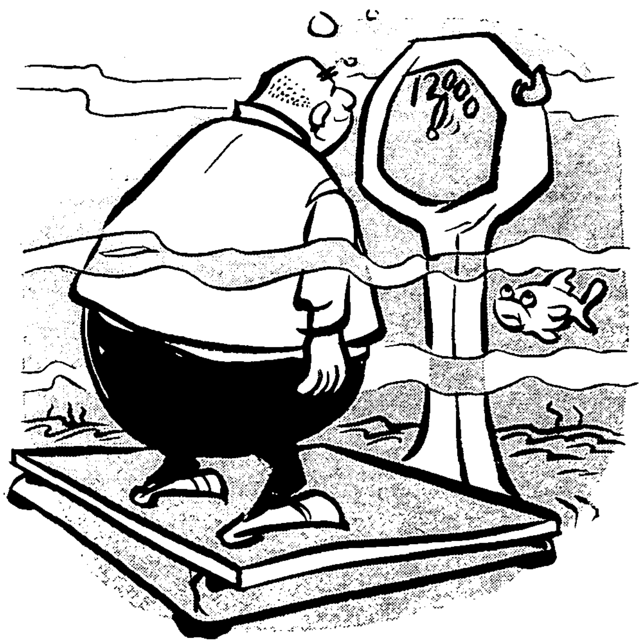
Solids in Primary Effluent, lbs/day = 2400 lbs/day

Calculate pounds of solids desired in aerator.

$$\text{Sludge Age, days} = \frac{\text{Suspended Solids in Aerator, lbs}}{\text{Suspended Solids in Primary Effluent, lbs/day}}$$

Rearrange the equation to obtain:

$$\begin{aligned}\text{Suspended Solids in Aerator, lbs} &= \text{Sludge Age, days} \times \text{Susp. Sol. in Prim. Effl., lbs/day}\\ &= 5 \text{ days} \times 2400 \text{ lbs/day}\\ &= 12{,}000 \text{ lbs}\end{aligned}$$



Suspended solids in the mixed liquor in the aerator should be allowed to build up until 12,000 pounds of solids are in the aerator. Sludge wasting may be started when the desired level is exceeded.

To determine when an excess of activated sludge is in the aerator and some should be wasted, many operators calculate the desired mixed liquor suspended solids concentration in the aerator. When this concentration is exceeded, some of the excess activated sludge is wasted.

Calculation of the desired mixed liquor suspended solids concentration in mg/l can be determined from either of the two formulas listed below (they are the same).

$$\text{Desired Mixed Liquor Suspended Solids, mg/l} = \frac{\text{Desired Susp. Sol. in Aerator, lbs}}{\text{Weight of Water in Aerator, million lbs}}$$

$$\text{or} = \frac{\text{Desired Susp. Sol. in Aerator, lbs}}{\text{Vol. of Aerator, M gal x 8.34 lbs/gal}}$$

$$= \frac{12{,}000 \text{ lbs}}{4.6 \text{ M lbs}} \text{ (factor from Section 7.44, Page 7-54)}$$

$$= 2608 \text{ mg/l}$$

$$= 2600 \text{ mg/l (target concentration)}$$

Wasting of activated sludge from the example plant should not start until the mixed liquor suspended solids concentration exceeds 2600 mg/l.

7.52 Wasting Activated Sludge

The amount of activated sludge wasted may vary from 1% to 20% of the total incoming flow. Normally waste activated sludge is expressed in gallons per day or pounds of solids removed from the aeration system. It is preferred that wasting be continuous. The main purpose is to maintain a sludge age that produces the best effluent.

Wasting (Fig. 7.7) is normally accomplished by diverting a portion of the return sludge to a primary clarifier, thickener, aerobic digester, or anaerobic digester. Normal operations in a conventional activated sludge plant will concentrate return sludge and waste sludge solids three to four times as much as the solids concentration of the mixed liquor. This may provide return sludge with a concentration of 2,000 to 10,000 mg/l, or 0.2 to 1.0% in terms of total solids. If the waste sludge line was discharged directly to the anaerobic digestion system, it would contain 10 to 20 times as much water as should be entering the anaerobic system with that amount of solids. Operating an anaerobic digester would be difficult under this condition. It would be wiser to waste to the primary clarifiers where combining with primary sludge minimizes the addition of excess water to the digester.

Wasting activated sludge will occur in the effluent whether or not it is controlled. In all activated sludge plants, wasting must be controlled by the operator. Mixed liquor suspended solids which need to be wasted accumulate from two sources. The first is the suspended solids in the plant flow from the primary clarifiers or raw wastewater. The second and main source is the new cell production by the microorganisms.

For every pound of BOD or solids removed in the activated sludge system, a part of that pound will remain in the system as microorganisms. The rate of production of excess sludge will depend on the type of process being operated and the nature of the waste load. The high-rate activated sludge plant is capable of producing 0.75 pounds of sludge volatile matter for every pound of BOD removed. The conventional plant runs around 0.55 pounds of excess sludge per pound of BOD removed in the activated sludge system. The extended aeration plant drops down to about 0.15 pounds of excess sludge per pound of BOD removed. Excessive silt or inert material may increase sludge production beyond that indicated by the BOD test.

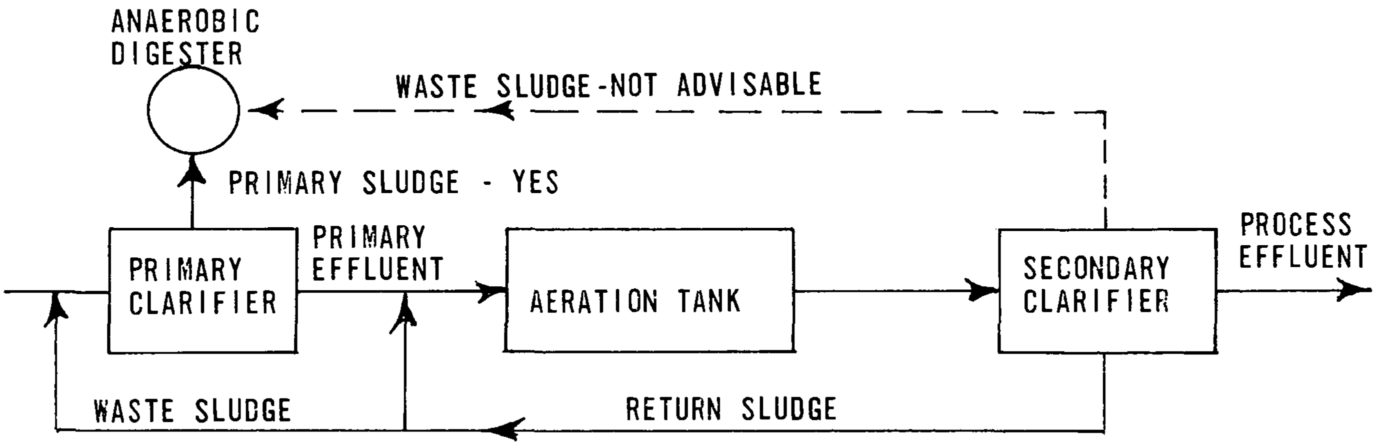


Fig. 7.7 Waste sludge flow diagram

7.53 Determination of Waste Sludge Pumping Rate

To illustrate the determination of a waste sludge pumping rate, assume the following plant data:

1. Mixed Liquor Suspended Solids = 2985 mg/l

2. Return Sludge, Suspended Solids = 6200 mg/l

3. Primary Effluent, Suspended Solids = 72 mg/l

4. Average Daily Flow = 4.0 MGD

Using the procedures outlined in this lesson, the following information can be calculated:

1. Solids in Aeration Tank = 13,731 pounds

2. Solids Added by Primary Effluent = 2400 lbs/day

3. Sludge Age = 5.7 days

The results of the calculations indicate that the sludge age is too high (5.7 days instead of 5 days) and the solids in the aeration tank also are too high (13,731 pounds instead of 12,000 pounds). To reduce the sludge age and solids in the aerator, some of the activated sludge removed by the secondary clarifier should be pumped to the inlet of the primary clarifier.

The formula to calculate the waste return sludge pumping rate is:

Waste Return Sludge Pumping Rate, MGD

$$= \frac{\text{Solids to be Wasted, lbs/day}}{\text{Return Sludge Conc., mg/l} \times 8.34 \text{ lbs/gal}}$$

$$= \frac{(13{,}700 \text{ lbs} - 12{,}000 \text{ lbs})/\text{day}^{*}}{6200 \text{ mg/l} \times 8.34 \text{ lbs/gal}}$$

$$= \frac{1700 \text{ lbs/day}}{6200 \text{ mg/l} \times 8.34 \text{ lbs/gal}} = \frac{1{,}700}{51{,}700} = 0.032 \text{ MGD}$$

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* Biological cultures should be subject to slow changes rather than rapid ones; therefore, the pounds wasted will be removed during a 24-hour period.

Usually the waste sludge pumping rate is expressed in gallons per minute instead of MGD.

$$\text{Pump Waste Rate, GPM} = \frac{\text{Pumping Rate, gals/day}}{1440 \text{ min/day}}$$

$$= \frac{32{,}000 \text{ gals/day}}{1440 \text{ min/day}}$$

$$= 22.2 \text{ GPM}$$

Set the waste pumping rate at 20 GPM for the next 24-hour period. It is better to waste a little less activated sludge than the theoretical calculation.

7.54 Summary

After a plant is started, the sampling and laboratory testing program must be continued to identify and correct operational problems whenever they start to develop. See Lesson 7 for possible approaches to solving operational problems.

QUESTIONS

7.5A Why must some activated sludge be wasted?

7.5B Where is the best place for excess activated sludge to be wasted?

7.5C Calculate the sludge age for an activated sludge process if the aerator volume is 0.5 MG and the mixed liquor suspended solids concentration is 2100 mg/l. The influent flow is 4.0 MGD, and the primary effluent suspended solids concentration is 70 mg/l.

END OF LESSON 5 OF 8 LESSONS

on

ACTIVATED SLUDGE

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. Activated Sludge

(Lesson 5 of 8 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 4.

22. Estimate the pounds of solids under aeration in a 200,000-gallon tank when the suspended solids concentration is 1600 mg/l. Show your work.

23. What level of dissolved oxygen should be maintained in the aeration tank during start-up?

24. What do the letters MLSS stand for?

25. Calculate the desired pounds of mixed liquor suspended solids in an aeration tank if the primary effluent suspended solids are 1800 pounds per day and the loading is based on a five-day sludge age. Show your work.

26. Calculate the desired mixed liquor suspended solids concentration (mg/l) if 4000 lbs are desired in a 200,000-gallon aeration tank. Show your work.

27. If sludge should be wasted at a rate of 0.05 MGD, what should be the waste pumping rate in GPM?

28. Why must some activated sludge be wasted?

CHAPTER 7. ACTIVATED SLUDGE

(Lesson 6 of 8 Lessons)

7.6 PACKAGE PLANTS (Extended Aeration)

7.60 Introduction

You may be assigned to operate a small extended aeration plant (Fig. 7.8). You may not have laboratory facilities and may not be supplied materials for simple tests, such as dissolved oxygen (DO), pH, or settleable solids. Fortunately, this type of plant is usually under a light load and/or sized for a long retention of the solids (extended aeration), and the sludge age may be greater than ten days. The operation of these plants is the same as the operation of any other activated sludge plant. A high quality effluent requires attention, understanding, and good plant operation.

This type of plant comes in many sizes, but basically there are just two compartments or tanks made from one large tank. The larger compartment is used for aeration, and the smaller one for clarification and settling. Usually provisions are not made for a primary settling compartment. The plant may be mechanically aerated or a small air compressor may provide air through diffusers. The settling tank is usually a double hopper tank equipped with a pump or air lift system for the return of sludge from the hoppers of the settling tank back to the aeration tank.

7.61 Pre-Start Check-Out

If the plant is being installed, an excavation is dug to accommodate the plant which is usually transported by truck to the site and placed in the excavation by a crane. The inlet sewer and discharge lines are connected and the plant is ready for service after power has been connected.

While the tank is empty, check the following:

1. Tank must be level from one end to the other.
2. If the tank is constructed of metal, is cathodic protection[17] required?

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[17] Cathodic Protection (ca-THOD-ick). An electrical system for prevention of rust, corrosion, and pitting of steel and iron surfaces in contact with water or wastewater.

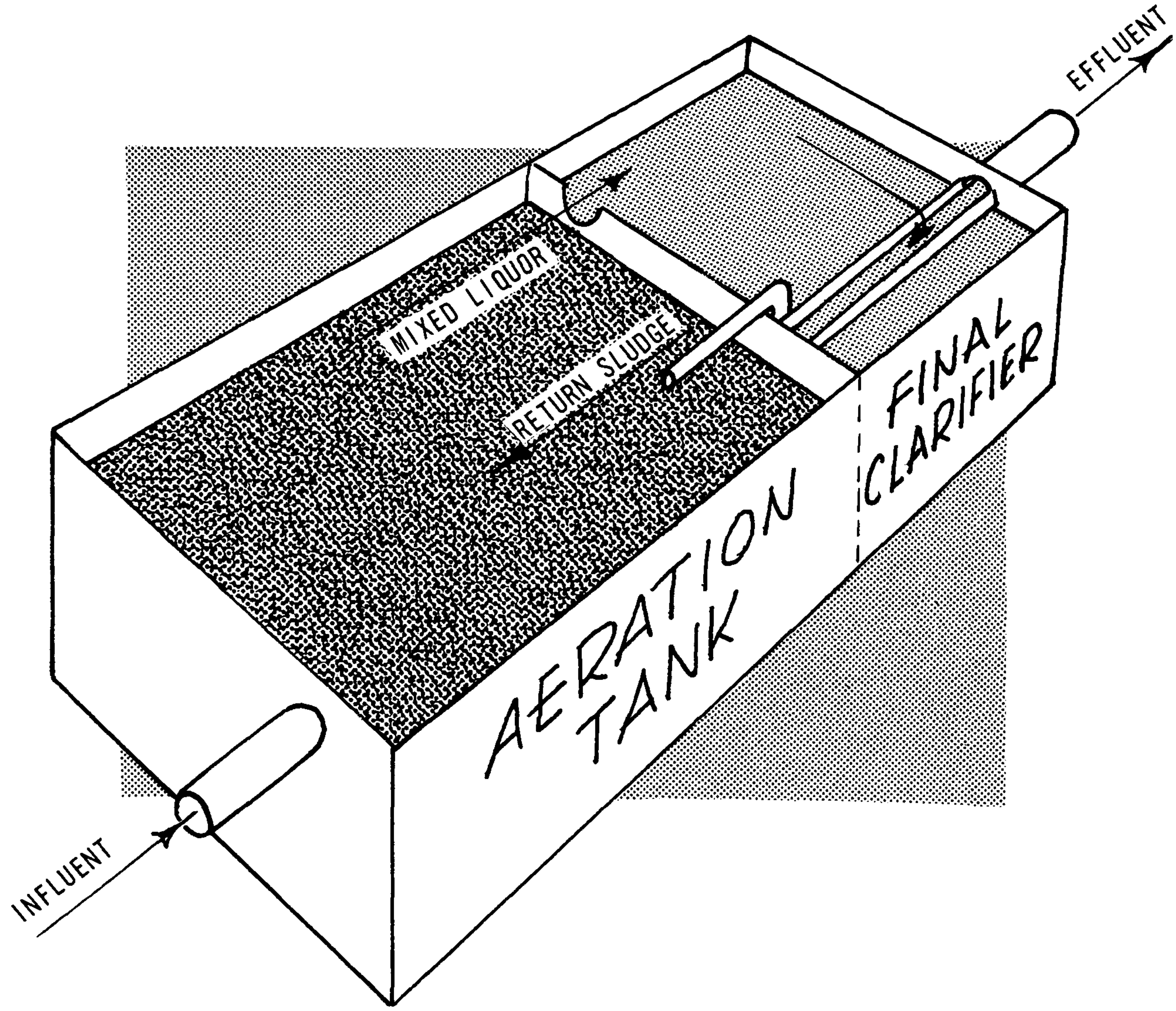


Fig. 7.8 Package plant

3. Condition of paint on exterior and interior.

4. Removal of all rocks and debris from both compartments.

5. If equipped with comminutor or grinder, check lubrication, clearance of cutters, and operation.

6. Check aeration device:

   a. Lubrication

   b. Direction of rotation

   c. Mechanical aeration--proper agitator depth

   d. Compressor, if diffused air

      (1) Air filter and oil bath
      (2) Air header and valves
      (3) Air lift tubes and valves
      (4) Diffusers installed
      (5) Swing header lifts easily and free

7. Record and file the following data:

   a. Plant model and serial number

   b. Two copies of plant manual

   c. Name plate data from equipment

      (1) Comminutor
      (2) Comminutor motor
      (3) Aeration motor
      (4) Compressor or agitator
      (5) Amperage of running equipment
      (6) Oils and greases specified for each unit

8. Check influent gate or valve for proper operation.

7.62 Starting the Plant

(See Section 7.4 for detailed instructions.) Once the flow is admitted to the aeration compartment and it is filled, the aerator compressor or agitator may be started. If the plant is the diffused air type and equipped with air lifts for return sludge, the air line valve to the air lifts will have to be closed until the settling compartment is filled or all the air will attempt to go to the empty compartment. Once the settling compartment is filled from the overflow from the aeration tank, the air lift valves may be opened and adjusted to return a constant stream of water and solids to the aeration tank. This adjustment is usually two to three turns open on the air valve to each air lift.

There may be a build-up of foam during the first week or so of start-up, and a one-inch water hose with a lawn sprinkler may be used to keep it under control until sufficient mixed liquor solids are obtained.

7.63 Operation of Aeration Equipment

Aeration equipment should be operated continuously. If a diffused air system is employed, the operator controls air flow to the diffuser by the header control valve which forces excess air to the air lifts in the settling compartment. Good treatment rarely results from interrupted operation and should not be attempted. Performance of the aeration equipment usually can be determined by the appearance of the water in the settling compartment and the effluent that goes over the weir.

If the water is murky or cloudy and the aeration compartment has a rotten egg odor (H_2S), insufficient air is supplied and the air supplied or aeration rate should be increased. If the water is clear in the settling compartment, the aeration rate is probably sufficient.

7.64 Wasting Sludge

Supposedly there is no control over the wasting of sludge in these plants because the excess sludge is carried out of the system with the effluent. In many localities the water quality standards are too strict to allow this practice. The operator then must waste a portion of the plant solids content out of the system periodically. For best results, in terms of effluent quality, waste about 5 percent of the solids each week during summer operation to prevent excessive solids "burping".

To waste the excess activated sludge, turn off the return pumps or air lifts for one hour and continue to let the rest of the plant function. After one hour of not returning sludge, about five percent of the waste solids in the settling compartment are pumped out with a portable pump to a sand or soil drying bed. The amount of solids pumped is determined by measuring the depth of the sludge blanket and then lowering it five percent. Record the pumping time and weekly waste solids for this time period if results are satisfactory.

Annually, check the bottom of the hoppers for rocks, sticks, and grit deposits. Also check the tail pieces of the air lifts to be sure that they are clear of rags and rubber goods and in proper working condition.

Frequency and amount of wasting may be revised after several months of operation by examining:

1. The amount of carryover of solids in the effluent.

2. The depth to which the solids settle in the settling compartment when the aeration device is off (should be greater than one-third of the distance from top to bottom).

3. The appearance of floc and foam in the aeration compartment as to color, settleability, foam make-up, and excess solids on water surface of the tank.

4. Results of laboratory testing (Section 7.66, Page 7-74)

A white, fluffy foam indicates low solids content in the aerator, while a brown, leathery foam suggests high solids concentrations. If excessive effluent solids are noticed periodically during typical daily flows, the solids loading may be too great for the aerator. Excessive solids indicate the sludge age is too long and more solids should be wasted.

7.65 Operation

Preferably this type of plant should be checked every day. Each visit should include the following:

1. Check appearance of aeration and final clarification compartment.

2. Check aeration unit for proper operation and lubrication.

3. Check return sludge line for proper operation. If the air lift is not flowing properly, briefly close the outlet valve which forces the air to go down and out the tail piece. This will blow it out and clear any obstructions. Reopen the discharge valve and adjust to desired return sludge flow.

4. Check comminuting device for lubrication and operation.

5. Hose down aeration tank and final compartment.

6. Brush weirs when necessary.

7. Skim off grease and other floating material such as plastic and rubber goods.

8. Check plant discharge for proper appearances, grease, or material of wastewater origin that is not desirable.

7.66 Laboratory Testing

Testing for solids condition may be accomplished by the settling test. Using a quart jar, take a sample from the aeration compartment after the aeration device has been operating for several minutes (10 - 15) and fill the jar to the top. Let the jar stand and watch the floc form and settle to the bottom of the jar. At the end of 30 minutes, the jar should be approximately half full of the settled solids, or slightly less, and have a chocolate brown color with clear water above it. The solids should appear granular. If the solids do not settle half way and the water above them is cloudy or murky in appearance, a longer aeration period, more air, or solids wasting is needed. If the solids settle to less than 1/4 of the jar and the water above the solids is murky or cloudy, no wasting of solids should be done and the solids level in the aerator should be allowed to increase.

If the solids settle to the bottom of the jar with a clear liquor on top and stay down one hour and come up in two hours, this is an indication of good operation. Solids should never be allowed to remain in the settling compartment longer than two hours. If the solids should rise in one hour, this is an indication usually of too much air, or too many solids. Make slight adjustment to reduce the air to the aeration compartment or increase the return sludge rate.

The final clarifier should be equipped with a scum baffle. A properly operated plant will produce some light, oxidized floc that will float to the surface of the settling compartment. A scum baffle will prevent this flow from leaving the compartment in the plant effluent. The better the treatment, the more likely scum will develop, unless the unit is septic.

If equipment is available for other testing, DO, pH, and suspended solids tests should be run on the unit occasionally. See Chapter 14, Laboratory Procedures and Chemistry, for procedure details.

QUESTIONS

7.6A How frequently should a package plant be visited?

7.6B When should sludge be wasted?

7.6C What should you do if you take a sample in a jar from the aeration compartment and after 30 minutes

a. solids do not settle to the bottom half of the jar?

b. solids settle to the bottom and then float to the top?

END OF LESSON 6 OF 8 LESSONS

on

ACTIVATED SLUDGE

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. Activated Sludge

(Lesson 6 of 8 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 5.

29. How would you control foaming on the aeration compartment of a package plant?

30. How would you operate the aeration device in a package plant?

31. How would you waste sludge in a package plant?

7.7 OPERATIONAL PROBLEMS

7.70 Typical Problems

An activated sludge plant can accept quite a shock load now and then without adverse effects to the system, but it cannot survive a continuous series of shock loads.

Many factors may change that the operator cannot anticipate or control but must compensate for by adjusting his operational controls. For example, a conventional activated sludge plant has operated satisfactorily for several weeks. The secondary clarifier had good clarity of 68 inches with a Secchi disc, and the effluent BOD and suspended solids were running from 5 to 18 mg/l. The aeration tanks had been maintained at 15,000 pounds of mixed liquor suspended solids with a volatile content of 78.5%, and sludge age of five days.

A minimum DO of 2.8 mg/l had been measured in the last two-thirds of the aerator. Sludge wasting had been at a rate of 2000 lbs/day from the system.

This week the situation has changed; the clarity in the secondary tanks has dropped to 18 inches. The suspended solids in the secondary clarifier effluent have remained about the same, but the BOD test started five days ago came out at 38 mg/l. If a COD test had been run at the time the BOD was started, an operational correction could have been made at that time.

Overall, the plant effluent has definitely deteriorated from the previous week.

Only you and your records can determine the cause and what corrective action should be taken.

Has plant flow increased or decreased? Have air rates been maintained? Have you received some toxic or untreatable slug dose in the influent? Are your sludge return pump and lines clear? Has the BOD load to the aeration tank changed? Have mixed liquor solids been the same? These are just a few of the conditions that may change effluent quality.

The difficult decision after determining the cause or probable cause is--should a change be made?

This is where the operator who knows his plant is effective. If he knows the situation is unusual and will only last a couple of days, appropriate minor changes should be contemplated to immediately improve the effluent quality. But if the condition occurred before and lasted several weeks according to past records, a process change may be necessary to compensate for it. This is where experience with your plant and records plays an important role in activated sludge operation.

By keeping accurate records you can find the desirable operating range in terms of efficiency of waste removal and cost of operation. Usually each plant will have some mixed liquor suspended solids concentration where the plant will function best. This concentration should produce a clear final effluent, with low suspended solids and BOD of 8 to 20 mg/l. However, depending on plant design, type of waste, and season of year, the best mixed liquor suspended solids concentration might be found to be anywhere from 1000 to 4000 mg/l. When a satisfactory mixed liquor suspended solids concentration is found for a specific plant under certain conditions, the operator should attempt to maintain this level until something changes.

If the mixed liquor suspended solids are allowed to start building up, the final effluent will begin to deteriorate by becoming turbid. When the mixed liquor suspended solids are allowed to increase too high for the conventional activated sludge plant, other problems can develop. The previous return sludge rate for the plant flow would not be sufficient. Return rates may have to be increased considerably. If the return sludge rate was not increased, the activated sludge in the final clarifiers would build a higher blanket. The deep blanket in the final tank could cause solids to be swept over the weirs during peak flow.

Another limiting factor is aeration equipment. The amount of oxygen supplied to the aerator also limits the microorganism mass that can be maintained in an aerobic state. A high oxygen demand in the aerator can be created by a high solids content in the plant influent.

The other factor is the organisms themselves. If insufficient food is available, only a limited number of organisms will develop energy to multiply. This is where the struggle for survival begins. When food supply is low, the microorganisms begin to feed upon themselves. This is the period of most complete oxidation, and new sludge production is at a minimum. Extended aeration plants are designed to operate under these conditions which tend to increase solids in the plant effluent.

QUESTIONS

7.7A Why are plant records of the activated sludge operation important?

7.7B What could happen if the mixed liquor suspended solids were allowed to increase beyond the best range in an activated sludge process?

7.71 Plant Changes

If the plant becomes upset, the first action before making any changes is to check the plant data for at least three previous weeks. The problem probably started last week or earlier. To look for the cause of the problem, ask yourself the following questions:

1. Have any changes been made to other plant units such as the digesters or primary clarifiers? Was a digester supernatant with excessive amounts of solids returned to the primary clarifiers? Return of supernatant should be slow and easy and at low load periods. Digester supernatant solids mixed with raw wastewater and waste activated sludge may create a light sludge that may be washed out of the primary clarifier. The solids washed out of the primary clarifier create undesirable recycle and loading problems.

2. Have plant daily flows and waste concentrations increased or decreased? Heavy rains following a dry spell, a new industrial plant, or a different process discharge from an existing industry can cause problems.

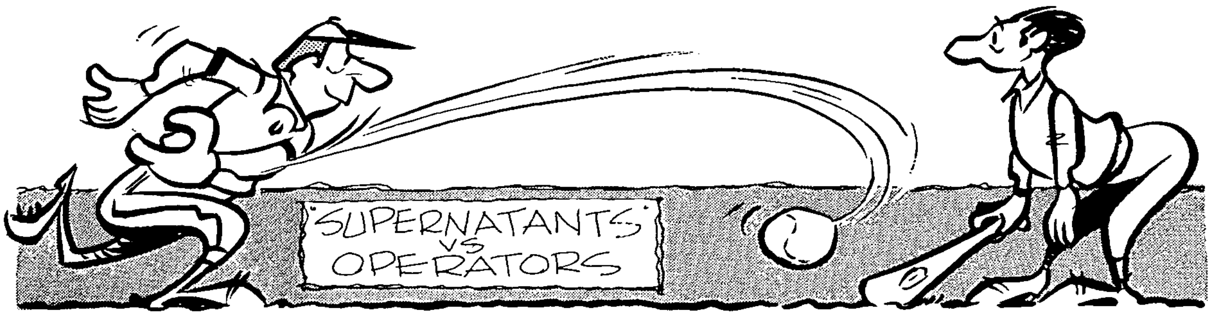
3. Has temperature of the influent changed a significant amount?

4. Has the sampling program been consistent?

Most of the time a plant upset can be found due to some in-plant problem and not the influent raw wastewater, unless your plant is frequently overloaded.

Condition 1:

A high solids content in digester supernatant can throw a curve to the operator. The solids in digester supernatants are



usually high in immediate oxygen demand and contain high colloidal and dissolved solids. If a large quantity of low volatile content solids escapes from the primary clarifier to the aeration system, several undesirable events occur. The supernatant solids are picked up by the activated sludge in the aerator and carried through the system. This creates extra oxygen demand, and air output must be increased. Digester solids make a good settling activated sludge, but the color of the floc will be darker. Total pounds of solids in the aerator will increase due to the supernatant solids, and the operator will normally increase waste sludge rates to hold the established range of solids or sludge age. Consequently, the effluent from the plant deteriorates. Why? Lab tests show that the solids in the aerator are at the desired level, and DO of the mixed liquor has been held at 2.0 mg/l (probably more air was required).

What has occurred is that by wasting apparently excess activated sludge, many of the microorganisms have been replaced in the aerator by digested or inert solids. They are sampled the same as mixed liquor suspended solids and are included as total pounds of solids under aeration. This is why many plants base aerator loadings on mixed liquor VOLATILE suspended solids and not mixed liquor suspended solids. They are making the assumption that the volatile content of the mixed liquor suspended solids is microorganisms.

Most activated sludge mixed liquor suspended solids fall into a range of 70 to 80% volatile content for municipal waste when the process is operating properly. This would mean that if you are striving to maintain a sludge age of five days, you are attempting to maintain a prescribed number of organisms for every pound of food applied to the aeration tanks. A five-day sludge age is equivalent to 20 pounds of food for every 100 pounds of organisms. When the supernatant was admitted into the aeration tank, the pounds of solids in the aerator were increased. When sludge was wasted to maintain the five-day sludge age, many of the organisms needed to treat the incoming wastes were replaced by the inert supernatant solids. This placed a higher food load on the remaining organisms of maybe 30 to 35 pounds per 100 pounds of organisms and reduced the effective sludge age from five days to possibly 3.5 days.

Storm wash may sweep excessive silt into the plant by infiltration into sewers or through combined sewer systems. Solids increase drastically but the percent of volatile solids may drop to 50% of the total solids. Wasting apparently excess solids on a suspended solids basis without consideration of the pounds of volatile solids in the aerator may produce serious organism losses.

In the example plant, the supernatant solids may not appear to produce much of a change, but over a period of several days the system could become severely upset. When the total pounds of volatile solids in the aerator becomes too low due to excessive amounts of inert solids from digester supernatant or storm inflow, the solution to the problem is to stop wasting sludge for several days. This will provide the time necessary to rebuild the microorganism population to handle the incoming waste load.

Try to hold the solids in the digester a little longer and try to increase solids concentration in the sludge fed to the digester. It is possible that the poor supernatant was due to overloading the digester and/or insufficient seed sludge in the digester. In this case the problem "snowballs"--first the digester is overloaded, then supernatant solids overload the aerator which overloads the clarifier, and the problem keeps getting worse.

Condition 2: (Flow or Waste Changes)

Always be alert for the possibility of toxic dumps, accidental spills (particularly the midnight variety), storms, or other up-sewer factors that may change the influent flow or waste characteristics.

A frequent problem is the increased flows from storm infiltration or other sources. These flows may create shorter aeration times or loss of activated sludge solids from the final clarifiers due to a hydraulic overload. To compensate for this condition, regulate return and waste sludge rates to hold as much of the solids as possible in the aerator.

Changes in waste characteristics may be caused by isolated dumps or spills, or changes may be seasonal. Become acquainted with plant managers whose activities may cause changes in the waste loadings on your plant and encourage these people to notify you whenever a problem discharge occurs. Try to convince them to release unusual dumps at a low discharge rate rather than all at once. Certain industries such as canneries create seasonal problems which the operator should prepare for in advance.

Condition 3: (Temperature Changes)

The activated sludge system is influenced by temperature changes similar to the response of trickling filters to temperature changes in spring and fall. During the summer, the activated sludge plant may operate satisfactorily in a certain loading range and air rates, but in winter the best loading ranges and air rates change and the plant requires less air and more solids under aeration. Usually a temperature change is not significant unless it raises or lowers the temperature more than 10°F.

Temperature is an important factor in oxidation relative to sludge accumulation. A high temperature produces a rapid microorganism growth and waste oxidation. Low temperatures cause a slower growth rate and more waste storage in the organism cell with less oxidation. Therefore, a larger net sludge production will result with lower biological activity, and the process will have a tendency to produce a thinner sludge.

Condition 4: (Changes in Sampling Program)

Data on system performance can be greatly affected by changes in a sampling program. If improper sampling locations or laboratory procedures are used, lab results could vary considerably. When the lab data varies widely from one day to the next, check sampling location, time, and lab procedures for errors.

When a major change is contemplated, first review the plant data. Next, make only one major change at a time. If two changes are made, you won't know whether one or both changes provided the corrective action. When a change is made, give the system at least one week before attempting another change or modification. Don't make too many changes too fast.

QUESTIONS

7.7C How would you determine the best solids loading for an aerator?

7.7D What would you do if an activated sludge plant became upset?

7.7E (a) What can happen if a digester supernatant with a high solids content is returned to the primary clarifier?

(b) How can this situation be remedied?

7.7F How would you correct or compensate for an upset created by high flows from storm water infiltration?

7.7G How would you correct an upset apparently caused by a temperature difference due to seasonal changes?

7.7H What would you do if a review of the lab data revealed considerable variation from day to day?

7.7I How long would you allow an activated sludge process to react and stabilize after a change?

7.72 Sludge Bulking

Bulking is the term applied to the condition in which the mixed liquor solids tend to show a very slow settling rate and compact to a limited extent. The liquid that does separate from the solids usually produces a crystal clear, high-quality effluent, but generally there is not enough time for complete removal of the solids in the secondary clarifier. The sludge blanket in the clarifier becomes deeper and rises to overflow the weirs and is discharged with the effluent.

Bulking may be associated with production of a highly jelly-like, water-logged (hydrated) sludge that has a very low sludge density, or by filamentous growth that may grow from one floc mass to another and act as stay rods to prevent compaction of the sludge particles and produce poor settling results.

Low pH, low DO, and low nitrogen concentrations have been related to bulking. High food-to-organism loading rates (low sludge ages) are the major items that will produce bulking consistently. Organisms that grow rapidly tend to become spread out and will not clump or form a floc mass until growth rates decrease. It is difficult to retain enough low-density (light) sludge to decrease the food-to-organism load ratio (or increase sludge age) without chemical flocculation or other tricks to increase the sludge density (weight). A rain may provide enough silt to favor increased sludge density. Low loads during weekends may help. Addition of some preaerated digested sludge (Kraus process, Section 7.92) helps reduce bulking. Some of the polyelectrolyte flocculent aids are very effective in controlling a bulking activated sludge. If it is possible, bulking may be reduced by decreasing the load to the aeration tanks until the sludge becomes sufficiently oxidized to flocculate. Addition of clay or bentonite has been used to control bulking.

The main objective of most bulking control procedures is to increase sludge age or decrease the ratio of waste (food) load added per day per unit of mixed liquor volatile solids in the aerator. Aluminum sulphate ($Al_2(SO_4)_3 \cdot 14\ H_2O$), iron as ferric chloride ($FeCl_3$), or ferric sulphate ($Fe_2(SO_4)_3 \cdot 3\ H_2O$) added as a flocculent with alkaline (lime) addition to prevent low pH are good methods for holding solids under aeration. The proper polyelectrolyte may cost more than other chemicals, but alkali addition may not be required to increase the pH.

Chlorination is not an effective cure because chlorine inactivates the organisms that are needed to treat the wastes. Effluent turbidity may increase for several days after an application of chlorine, and bulking is likely to return if the solids retention problem is not corrected.

When bulking occurs it will generally be associated with the load ratio or sludge age. Plant records should be reviewed in an attempt to locate the cause of the problem. Identification of the cause will not remedy the present bulking condition, but should be considered a valuable lesson, and measures should be taken to prevent the same conditions from occurring again.

To prevent sludge bulking from occurring, the following items should be carefully controlled in an activated sludge plant:

1. Suitable Sludge Age. Carefully review plant records and maintain a sludge age that produces the best quality effluent. Watch influent solids loadings, maintain desired level of solids in the aerator, and carefully regulate waste sludge rates. Generally, bulking may be cured by increasing the sludge age.

2. Low DO. Prevent low levels of DO from developing. Mixed liquor DO determinations are a quick, simple test; and if a DO probe is used, it gives a continuous reading. There is no valid excuse for low DO concentrations during normal conditions if sufficient oxygenation capacity is available, unless a slug of waste with an excessive oxygen demand is received.

3. Short Aeration Period. Bulking caused by the aeration period being too short is usually the result of a design problem, unless the operator has formed the habit of returning too high a volume of return sludge. This can be corrected by reducing the return sludge rate and thickening the return sludge solids concentration by coagulation (ko-AGG-u-LAY-shun), if necessary, thereby still returning the same number of organisms to meet the new food (waste) entering the aerator, but effectively reducing the total flow through the aerator and clarifier.

4. Filamentous Growth. Occurrence of filamentous growth may be caused by incorrect sludge age or nutritional differences, such as a shortage or abundance of nitrogen,

phosphorus, or carbon. If filamentous growths are allowed to become well established, they create a difficult problem to overcome. Control may be achieved by maintaining a higher sludge age, and in special instances supplementing the nutrient deficiency.

7.73 Septic Sludge

Septic sludge may be produced when any type of sludge remains too long in such places as hoppers and channels. It is likely to cause a foul odor, rises slowly, and sometimes rises in clumps. Even small amounts can upset an aerator.

Septic sludge may occur in poorly designed or constructed hoppers, wet wells, channels, or pipe systems. This occurs when activated sludge is allowed to be deposited and anaerobic decomposition starts. Septic sludge deposits also may develop on the floor of the aerator due to insufficient air rates that are not keeping the tank completely mixed. A high solids load also can cause septic problems.

To effectively control septic sludge, aerators must be thoroughly mixed and sludge must be pumped frequently. In channels and pipelines, a velocity over 1.5 feet per second will prevent the formation of sludge deposits that could become septic.

Sludge going septic in the secondary clarifier may develop from four causes:

1. Return sludge rate too low, thus holding the solids in the final clarifier too long and allowing them to become septic.

2. Clarifier collection mechanism turned off, thus the sludge is not being moved to the draw-off hopper.

3. Sludge draw-off lines plugged, obstructed, or used infrequently.

4. Return sludge pump off or a valve closed.

A good operator checks his system several times a day. In most new activated sludge plants the secondary clarifiers have air lift samplers or photocells to indicate sludge blanket level in the tank. Whenever the final clarifier sludge blanket level changes, an immediate investigation should be undertaken. In any of the cases above, the correction is quite obvious--restore suitable return sludge flow as soon as possible.

7.74 Toxic Substances

Toxicity causes inhibition or death of working organisms to produce system and effluent upsets. The operator has limited control over the cause. When this cause is identified, sludge wasting should be stopped immediately and all available solids returned to the aerator. Toxic materials such as heavy metals, acids, insecticides, and pesticides should never be dumped into a sewer system without proper control.

7.75 Rising Sludge

Rising sludge is not to be confused with bulking. The sludge settles and compacts satisfactorily on the bottom of the clarifier, but after settling it rises to the top of the secondary tank in patches or small particles the size of a pea. This is usually accompanied by a fine scum or froth (brown in color) on the surface of the aeration and secondary tanks.

Rising sludge is caused by denitrification or septicity and results from too long a detention time in the secondary clarifiers. The secondary clarifiers should be equipped with scum baffles and skimmers to prevent these solids from escaping in the plant effluent.

Denitrification is most common when the sludge age is high (extended aeration). When this type of activated sludge flows from the aerator to the secondary clarifier or becomes short of oxygen, the organisms first use the available dissolved oxygen and the oxygen in the nitrates resulting in the release of nitrogen gas. Denitrification is an indication of good treatment, providing the sludge in the settleability test stays on the bottom of the cylinder for at least one hour, but floats to the surface in two hours. If it floats up too early in the settleability test, the sludge age should be reduced or the food-to-organism ratio should be increased. If the sludge stays down for an hour in the settleability test but problems are still present in the secondary clarifier, increase the return sludge rates to move the solids out of the clarifier at a faster rate.

7.76 Frothing

Aerator frothing has been a problem for some plants. There have been many theories presented on the cause, such as surfactants (detergents), polysaccharides, and over-aeration. Whatever the cause, there is a definite relationship between froth build-up on the aerator and the amount of suspended solids in the mixed liquor and air supply to the aerator.

For control:

1. Maintain higher mixed liquor suspended solids concentrations.

2. Reduce air supply during periods of low flow while still maintaining DO.

3. Return supernatant to the aeration tank during low flows (be cautious in this method--supernatant should be returned slowly and steadily because too much supernatant could cause an excess oxygen demand).

Most plants are equipped with water sprays along the aerator to dissipate the foam. If mixed liquor solids are allowed to be reduced, low water sprays will not be sufficient to hold the foam. When this occurs, two problems develop--maintenance and safety.

> SAFETY FIRST--The froth from an aerator is an excellent vehicle for minute grease particles and when deposited on "Y" walls or walks will leave a grease deposit that is very slippery. More than one operator has been injured by slipping on a walk or step previously coated with foam.

This deposit not only is unsafe, but unsightly, and it must be cleaned up immediately. The best way to remove this type of deposit is with water (preferably hot), trisodium phosphate (TSP), and a stiff bristle deck brush. Wet the area to be cleaned, lightly sprinkle TSP granules on the area, let the TSP dissolve for a few minutes, and then brush the area to spread the TSP and loosen the grease. Let it work for five minutes, rebrush, and then hose off.

QUESTIONS

7.7J How can froth or foam be controlled in an aerator?

7.7K How can grease deposits (from foam) on walks be removed?

7.7L How would you differentiate between bulking and rising sludge?

7.7M What would you do to correct a rising sludge problem?

END OF LESSON 7 OF 8 LESSONS

on

ACTIVATED SLUDGE

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. Activated Sludge

(Lesson 7 of 8 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 6.

32. When an activated sludge plant becomes upset, what should the operator do first?

33. Why do many activated sludge plants base aerator loadings on mixed liquor volatile suspended solids and not mixed liquor suspended solids?

34. When attempting to correct an upset activated sludge process, why should only one major change be made at a time?

35. Is sludge bulking undesirable? Why?

36. What is the purpose of the 60-minute Settleability Test?

37. Can a frothing aerator deposit grease on walks?

7.8 AERATOR LOADING PARAMETERS

7.80 General

Sludge age has been suggested as the method for controlling the solids in the activated sludge process. Other operational controls used successfully by operators include the waste load (food)/sludge volatile solids (organisms) ratio and the mean cell residence time (MCRT). Mathematically, one can show that aerator loadings based on sludge age, food/organism ratio, and MCRT are theoretically similar. In each case the operator selects a number or value for the parameter to start with on the basis of experience and data available from other plants. He then adjusts this value until he finds an operating range which produces the best quality effluent for his plant.

In each case, the critical factor is the food/organism relationship which cannot be precisely estimated for any specific plant. The operator attempts to maintain in the aerator tank sufficient solids (organisms) to use up the incoming waste (food). He doesn't want too many organisms nor too few organisms in the aeration tank in relation to the incoming food. Operation of the activated sludge process requires removing the organisms (settled activated sludge) from the secondary clarifier as quickly as possible. The organisms are either returned to the aerator to use the incoming food, or they are wasted. Therefore, a critical decision is to determine the amount of solids to be wasted. This procedure has been discussed and an example provided in Section 7.52 for the sludge age aerator loading parameter. Select a method to operate your plant and stick with it. Don't continually try to switch from one method to another.

7.81 Food/Organism Ratio

The food-to-organism loading ratio is based upon the food provided each day to the microorganism mass in the aerator. Food (waste) provided is preferably measured by the COD of the influent to the aerator. COD is recommended because test results are available within four hours and process changes can be made before the process becomes upset. Many operators load aerators on the basis of the BOD test, but results five days later are too late for operational control. The ratio of food load provided each day to the volatile solids in the aerator is the reciprocal of the sludge age (see Table 7-1, Section 7.25). Typical loading parameters have been established for the three operational zones of activated sludge and are summarized as follows:

1. High-Rate

   COD: 1 lb COD per day/1 lb of MLVSS[18] under aeration.

   BOD: >0.5* lb BOD per day/1 lb of MLVSS under aeration.

2. Conventional

   COD: 0.5 to 1.0 lb COD per day/1 lb of MLVSS under aeration.

   BOD: 0.25 to 0.5 lb BOD per day/1 lb of MLVSS under aeration.

3. Extended Aeration

   COD: <0.2* lb COD per day/1 lb MLVSS under aeration.

   BOD: 0.05 to 0.10 lb BOD per day/1 lb MLVSS under aeration.

* > means greater than. Greater than 0.5 lb BOD.
< means less than. Less than 0.2 lb COD.

7.82 Calculation of Food/Organism Aerator Loading

Determine the amount of mixed liquor volatile suspended solids to be maintained in the aerator of the conventional plant studied in this chapter. Assume a food/organism ratio of 0.5 lb COD per day/1 lb of mixed liquor volatile suspended solids under aeration. Frequently this loading is expressed as 50 lbs COD per day/100 lbs of MLVSS.

[18] MLVSS means Mixed Liquor Volatile Suspended Solids.

Information needed:

1. Average COD of primary effluent, 150 mg/l
2. Average daily flow, 4.0 MGD
3. Average volatile content of mixed liquor suspended solids, 80%

Find pounds of COD provided aerator per day.

$$\text{Aerator Loading, lbs COD/day} = \text{Prim. Effl. COD, mg/l} \times \text{Daily Flow, MGD} \times 8.34 \text{ lbs/gal}$$

$$= 150 \text{ mg/l} \times 4.0 \text{ MGD} \times 8.34 \text{ lbs/gal}$$

$$= 5004 \text{ or } 5000 \text{ lbs COD/day}$$

Find desired pounds of Mixed Liquor Volatile Suspended Solids under aeration, based upon 0.5 lb COD per day/1 lb of MLVSS.

$$\text{MLVSS, lbs} = \frac{\text{Primary Effluent COD, lbs/day}}{\text{Loading Factor in lbs COD/day/1 lb MLVSS}}$$

$$= \frac{5000 \text{ lbs COD/day}}{0.5 \text{ lb COD/day/lb MLVSS}}$$

$$= \frac{5000}{0.5/\text{lbs MLVSS}}$$

$$= 10{,}000 \text{ lbs MLVSS under aeration}$$

The MLVSS is a measure of the organisms in the aerator available to work on the incoming waste (food). When operating your plant on the basis of MLVSS, you should determine any flucuations that may occur during the week and make appropriate adjustment.

If the COD load applied to the aerator increases or drops to a significantly different level for two consecutive days, a new mixed liquor solids value should be calculated and activated sludge wasting adjusted to achieve the new value of solids desired under aeration. Calculation of waste sludge rates is outlined in Sections 7.52 and 7.53.

7.83 Mean Cell Residence Time (MCRT)

Another approach for solids control used by operators is the Mean Cell Residence Time (MCRT) or Solids Retention Time (SRT). This is a refinement of the sludge age. Both terms are almost the same. The equation for MCRT is:

$$\text{MCRT, days} = \frac{\text{Pounds of Suspended Solids in Total Secondary System}}{\text{Lbs of Susp Sol Wasted/day + Lbs of Susp Sol Lost in Effl/day}}$$

The most desirable MCRT for a given plant is determined experimentally just as with the use of sludge age or the mixed liquor volatile suspended solids concentration. The desired MCRT for conventional plant operation should fall between 5 and 15 days. (Don't confuse this time with the recommended range for Sludge Age of 3.5 to 10 days.)

A way of determining MCRT for the example plant in this chapter would be as follows:

Required Data:

1. Aerator	=	1,000,000 gals
2. Final clarifier volume	=	500,000 gals
Total secondary system volume	=	1.5 MG
3. Wastewater flow to aerator	=	4.0 MGD
4. Waste sludge flow for past 24 hrs	=	0.075 MGD
5. Mixed liquor suspended solids concentration	=	2400 mg/1
6. Waste sludge (or return sludge) suspended solids concentration	=	6200 mg/1
7. Final effluent suspended solids concentration	=	12 mg/1

7.84 Calculation of Mean Cell Residence Time

$$\text{MCRT, days} = \frac{\text{Suspended Solids in Total Secondary System, lbs}}{\text{Susp Sol Wasted, lbs/day} + \text{Susp Sol Lost in Effl, lbs/day}}$$

$$\text{MCRT} = \frac{\text{Susp Sol in Mixed Liq, mg/l} \times (\text{Aerator, MG} + \text{Final Clarifier Vol, MG}) \times 8.34\ \text{lbs/gal}}{(\text{Susp Sol in Waste, mg/l} \times \text{Waste Rate, MGD} \times 8.34\ \text{lbs/gal}) + (\text{Susp Sol in Effl, mg/l} \times \text{Plant Flow, MGD} \times 8.34\ \text{lbs/gal})}$$

$$= \frac{2400\ \text{mg/l} \times (1.0\ \text{MG} + 0.5\ \text{MG}) \times 8.34\ \text{lbs/gal}}{(6200\ \text{mg/l} \times 0.075\ \text{MGD} \times 8.34\ \text{lbs/gal}) + (12\ \text{mg/l} \times 4.0\ \text{MGD} \times 8.34\ \text{lbs/gal})}$$

$$= \frac{2400\ \text{mg/l} \times 1.5\ \text{MG} \times 8.34\ \text{lbs/gal}}{(6200\ \text{mg/l} \times 0.075\ \text{MGD} \times 8.34\ \text{lbs/gal}) + (12\ \text{mg/l} \times 4.0\ \text{MGD} \times 8.34\ \text{lbs/gal})}$$

$$= \frac{30{,}024\ \text{lbs}}{3878\ \text{lbs/day} + 400\ \text{lbs/day}}$$

$$= \frac{30{,}024\ \text{lbs}}{4278\ \text{lbs/day}}$$

$$= 7.0\ \text{days}$$

If you are operating the plant on the basis of MCRT and the plant operates satisfactorily at the MCRT of 8, 9, 10, 11, or even 15 days, the main method of control is to adjust the waste sludge rate to maintain the MCRT at the desired number of days.

Rearranging the equation on the previous page, calculation of the sludge waste rate from the system merely means plugging in the chosen MCRT (use 7 days) and solids figures.

Example:

$$\text{Waste Sludge, lbs/day} = \frac{\text{Susp Sol in System, lbs}}{\text{MCRT, days}} - \text{Susp Sol in Effl, lbs/day}$$

$$= \frac{2400 \text{ mg/l} \times 1.5 \text{ MG} \times 8.34 \text{ lbs/gal}}{7 \text{ days}} - \begin{array}{l}12 \text{ mg/l} \times 4.0 \text{ MGD} \\ \times 8.34 \text{ lbs/gal}\end{array}$$

$$= \frac{30{,}024 \text{ lbs}}{7 \text{ days}} - 400 \text{ lbs/day}$$

$$= 4289 \text{ lbs/day} - 400 \text{ lbs/day}$$

$$= 3889 \text{ lbs/day}$$

The waste sludge pumping rate of 3878 lbs/day appears to be correct to maintain a Mean Cell Residence Time of 7 days.

QUESTIONS

7.8A Why is it sometimes necessary to waste some activated sludge?

7.8B If you calculate that your plant has 12,000 pounds of mixed liquor volatile suspended solids under aeration and you need 9,000 pounds under aeration, how many pounds should be wasted?

7.8C What should be the waste sludge pumping rate (GPM) if a plant should be wasting 3000 pounds per day and the concentration of return sludge is 6000 mg/l?

7.8D Estimate the waste sludge rate (lbs/day) from an activated sludge plant operating at an MCRT of 10 days. The system contains 40,000 pounds of suspended solids and the effluent has a suspended solids concentration of 10 mg/l at a flow of 5 MGD.

7.9 MODIFICATIONS OF THE ACTIVATED SLUDGE PROCESS

7.90 Reasons for Other Modes of Operation

Modification of the conventional activated sludge process has been developed to improve operational results under certain circumstances. Some of these conditions may be:

1. Current or actual loadings are in excess of design loading for conventional operation.

2. Wastewater constituents require added nutrients to properly treat influent waste load.

3. Flow or strength of waste varies seasonally.

7.91 Contact Stabilization (Fig. 7.9)

Operation of an activated sludge plant on the basis of contact stabilization requires two aeration tanks. One tank is for separate reaeration of the return sludge for a period of at least four hours before it is permitted to flow into the other aeration tank to be mixed with the primary effluent requiring treatment. Loading factors are the same as for conventional activated sludge, but at times the solids in the aeration tank may be almost twice as high as normal ranges in conventional plants.

If the solids content in aeration tank "A" (mixed liquor aerator, Fig. 7.9) and aeration tank "B" (return sludge aeration only) are combined, the loading ratio of food/organisms is the same as conventional operation, but if you only look at aeration tank "A" where the load is applied, we approach double the load ratio established for conventional activated sludge.

Contact stabilization attempts to have organisms assimilate and store large portions of the influent waste load in a short time (as short as 30 minutes). The activated sludge is separated from the treated wastewater in the secondary clarifier and returned to the reaeration tank "B". No new food is added to the reaeration tank and the organisms must use the waste material they collected and stored in the first aeration tank. When the stored food is used up, the organisms begin searching for more food and are ready to be returned to tank "A".

Process controls for a contact stabilization plant are the same as those described for a conventional plant in this chapter. When a plant has exceeded design flows, or is subject to periodic high

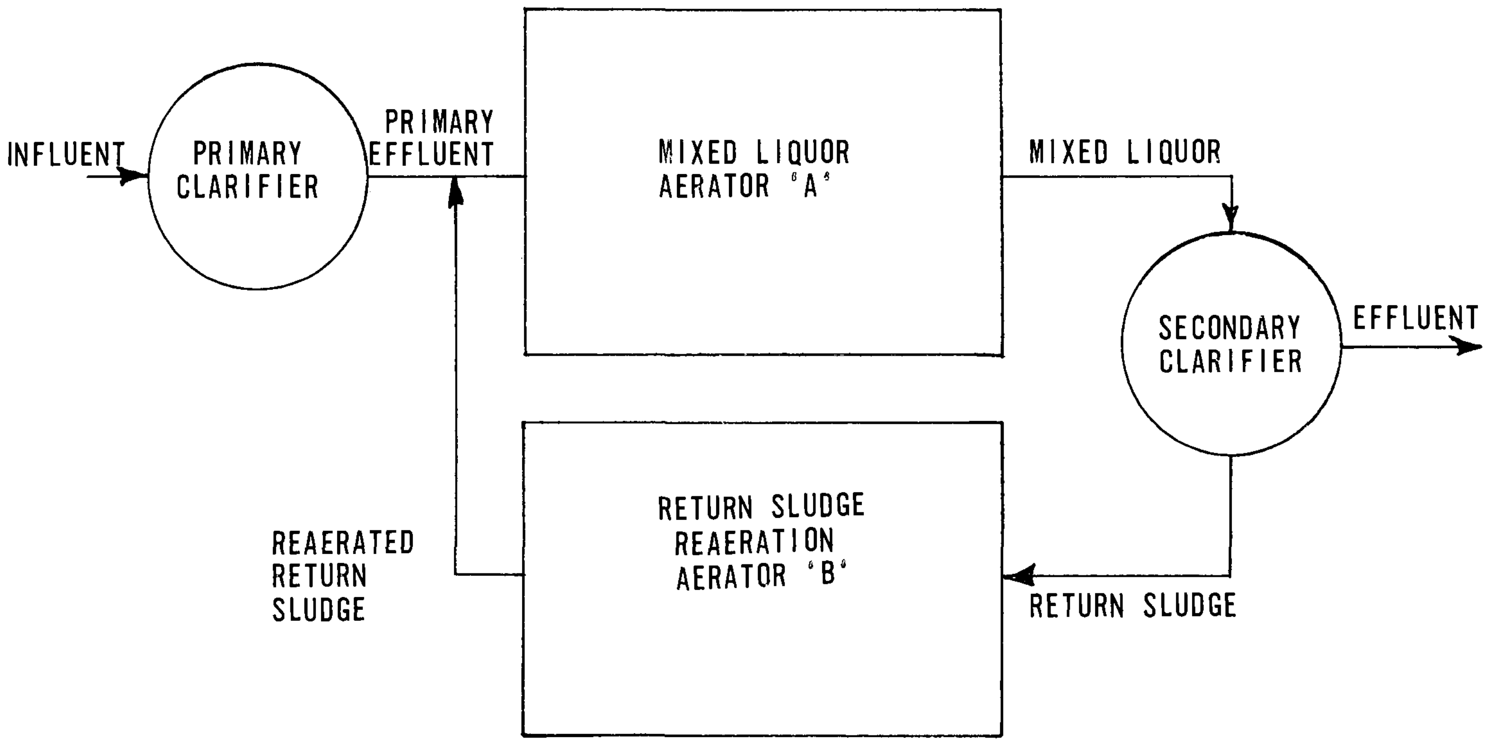


Fig. 7.9 Plan layout of contact stabilization plant

flows or shock waste loads, then contact stabilization is capable of treating the plant influent because a ready reserve of organisms is available in the reaeration tank "B".

7.92 Kraus Process (Fig. 7.10)

The Kraus process is a modification of conventional activated sludge, and the process is patented by its developer. The process is widely used when the wastewater contains a much greater ratio of carbonaceous to nitrogenous material than found in normal domestic wastewater.

This imbalance commonly occurs when wastes from canneries or dairies are treated. When the organisms use all of a limiting constituent, they refuse to remove the remaining portions of the other constituents. Normally this nutrient deficiency is nitrogenous material which is readily available in anaerobic digester supernatant and sludges. Feeding anaerobic digester supernatant or digester sludge to the aeration system will usually supply the proper nutrients to maintain the balance. The method of application is very important.

In the Kraus process, the return sludge is sent to the reaeration aerator ("B") to be mixed with the digested sludge from a completely mixed digester. In the reaeration tank ("B"), the digested sludge and the return sludge are mixed, reaerated, and then sent to the mixed liquor aerator ("A"). The amount of digested sludge introduced to the system is determined by laboratory evaluation and by carbonaceous material removal through the system.

The same controls apply as described for controlling a conventional activated sludge plant. The main objective is to properly balance nutrients; however, one added advantage (similar to contact stabilization) is the ability to maintain a large mass of organisms under aeration in a relatively smaller system.

7.93 Step-Feed Aeration (Fig. 7.11)

Step-feed aeration actually is a step-feed process based on conventional activated sludge loading parameters. The difference between step-feed and conventional operation is that in conventional activated sludge the primary effluent and return sludge are introduced at one point only, the entrance to the aeration tanks. In step-feed aeration the return sludge is introduced separately and in many cases allowed a short reaeration period by itself at the entrance to the tank. The primary effluent is admitted to the aeration tanks at several different locations. These locations distribute

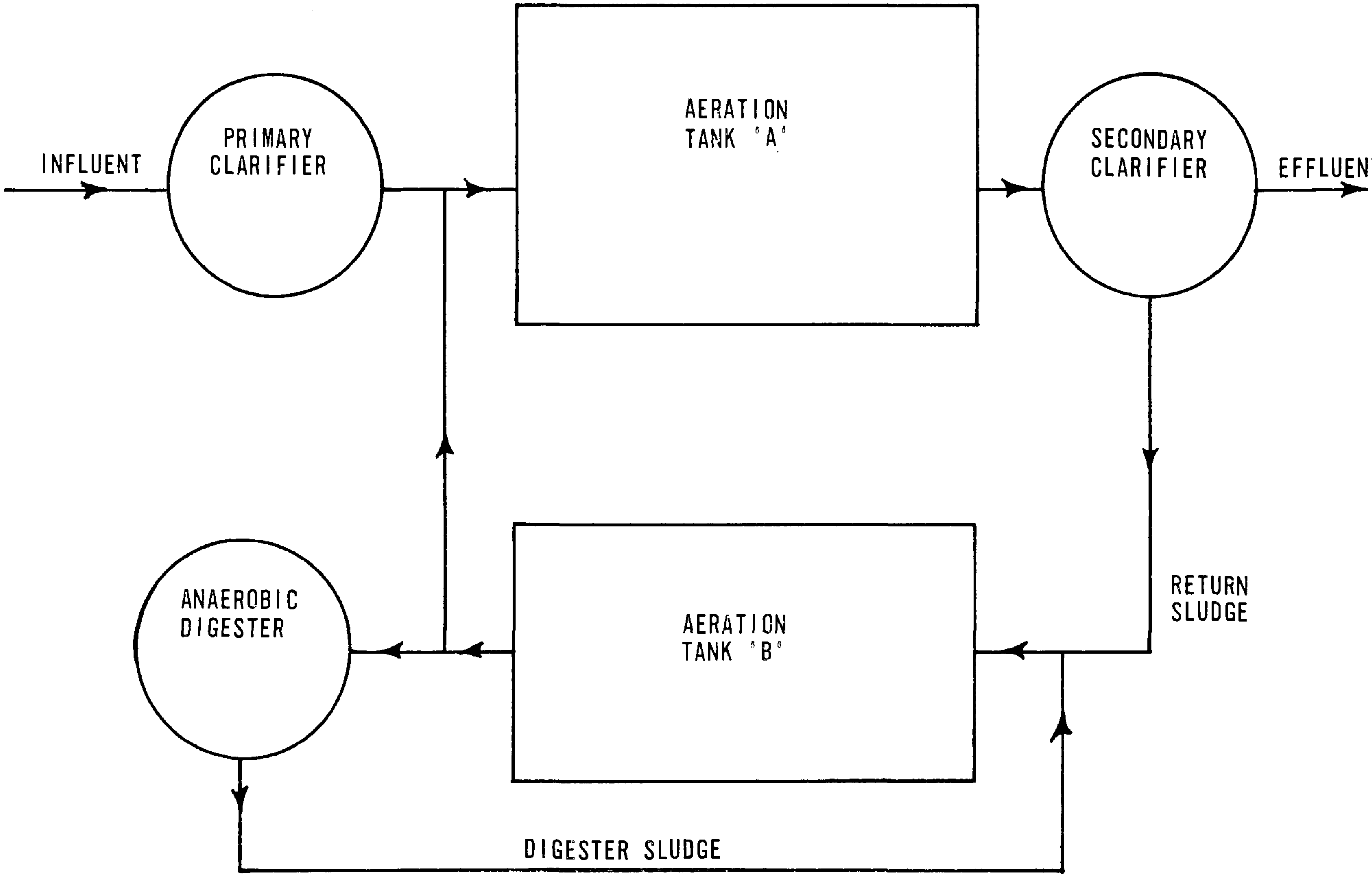
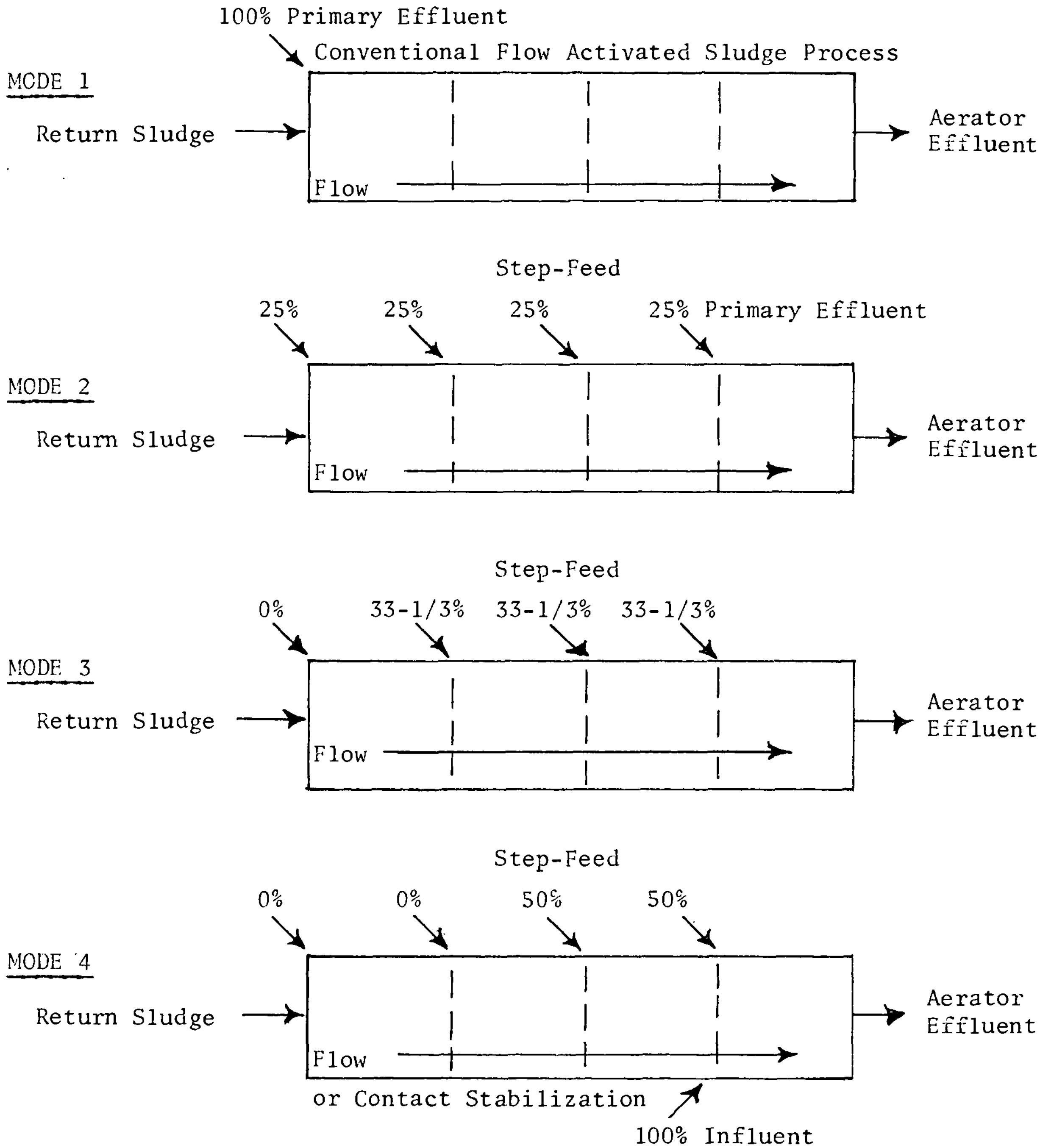


Fig. 7.10 Kraus process

MODES OF FLOW



Several possible modes of feeding primary effluent to the aeration tanks. Some tanks may have more or fewer points of discharge into the tank.

Fig. 7.11 Modes of step aeration

the waste load over the aeration tank and reduces oxygen sags in an aerator. If you introduce the influent near the outlet end of the aeration tank, the process will become similar to contact stabilization.

Step-feed aeration distributes the oxygen demand from the wastewater over the entire aerator instead of concentrating it at the inlet end. Some of its advantages over conventional operation include less aeration volume to treat the same volumes of wastewater, better control in handling shock loads, and better control of the solids entering the secondary clarifiers. When a conventional plant is operating above design loads and the secondary clarifiers cannot handle the solids load, switching to step-feed aeration or contact stabilization allows the operator to maintain the desired amount of solids under aeration. Successful operation requires good waste storage transfer into the solids in the short time interval before the waste reaches the effluent end of the aeration tank.

This mode of operation is controlled by the same procedures used for the conventional process except that the mixed liquor suspended solids determinations must be made at each point of wastewater addition to measure the waste content and dilution factor provided by the primary effluent to determine the total pounds of solids in the aeration tank.

7.94 Complete Mix (Fig. 7.12)

The complete mix mode of operation is a design modification of tank mixing techniques to insure equal distribution of applied waste load, dissolved oxygen, and return sludge throughout the aeration tank. The theory of this modification is that all parts of the aeration tank should be similar in terms of amounts of food, organisms, and air. This is accomplished by providing diffuser location and application points of influent and return sludge to the aerator at several locations. Providing a similar condition throughout the entire aeration tank allows a food/organism ratio of 1/1 and still produces effluent qualities comparable to conventional operation. Generally, smaller aeration tanks are more completely mixed than larger ones. Usually aeration is more efficient in a complete mix facility such as illustrated in Fig. 7.12 because of the locations of the air headers.

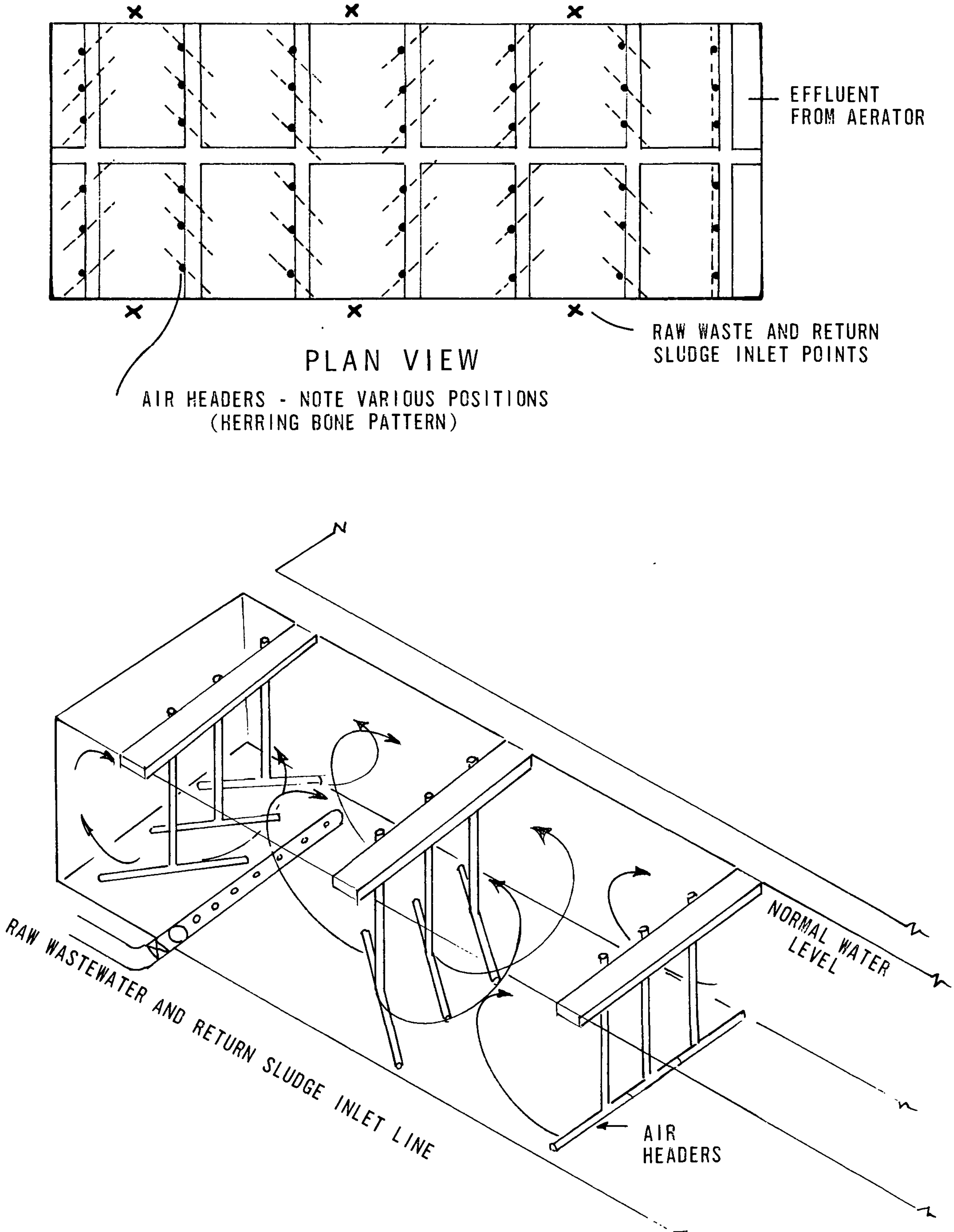


Fig. 7.12 Air header locations in complete mix

7.95 Modified Aeration (Fig. 7.13)

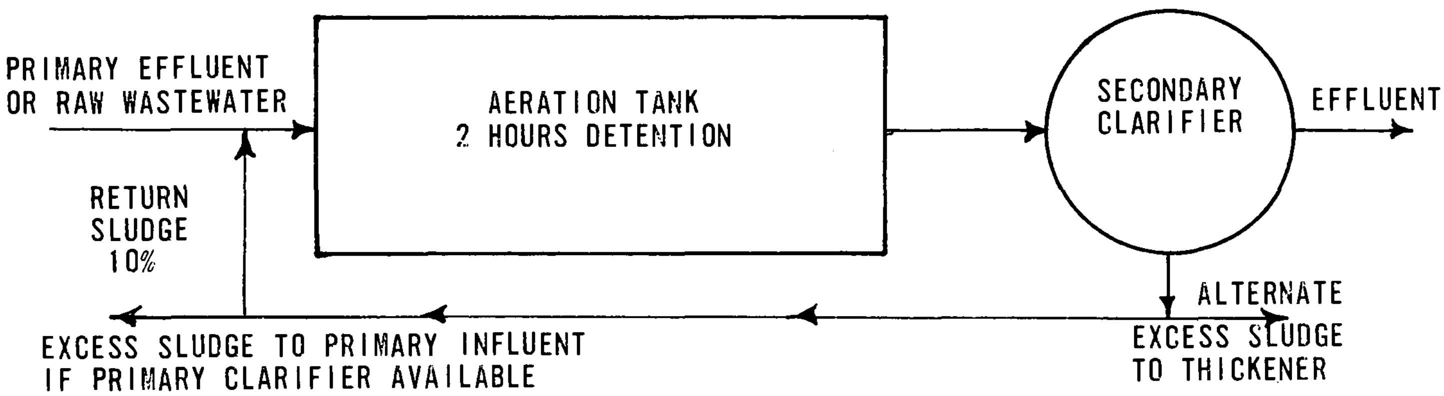


Fig. 7.13 Modified aeration

Modified aeration is also known as high-rate activated sludge. Frequently it is used as intermediate treatment where the discharge requirements demand higher treatment than primary, but not as high as conventional activated sludge, in terms of BOD and suspended solids removals.

Either raw wastewater or primary effluent is applied to an aeration tank with a detention time of two hours and a mixed liquor suspended solids concentration of less than 1000 mg/l. Air requirements are lower because of fewer organisms (solids) under aeration. Effluent quality ranging from primary treatment to conventional activated sludge treatment can be achieved by the operator by controlling the air supply, aeration period, and the pounds of solids under aeration.

7.10 ACKNOWLEDGEMENT

Mr. F. J. Ludzack, Chemist, National Training Center, Federal Water Quality Administration, provided many helpful comments to the development of this chapter. His contributions are gratefully appreciated.

7.11 ADDITIONAL READING

a. MOP 11, pages 108-122.

b. New York Manual, pages 58-69.

c. Texas Manual, pages 236-282.

d. <u>Sewage Treatment Practices</u>, pages 55-62.

e. Jenkins, D., and Garrison, W.E., "Control of Activated Sludge by Mean Cell Residence Time," JWPCF, Vol. 40, No. 11, p. 1905 (November 1968).

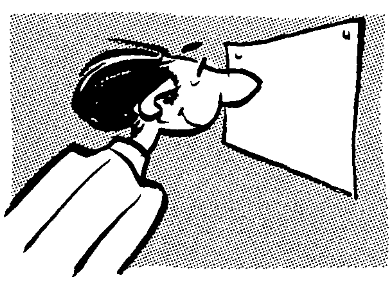
f. McKinney, R.E., and O'Brien, W.J., "Activated Sludge--Basic Design Concepts," JWPCF, Vol. 40, No. 11, p. 1831 (November 1968).

g. Stewart, M.J., "Activated Sludge Process Variables--The Complete Spectrum," Water and Sewage Works Magazine, Reference Volume, p. R-241 (November 30, 1964).

h. Aeration Practice, MOP No. 5, Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016. $3.00 to members, $6.00 to others.

or

Journal Water Pollution Control Federation, Vol. 41, Nos. 11 and 12, and Vol. 42, No. 1.



END OF LESSON 8 OF 8 LESSONS

on

ACTIVATED SLUDGE

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. Activated Sludge

(Lesson 8 of 8 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 7.

38. What is the formula for calculating the Mean Cell Residence Time?

39. Calculate the MCRT for an activated sludge process. Plant inflow is 4.0 MGD, MLSS is 2700 mg/l, waste sludge flow 0.05 MGD, total secondary system volume is 2.0 MG, waste sludge suspended solids concentration is 6500 mg/l, and final effluent suspended solids concentration is 15 mg/l.

40. Why might an operator wish to use step-feed aeration?

41. What is the name of the treatment process that is capable of producing effluents with a quality (BOD and suspended solids) between primary treatment and conventional activated sludge?

SUGGESTED ANSWERS

Chapter 7. Activated Sludge

7.0A The purpose of the activated sludge process in treating wastewater is to oxidize and remove soluble or finely divided suspended materials that were not removed by previous treatment.

7.0B A stabilized waste is a waste that has been treated or decomposed to the extent that, if discharged or released, its rate and state of decomposition would be such that the waste would not cause a nuisance or odors.

7.1A Air is added to the aeration tank in the activated sludge process to provide oxygen to sustain the living organisms and for oxidation of wastes to obtain energy for growth. The application of air also encourages mixing in the aerator.

7.1B Air requirements increase when the strength (BOD) of the incoming wastes increases because more food (wastes) encourages biological activity (reproduction and respiration).

7.1C Factors that could cause an unsuitable environment for the activated sludge process in an aeration tank include:

1. Intolerable concentrations of acids, bases, and other toxic substances.
2. Unduly fluctuating loads that cause overfeeding or starvation.
3. Insufficient oxygen.

7.2A The two major variables that affect the operation of an activated sludge plant are (1) the dischargers to the collection system and (2) in-plant operational variables.

7.2B Variables in the collection system affecting the activated sludge plant include the (1) wastes discharged, (2) storm water inflow, and (3) maintenance activities.

7.2C Excessive storm water can upset the activated sludge process by (1) reducing treatment time of the wastewater, (2) increasing the amount of grit and silt, (3) increasing the organic loading, and (4) causing fluctuations in wastewater temperature and solids content.

7.2D The COD test is recommended to measure the strength of the influent wastewater to the activated sludge process because the results are available within four hours and can be used to control the process.

7.2E The aerator pH should be measured in the aerator because the pH of the sample can change very rapidly outside of the aerator.

7.2F True.

7.2G The two methods used to supply oxygen from air to bacteria in the activated sludge process are (1) mechanical aeration and (2) diffused aeration.

7.2H $$\text{Sludge Age, days} = \frac{\text{Suspended Solids Under Aeration, lbs}}{\text{Suspended Solids Added, lbs/day}}$$

7.3A The main reasons are to familiarize the operator with plant equipment and locations of piping. Also to be reasonably sure that everything will function properly when the plant is put into service.

7.3B Lines and channels should be cleaned before start-up to remove any sand, debris, or material that will occupy space or damage equipment. Cleaning also will familiarize the operator with the flow routes.

7.3C Chips and scrapes on gates should be painted for the protection of the equipment. The cost of equipment is expensive, and it is part of the operator's responsibility to obtain as long a life as possible for plant equipment.

7.3D If the sluice gate travels down from an overhead stem, it may be possible to drop the slide gate into the tank. The main purpose of the stop-nuts on the stems of mud valves is to set length of travel.

7.3E The effluent weir should be level to prevent short-circuiting and an uneven flow of solids over the weir.

7.3F The water sprayed on a walk may create a hazard by being slippery either from ice in the winter or algal growths in the summer.

7.3G Air passing through porous media diffusers must be free of dirt or it will clog the inside of the diffuser making it necessary to remove the diffusers for cleaning. The dirt is removed by filters.

7.3H Some filters clean themselves while in operation and require only routine maintenance. Fixed filter cleaning is determined by the differential pressure between the intake and discharge of the filter.

7.3I Each manufacturer normally supplies a one-year warranty on their equipment. If the equipment is mistreated due to improper operation, the warranty becomes void, and your community or district must absorb the cost. Proper operation prolongs the life of equipment and reduces the cost of repairs and replacement.

7.3J Usually in the construction specifications the equipment suppliers are requested to supply three or four copies of instructions for each piece of equipment. If they are lost, a new one may be obtained by writing to the manufacturer and giving the name, size, serial number, and the treatment plant location and contract number if possible.

7.3K Proper starting, operating, and stopping procedures must be followed when running equipment to reduce equipment wear and failure.

7.3L The sharp edge of a metering orifice is usually on the same side as the orifice information which is stamped on the orifice plate handle. The sharp edge should be placed so as to be facing the stream flow with the bevel on the discharge side. If the orifice is installed backwards, it will give an incorrect reading.

7.3M If the hoist is not anchored properly and a header is being raised, the hoist could catapult into the aeration tank and could cause injury to man and equipment.

7.3N Important safety precautions which should be observed when working on a center"Y" wall include the wearing of life preservers, having help standing by, keeping the area clear and free of slippery materials, providing secure footing, and requiring adequate lighting.

7.3O If air diffuser headers, or the pipe containing them, are slanted so that one end of the header cross arm is higher than the other (by as little as 1/2 inch), the air will be unevenly released into the aerator. The diffusers on the high side at low air rates will allow most of the air to pass out of them through the path of least resistance rather than go through the diffusers on the low end of the header, which have only 1/2 inch more water over the top of them. This creates an undesirable flow pattern in the tank.

7.3P Whenever a blower is first put on the line, the bearing lubrication and temperature should be checked, along with driven equipment load, air flow rates, and temperature.

7.3Q Grease should be applied to the threads of a diffuser to serve as a protective coating and to make it easier to remove the diffuser for cleaning.

7.3R
a. Name of pump: ______________________
b. Location of pump: ______________________
c. Pump suction pressure: ______________________
d. Pump discharge pressure: ______________________
e. Water level in wet well: ______________________
f. Motor amperage: ______________________
g. Pump discharge (flow): ______________________
h. Date of test: ______________________
i. Name of operator: ______________________

7.4A Chlorination equipment should be put in service to disinfect the plant effluent and to protect the health of the receiving water users.

7.4B Return sludge rates during start-up are selected to return the settled activated sludge in the secondary clarifier as fast as possible and to keep the sludge blanket in the secondary clarifier as low as possible.

7.4C Blowers should be started and air should be flowing out the diffusers before wastewater is admitted to the aeration tanks to prevent diffuser clogging by waste solids. This is particularly important if porous type diffusers are used.

7.4D DO should be checked at the effluent end of the aerator for control, and periodically checked at the inlet and midpoint to see if sufficient air is being supplied.

7.4E To record the solids build-up in the aeration tank the operator should collect a grab sample at the same time every day, preferably during peak flows. The sample of mixed liquor should be collected approximately 5 feet from the effluent end of the aeration tank and 1.5 to 2 feet below the water surface to insure a good sample.

7.4F Calculate pounds of solids under aeration.

Solids, lbs

= Mixed Liq Susp Sol, mg/l x Aerator Vol, MG x 8.34 lbs/gal

= 640 mg/l x 0.25 MG x 8.34 lbs/gal

= 1334 lbs

7.4G Estimate return sludge pumping rate, GPM.

Flow to aerator from primary clarifier	=	2.0 MGD
Return sludge flow to aerator	=	0.5 MGD
Total flow through aerator	=	2.5 MGD

Return Sludge Rate, MGD = Aerator Flow, MGD x Settleable Solids, %

= 2.5 MGD x 0.17

= 0.425 MGD

$$\text{Return Sludge Rate, GPM} = \frac{425{,}000 \text{ GPD}}{1440 \text{ min/day}}$$

= 295 GPM

7.5A Some activated sludge must be wasted to prevent an excessive solids build-up in the aerator.

7.5B The best place to waste excess activated sludge is to divert it to the primary clarifier, sludge thickener, or aerobic digester, but not directly to an anaerobic digester.

7.5C

$$\text{Sludge Age, days} = \frac{\text{Suspended Solids in Aerator, lbs}}{\text{Suspended Solids in Primary Effluent, lbs/day}}$$

$$= \frac{(2100 \text{ mg/l})(0.5 \text{ MG})(8.34 \text{ lbs/gal})}{(70 \text{ mg/l})(4.0 \text{ MGD})(8.34 \text{ lbs/gal})}$$

$$= \frac{(30)\ (0.5)}{4} = 3.75 \text{ days}$$

7.6A A package plant should be visited every day.

7.6B For best results, in terms of effluent quality, waste about 5% of the solids each week during warm weather operation.

7.6C a. If the solids do not settle in the jar, the aeration rate should be increased.

b. If the solids settle and then float to the surface, the aeration rate should be reduced a little each day until the solids settle properly.

7.7A Plant records of the activated sludge operation are important because they are helpful in identifying the cause of operational problems or upsets and indicating what corrective action should be taken.

7.7B If the mixed liquor suspended solids were allowed to build up too high, the quality of the plant effluent would deteriorate.

7.7C The best solids loading for an aerator is determined by experimentation and careful measurement of loading parameters and effluent quality.

7.7D Check the plant records to determine the cause and then make adjustments to process. However, only one change at a time should be made to the activated sludge system, and one week should be allowed to observe the response.

7.7E When digester supernatant with a high solids content is returned to the primary clarifier, this may greatly increase the suspended solids content of the primary effluent, particularly if waste activated sludge is also being applied to the same primary clarifier. The remedy is to draw sludge from the digester to reduce the supernatant load to the plant.

7.7F During the high flows a solids loss could occur. If possible, change the plant to step-feed aeration to retain more mixed liquor solids in the aeration tank. If the solids were already lost, stop wasting and attempt to build more solids.

7.7G There could be a significant increase in air flow rates to maintain desired DO level in the mixed liquor if the wastewater temperature increases. The suspended solids in the mixed liquor should be increased if the wastewater temperature increases. Also, bacteria are more active at higher temperatures.

7.7H When lab data varies considerably from day to day, check sampling times, locations, methods, and laboratory procedures for causes of variations.

7.7I Allow one week for a plant to stabilize after a process change. An experienced operator who knows his plant may be able to determine if he is on the proper approach after several days, but some plants require up to two weeks to stabilize after a change.

7.7J Froth or foam may be controlled by:

1. Maintaining higher mixed liquor suspended solids concentrations.
2. Reducing air supply during periods of low flow while still maintaining DO.
3. Returning supernatant to the aeration tank during low flows.

7.7K Grease deposits can be removed from walks using trisodium phosphate and a stiff bristle deck brush and hose.

7.7L Bulking sludge will be indicated by large mats of floating sludge or a tremendous amount of suspended solids being carried out of the final clarifier in the effluent. Rising sludge will be light flocculent particles of floc collecting mainly on the surface of the final tanks and forming a thin surface scum. Rising sludge is accompanied by high DO in the aerator effluent and final clarifier.

7.7M Several adjustments may be attempted to correct a rising sludge problem, but only one should be undertaken at a time.

1. Increase return sludge rates, but control final clarifier sludge level.
2. Increase load to aerator by removing a primary clarifier from service if more than one is being used.
3. Admit raw wastewater directly to the aerator during low flows.
4. Check the possibility of going to a tapered aeration diffuser placement.

7.8A New microorganisms are continually being reproduced, and some of them must be removed from the system to control their population in order to balance the food supply.

7.8B Solids Wasted, lbs

$$= \text{Solids in System, lbs} - \text{Desired Solids, lbs}$$

$$= 12{,}000 \text{ lbs} - 9{,}000 \text{ lbs}$$

$$= 3000 \text{ lbs}$$

7.8C Waste Sludge Rate, MGD

$$= \frac{\text{Solids to be Wasted, lbs/day}}{\text{Return Sludge Conc., mg/l} \times 8.34 \text{ lbs/gal}}$$

$$= \frac{3000 \text{ lbs/day}}{6000 \text{ mg/l} \times 8.34 \text{ lbs/gal}}$$

$$= \frac{3000/\text{day}}{6000} \times \frac{1}{8.34/\text{MG}}$$ (Remember, one liter = 1 M mg)

$$= \frac{3000/\text{day}}{50{,}040/\text{MG}} \text{ or } \frac{3000/\text{day}}{50{,}000/\text{MG}}$$

$$= 0.06 \text{ MGD}$$

Waste Sludge Rate, GPM

$$= \frac{0.06 \text{ MGD}}{1440 \text{ min/day}}$$

$$= \frac{60{,}000 \text{ gals}}{1440 \text{ mins}}$$

$$= 41.8 \text{ GPM}$$

7.8D Waste Sludge, lbs/day

$$= \frac{\text{Susp Sol in System, lbs}}{\text{MCRT, days}} - \text{Susp Sol in Effl, lbs/day}$$

$$= \frac{40{,}000 \text{ lbs}}{10 \text{ days}} - 10 \text{ mg/l} \times 5.0 \text{ MGD} \times 8.34 \text{ lbs/gal}$$

$$= 4000 \text{ lbs/day} - 417 \text{ lbs/day}$$

$$= 3583 \text{ lbs/day}$$

OBJECTIVE TEST

Chapter 7. Activated Sludge

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to each question.

Match the word with the correct definition by marking the number of the definition on the answer sheet opposite the number of the word.

EXAMPLE

Word		*Definition*
1. Plant Operator	*1.*	*Women's Liberation advocate*
	2.	*Hard-working water quality protector*
	3.	*Uneducated individual*
	4.	*Town clown*
	5.	*None of these*

	1	*2*	*3*	*4*	*5*
1.		▮			

Word		Definition
1. Aliquot	1.	Airline schedule
2. Coning	2.	Bacteria that have come together and formed a cluster
3. Flights	3.	Portion of a sample
4. Floc	4.	Scraper boards used to remove settled sludge to collection hoppers
	5.	Caused by sludge when removed too quickly
5. Meniscus	1.	A thin plate with a hole in the middle used to measure flow
6. Orifice	2.	Membranes in the nose and throat
7. Protozoa	3.	Jelly-like substances of bacteria
	4.	The curved top of a column of liquid in a tube
8. Zoogleal Mass	5.	A group of microscopic animals found in treatment processes

9. The activated sludge process:

   1. Requires aeration
   2. Requires activated carbon
   3. Is a biological process
   4. Usually follows primary sedimentation
   5. Is an anaerobic process

10. Before starting a new plant, the operator should check:

   1. The blower system
   2. Control gates and mud valves
   3. The aeration equipment
   4. For chips and scrapes on painted gates
   5. Effluent weirs for level

11. The hoist used to lift the air headers in the aeration tank must be properly anchored or it:

   1. Will float away
   2. Could fall into the aerator
   3. Won't allow even distribution of the air
   4. Could hurt someone
   5. Could not lift the aerator

12. How many pounds of solids are in a 400,000-gallon aeration tank if the suspended solids concentration is 1200 mg/l? Select the closest answer.

   1. 3600
   2. 4000
   3. 4400
   4. 4800
   5. 5200

13. When the return sludge rate is too low, what happens?

   1. The tank will not fill.
   2. There will be insufficient organisms to meet the waste load entering the aerator.
   3. The activated sludge in the aerator will starve.
   4. The activated sludge in the secondary clarifier could become septic.
   5. The sludge blanket in the secondary clarifier could become too high.

14. When operating an activated sludge plant, which is the most important suspended solids test for operational control?

   1. Primary effluent
   2. Aerator mixed liquor
   3. Return sludge
   4. Final clarifier effluent
   5. Plant influent

15. The main operational process controls available to an operator include:

    1. Air rates
    2. Pounds of solids under aeration
    3. Maintenance
    4. Return sludge rate
    5. BOD test

16. What should be the waste sludge pumping rate if a plant should be wasting 2000 pounds per day and the concentration of return sludge is 5000 mg/l? Select the closest answer.

    1. 30 gpm
    2. 33 gpm
    3. 35 gpm
    4. 36 gpm
    5. 40 gpm

17. What items would you check if an activated sludge plant becomes upset?

    1. Influent temperature
    2. Daily flow rates
    3. BOD loadings
    4. Digester operation
    5. Chlorinator

18. How long would you allow an activated sludge process to react and stabilize after a change?

    1. 3 hours
    2. 12 hours
    3. 1 day
    4. 2 days
    5. 1 week

19. Causes of sludge bulking include:

    1. Bulk of sludge too large
    2. Air supply too low
    3. Loading rate too high
    4. Aeration period too short
    5. Sludge going septic in secondary clarifier

20. Package plants usually:

    1. Operate the aeration device continuously
    2. Have an operator at the plant 24 hours a day
    3. Waste sludge out the effluent, but shouldn't when operated properly
    4. Have an extensive lab testing program
    5. None of these

21. The effectiveness of the organisms in the aerator depends on the:

    1. Temperature
    2. pH
    3. Presence of inhibiting substances
    4. Characteristics of food supply
    5. Time of reaction or time available for the reaction

22. What is the food/organism loading ratio in an activated sludge plant with a flow of 1 MGD? The average BOD to the aerator is 140 mg/l, the aeration tank contains 250,000 gallons, and the mixed liquor suspended solids concentration is 2000 mg/l. Select the closest answer.

    1. 25 lbs BOD per day/100 lbs MLSS
    2. 28 lbs BOD per day/100 lbs MLSS
    3. 30 lbs BOD per day/100 lbs MLSS
    4. 32 lbs BOD per day/100 lbs MLSS
    5. 35 lbs BOD per day/100 lbs MLSS

23. Why is the COD test a better operational control test than the BOD test?

    1. It isn't better.
    2. The oxygen demand is not caused by biological organisms.
    3. Everyone uses it.
    4. The results are available sooner.
    5. This chapter says so.

24. Why should all of the diffusers in an aeration tank be cleaned at once?

    1. To get the job done in a hurry
    2. So the air will flow evenly out all of the diffusers
    3. To improve step-feed aeration
    4. So the plant won't use too much air
    5. None of these

Please write on your IBM answer sheet the total time required to work Chapter 7.

APPENDIX

Monthly Data Sheet

CLEANWATER, U.S.A.

WATER POLLUTION CONTROL PLANT

MONTHLY RECORD ________ 19__ OPERATOR: ____________

DATE	DAY	WEATHER	FLOW – MGD	RAW WASTEWATER TEMP.	RAW WASTEWATER pH	RAW WASTEWATER SETT. SOLIDS	RAW WASTEWATER B.O.D.	RAW WASTEWATER SUSP. SOLIDS	PRIM. EFF. B.O.D.	PRIM. EFF. SUSP. SOLIDS	PRIM. EFF. D.O.	FINAL EFFLUENT pH	FINAL EFFLUENT B.O.D.	FINAL EFFLUENT SUSP. SOLIDS	FINAL EFFLUENT D.O.	FINAL EFFLUENT CL_2 RES.	AERATION SYSTEM LBS. VOL. SOLIDS	AERATION SYSTEM SUSP. SOLIDS	AERATION SYSTEM % VOL.	AERATION SYSTEM 30 MIN. SETT.	AERATION SYSTEM S.V.I.	AERATION SYSTEM D.O.	AERATION SYSTEM RETURN SUSP. SOLIDS	AERATION SYSTEM RETURN-MGD	AERATION SYSTEM WASTE GAL. X 1000	AERATION SYSTEM WASTE LBS./DAY
1	S	CLEAR	1.782	75	7.2	14			118	84	0.6	6.9	19	18	0.9	2.7	6746	2036	78.9	150	73	2.5	5961	0.702	70	3480
2	M	CLEAR	2.347	74	7.3	13	218	150	156	84	0.3	6.8	19	15	1.0	2.8	6859	2078	78.6	150	72	1.4	4683	0.711	72	2812
3	T	CLEAR	2.165	74	7.3	8			109	66	0.8	6.8	14	9	1.2	8.8	7224	2211	77.8	170	76	2.1	6625	0.708	71	3922
4	W	CLEAR	2.012	74	7.3	12			135	74	0.5	6.8	16	14	0.8	4.4	7305	2213	78.6	180	81	2.0	6641	0.712	70	3877
5	T	CLEAR	2.483	74	7.2	13	189	138	134	62	0.3	6.8	9	11	1.7	5.2	7014	2106	79.3	170	80	2.6	6098	0.722	78	3966
6	F	CLEAR	2.386	74	7.2	13			112	60	0.4	6.8	18	6	2.6	6.0	6754	2069	79.0	160	77	3.5	5862	0.700	80	3911
7	S	CLEAR	2.131	75	7.3	13			89	66	0.7	6.9	14	7	1.2	4.4	6296	1905	78.7	150	78	2.6	5564	0.706	80	3712
8	S	CLEAR	1.867	76	7.4	12	174	134	84	74	0.9	6.9	9	15	0.8	4.2	7057	2138	78.6	180	84	0.9	6758	0.703	72	4058
9	M	CLEAR	2.634	75	7.3	14			117	68	0.3	6.9	11	11	1.6	3.5	6767	2037	79.1	160	78	2.5	6022	0.712	70	3515
10	T	CLEAR	2.307	76	7.3	18			120	66	0.3	7.1	8	8	1.5	6.6	6119	1861	78.3	170	91	2.8	6135	0.705	64	3274
11	W	CLEAR	2.198	76	7.3	18	192	142	111	68	0.4	7.0	9	10	1.1	6.6	7035	2123	78.9	200	94	1.7	6183	0.700	70	3609
12	T	CLEAR	2.202	76	7.3	11			99	72	0.4	7.0	11	9	2.0	3.8	6352	1954	77.4	190	97	3.0	6027	0.704	70	3518
13	F	CLEAR	2.178	77	7.3	11			81	58	0.6	7.0	15	18	3.5	4.0	6313	1937	77.6	170	87	4.8	5542	0.689	72	3327
14	S	CLEAR	2.006	78	7.3	12	155	156	105	76	0.3	6.9	12	8	3.1	3.8	6335	1929	78.2	160	82	4.3	4856	0.703	70	2834
15	S	CLEAR	1.942	78	7.2	12			113	74	0.4	6.9	9	9	1.3	4.4	6873	2090	78.3	180	86	2.2	5753	0.711	73	3502
16	M	CLEAR	2.464	78	7.2	11			128	74	0.3	6.9	10	10	1.8	3.0	7082	2162	78.0	200	92	2.5	6852	0.723	76	4343
17	T	CLEAR	2.321	78	7.1	8	168	144	110	64	0.4	6.8	10	11	1.9	6.6	6215	1937	76.4	190	98	2.8	6654	0.698	74	4106
18	W	CLEAR	2.611	78	7.3	15			105	64	0.2	6.9	11	7	2.2	4.4	6227	1923	77.1	190	98	3.3	5767	0.717	83	3992
19	T	CLEAR	2.457	78	7.3	12			87	72	0.5	6.9	10	7	2.9	6.2	4844	1534	75.2	170	110	4.5	4762	0.721	25	992
20	F	CLEAR	2.498	79	7.3	11	193	118	105	66	0.7	6.9	18	12	3.1	4.4	5846	1822	76.4	190	104	4.1	5123	0.719	0	0
21	S	CLEAR	2.213	76	7.1	12			109	76	0.6	7.1	10	9	1.2	4.2	6892	2096	78.3	200	95	2.6	5928	0.706	35	1730
22	S	CLEAR	1.878	76	7.3	12			131	78	0.4	6.9	14	10	0.5	4.2	7518	2263	79.1	260	114	1.8	3894	0.703	35	1136
23	M	CLEAR	2.901	77	7.3	12	187	142	133	89	0.2	6.9	13	13	0.3	2.5	8388	2541	78.6	310	121	1.9	8396	0.741	70	4901
24	T	N.M. CLEAR	2.346	78	7.3	13			114	56	0.3	6.9	14	10	2.2	4.2	7962	2409	78.7	230	95	3.6	8824	0.700	71	5225
25	W	CLEAR	2.421	78	7.3	13			89	56	0.4	7.0	12	8	2.8	4.0	7688	2332	78.5	230	98	4.1	7382	0.713	72	4432
26	T	CLEAR	2.562	79	7.3	12	212	170	143	87	0.6	7.0	10	6	1.7	4.3	6697	2047	77.9	210	102	2.6	6867	0.698	70	4008
27	F	CLEAR	2.428	79	7.3	10			128	84	0.5	6.8	15	10	0.5	3.8	6923	2103	78.2	200	94	1.2	7436	0.702	64	3969
28	S	CLEAR	2.149	78	7.3	12			84	66	0.9	6.9	16	5	0.6	3.5	7169	2180	78.3	200	91	1.7	8412	0.706	68	4770
29	S	CLEAR	1.862	79	7.3	7	176	102	117	60	0.5	6.9	14	8	0.5	3.9	7852	2397	78.0	230	95	1.0	7117	0.700	66	3917
30	M	CLEAR	2.746	79	7.3	13			107	73	0.2	6.8	8	8	1.6	3.5	7688	2335	78.4	220	94	2.9	7735	0.713	70	4515
31																										
MAX			2.901	79	7.4	18	218	170	156	89	0.9	7.1	19	18	3.5	8.8	8388	2541	79.3	310	121	4.8	8824	0.741	83	5225
MIN			1.782	74	7.1	7	155	102	84	56	0.2	6.8	8	5	0.5	2.5	4844	1534	76.4	150	72	0.9	4683	0.698	0	0
AVG			2.283	77	7.3	12	186	139	112	70		6.9	12	10	1.6	4.4	6868	2092	78.1	192	91	2.6	6328	0.708	65	3511

SUMMARY DATA

% REMOVAL	B.O.D.	S.S.
INF – PRI	39.7	49.6
INF – EFF	93.5	92.8

SLUDGE DATA

% SOLIDS — AVG.	5.6
LBS. DRY SOLIDS / DAY	5579
% VOL. SOLIDS — AVG.	79.8
LBS. VOL. SOLIDS / DAY	4452
LBS. VOL. SOL./1000 FT^3/DAY	67.5
GALS. SLUDGE TO BEDS	28,000
CU. YDS. CAKE REMOVED	63
FT^3 GAS / LB. VOL. SOLIDS	6.8
FT^3 GAS / LB. MG FLOW	14,286

COST DATA

MAN DAYS 63 PAYROLL	2,325.78
POWER PURCHASED	520.32
OTHER UTILITIES (GAS, H_2O)	NONE
GASOLINE, OIL, GREASE	108.56
CHEMICALS AND SUPPLIES	547.25
MAINTENANCE	238.48
VEHICLE COSTS	NONE
OTHER	NONE
TOTAL	$ 3,740.39
OPER. COST/MG TREATED	$ 54.62
OPER. COST/CAPITA/MO.	$ 0.158

FLOW METER:
LAST 222046
1st 153549
TOTAL 68.497 MG

ELECTRIC METER:
LAST 7838
1st 5670
TOTAL 2168
MULT 40 X 2168 = 86,720 KWH

RAW SLUDGE:
LAST 798324
1st 432984
STROKES 365340
TOTAL 365340 X 1.0 = 365,340 GALS

GAS METER:
LAST 2181110
1st 1265230
TOTAL 915880 FT^3

RETURN SLUDGE:
LAST 67635048
1st 67613800
TOTAL 21.248 MG

WASTE SLUDGE:
LAST 134251
1st 132560
TOTAL 1961 x 1000 MG

CHAPTER 8

SLUDGE DIGESTION AND HANDLING

by

John Brady

(With a special section by William Garber)

TABLE OF CONTENTS

Chapter 8. Sludge Digestion and Handling

PRE-TEST

Chapter 8. Sludge Digestion and Handling

The purpose of this Pre-Test is to indicate to you the important points in this chapter. Work this test before reading the chapter. It's okay if you don't know many of the answers.

Please write your name and mark the correct answers on the IBM answer sheet. There may be more than one answer to each question.

1. The environment in an anaerobic digester may be controlled by regulating the:

    1. Air supply
    2. Food supply
    3. Domestic water supply
    4. Temperature
    5. Mixing

2. Material not readily decomposed in digesters includes:

    1. Rubber goods
    2. Fruit
    3. Plastic
    4. Hair
    5. Grit

3. Sludge should be pumped from the primary clarifier to the digester several times a day to:

    1. Keep the pump from becoming clogged
    2. Prevent temporary overloading of the digester
    3. Maintain better conditions in the clarifier
    4. Permit thicker sludge pumping
    5. Prevent coning

4. Digester gas may be used as a fuel when the methane content exceeds:

    1. 25%
    2. 35%
    3. 50%
    4. 65%
    5. 75%

5. The following precautions must be taken when applying sludge to a drying bed:

   1. Withdraw the sludge slowly from the digester
   2. Loosen sand before applying sludge
   3. Make sure the bed is covered with sludge
   4. Never smoke in the vicinity where the sludge is being drawn
   5. When finished, flush the draw-off line and leave one end open

6. High volatile acid/alkalinity relationship in a digester may be caused by:

   1. Overloading the tank with organic material
   2. Pumping too thin a raw sludge
   3. Filling the tank too full
   4. Withdrawing supernatant
   5. Adding lime

7. Useful digester control tests include:

   1. BOD
   2. pH
   3. Volatile acid/alkalinity relationship
   4. DO
   5. Temperature

8. Laboratory tests indicate that the volatile content of a raw sludge was 71% and after digestion the content is 53%. The percent reduction in volatile matter is:

   1. 25%
   2. 50%
   3. 54%
   4. 60%
   5. 68%

9. Calculate the volatile matter destroyed (lbs/day/cu ft) in a 20,000 cubic foot digester receiving 2400 gallons per day of raw sludge. The solids content is 5%, the volatile content 71%, and the volatile solids are reduced 50% by digestion:

   1. .015
   2. .018
   3. .020
   4. .023
   5. .025

10. A positive displacement pump should never be started against a closed valve because:

    1. It will pump nothing
    2. Excessive pressure may damage the line, the pump, or the motor
    3. The sludge will spill
    4. The valve will swing open
    5. The power driver will stall and overheat

11. Digester gas may be used to:

    1. Heat digesters
    2. Supply oxygen to activated sludge aeration tanks
    3. Digest solids
    4. Run engines
    5. Gas rats around the plant

12. Flame arrestors should be installed:

    1. Between vacuum and pressure relief valves and the digester dome
    2. After sediment trap on gas line from digester
    3. At waste gas burner
    4. Before every boiler, furnace, or flame
    5. In the vent of the waste gas burner

13. The pilot flame in the waste gas burner should be checked daily to:

    1. Make sure it has not been blown out by the wind
    2. Prevent valuable gas from escaping
    3. Prevent odorous gas from escaping
    4. Prevent explosive conditions from developing
    5. Make sure proper temperatures are maintained in the digester

14. The contents of a primary digester should be mixed to:

    1. Distribute food in the tank
    2. Allow solids separation
    3. Prevent formation of a scum blanket
    4. Warm up the sludge
    5. Keep the temperature the same throughout the tank

15. Successful digester operation depends on:

    1. Understanding what's happening in the digester
    2. Keeping all the digested sludge out of the digester
    3. Analysis and application of information from laboratory tests
    4. Cleaning the digester at regular intervals to maintain capacity
    5. Regularly checking the skimmers

16. Sludge pumped to the digester should be as thick as possible:

    1. To reduce heat requirements in the digester
    2. So the sludge will settle to the bottom of the digester
    3. So large amounts of digested sludge will not be displaced to the secondary digester
    4. So a scum blanket won't be formed in the digester
    5. None of these

17. The temperature of a digester should not be changed more than one degree per day to:

    1. Avoid excessive heat losses
    2. Avoid overloading the heat exchanger
    3. Allow the walls of the digester time to expand and contract
    4. Allow the organisms in the digester time to adjust to the temperature change
    5. Allow time for heating gas to be produced in the digester

18. The function of the water seal on the gas dome of the digester is to keep:

    1. Air from entering the digester
    2. Digester gas from escaping the digester
    3. Insects and rodents out of the digester
    4. Sludge from leaking out of the digester
    5. Foam inside the digester

19. Sludge or gas should not be removed too rapidly from the digester because:

    1. The sludge drying beds may become overloaded
    2. If a vacuum develops in the tank it may collapse
    3. If a vacuum develops in the tank air may be drawn in and form an explosive mixture
    4. The water seal could break
    5. The waste gas burner may become overloaded

20. A scum blanket in a digester may be broken up by:

    1. Vigorously mixing the digester contents
    2. Burning
    3. Use of long poles
    4. An ax
    5. Rolling back the blanket

21. The purpose of the secondary digester is to allow:

    1. For more sludge digestion
    2. An opportunity for more mixing
    3. Storage for seed sludge
    4. The liquids and solids in digested sludge to separate
    5. The designer to make more money

22. What could be happening if gas production in a digester starts decreasing?

    1. The volatile acid/alkalinity relationship is increasing
    2. The raw sludge volume fed to the digester is decreasing
    3. The raw sludge volume fed to the digester is excessive
    4. The scum blanket is breaking up
    5. The volatile acid/alkalinity relationship is decreasing

23. Sludge should be withdrawn slowly from a digester to prevent:

    1. Coning
    2. Supernatant from overloading the plant
    3. Forming a vacuum in the digester
    4. The possibility of an explosive gas mixture developing in the digester
    5. The possibility of the digester cover collapsing

24. What would you do if the volatile acid/alkalinity relationship started to increase in a digester?

    1. Increase time of mixing
    2. Maintain constant temperature throughout the digester
    3. Decrease sludge withdrawal rates
    4. Return some digested sludge
    5. Reduce volume of raw sludge pumped to digester

25. After sludge has been applied to the drying bed, the sludge draw-off line should be:

    1. Closed at both ends to keep out rodents and insects
    2. Open at one end to allow gas to escape
    3. Washed out
    4. Left full of sludge
    5. Filled with plant effluent

GLOSSARY

Chapter 8. Sludge Digestion and Handling

Anaerobic Digestion (AN-air-O-bick): Wastewater solids and water (about 5% solids, 95% water) are placed in a large tank where bacteria decompose the solids in the absence of dissolved oxygen. At least two general groups of bacteria act in balance: (1) Saprophytic bacteria break down the complex solids to volatile acids; and (2) Methane fermenters break down the acids to methane, carbon dioxide, and water.

BTU: British Thermal Unit. The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Buffer: A measure of the ability or capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water or wastewater for offering a resistance to changes in the pH.

Coning (CONE-ing): A condition that may be established in a sludge hopper during sludge withdrawal when part of the sludge moves toward the outlet while the remainder tends to stay in place. Development of a cone or channel of moving liquid surrounded by relatively stationary sludge.

Dewaterable: A material is considered dewaterable if water will readily drain from it. Generally raw sludge dewatering is more difficult than water removal from digested sludge.

Elutriation (e-LOO-tree-a-shun): The washing of digested sludge in plant effluent with a suitable ratio of sludge to effluent. The objective is to remove (wash out) fine particulates or certain soluble components in sludge.

Endogenous (en-DODGE-en-us): A diminished level of respiration in which materials previously stored by the cell are oxidized.

Enzymes (EN-zimes): Enzymes are substances produced by living organisms that speed up chemical changes.

Hydrolysis (hi-DROL-e-sis): The addition of water to the molecule to break down complex substances into simpler ones.

Inoculate (in-NOCK-you-LATE): To introduce a seed culture into a system.

Liquefaction (LICK-we-FACK-shun): Liquefaction as applied to sludge digestion means the transformation of large solid particles of sludge into either a soluble or a finely dispersed state.

Mesophilic Bacteria (mess-O-FILL-lick) (medium temperature): A group of bacteria that thrive in a temperature range between 68°F and 113°F.

Psychrophilic Bacteria (sy-kro-FILL-lick) (cold temperature): A group of bacteria that thrive in temperatures below 68°F.

Saprophytic Organisms (SAP-pro-FIT-tik): Organisms living on dead or decaying organic matter. They help natural decomposition of the organic solids in wastewater.

Stasis (STAY-sis): Stagnation or inactivity of the life processes within organisms.

Stuck: A stuck digester does not decompose organic matter properly. It is characterized by low gas production, high volatile acid/alkalinity relationship, and poor liquid-solids separation. A digester in a stuck condition is sometimes called a "sour" digester.

Supernatant (sue-per-NAY-tent): In a sludge digestion tank, the supernatant is the liquor between the surface scum and the settled sludge on the bottom of the tank.

Thermophilic Bacteria (thermo-FILL-lick) (hot temperature): A group of bacteria that thrive in temperatures above 113°F.

Wet Oxidation: Any process in which substances are converted to a higher oxidation state in a water media such as activated sludge, trickling filters, ponds, or digesters.

CHAPTER 8. SLUDGE DIGESTION AND HANDLING

(Lesson 1 of 5 Lessons)

8.0 INTRODUCTION

Settled solids removed from the bottom and floating scums removed from the top of clarifiers and sedimentation tanks are a watery, odorous mixture called raw sludge and scum. Frequently this raw sludge is pumped to a sludge digester for treatment before disposal. In the anaerobic sludge digester, the most common kind, bacteria decompose the organic solids in the absence of dissolved oxygen. Figure 8.1 shows the location of an anaerobic sludge digester in a typical plant. Figures 5.2, 6.2, and 7.2 also show plan views of the location of sludge digestion and handling facilities in relation to other treatment processes.

8.00 Purpose of Sludge Digestion

Anaerobic digestion[1] reduces wastewater solids from a sticky, smelly mixture to a mixture that is relatively odor free, readily dewaterable,[2] and capable of being disposed of without causing a nuisance.

In the process organic solids are liquefied, the solids volume is reduced, and valuable methane gas is produced in the digester by the action of two different groups of bacteria living together in the same environment. One group consists of saprophytic organisms,[3] commonly referred to as "acid formers". The second group, which utilized the

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[1] Anaerobic Digestion (AN-air-O-bick). Wastewater solids and water (about 5% solids, 95% water) are placed in a large tank where bacteria decompose the solids in the absence of dissolved oxygen. At least two general groups of bacteria act in balance: saprophytic bacteria (see Footnote 3) and methane fermenters break down the acids to methane, carbon dioxide, and water.

[2] Dewaterable. A material is considered dewaterable if water will readily drain from it. Generally raw sludge dewatering is more difficult than water removal from digested sludge.

[3] Saprophytic Organisms (SAP-pro-FIT-tik). Organisms living on dead or decaying organic matter. They help natural decomposition of the organic solids in wastewater.

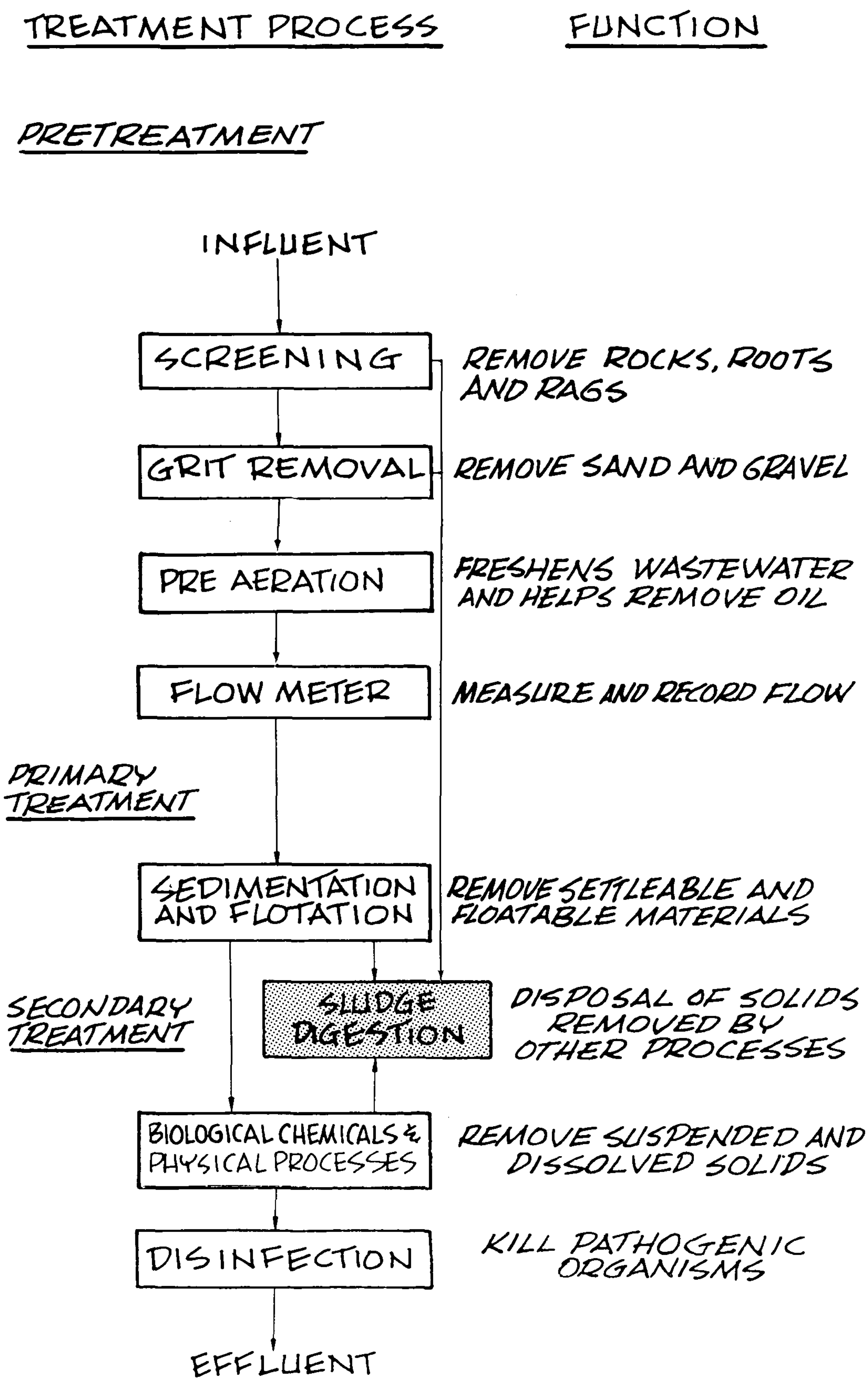

Fig. 8.1 Flow diagram of typical plant

acid produced by the saprophytes, are the "methane fermenters". The methane fermenters are not as abundant in raw wastewater as are the acid formers. The methane fermenters desire a pH range of 6.5 to 8.0 and will reproduce only in that range.

The object of good digester operation is to maintain suitable conditions in the digester for a growing (reproducing) population of both acid formers and methane fermenters. You must do this by the control of food supply (organic solids), volatile acid/alkalinity relationship, mixing, and temperature. Generally, you have done your job properly if the digester reduces the volatile (organic) solids content by between 40 and 60% of what they were in the raw sludge.

To obtain the desired degree of organic solids reduction may require from 5 to 120 days of digestion time. The time required depends on how good a job you are required to do on digesting the sludge, and on the adequacy of mixing, the organic loading rate, and the temperature at which the bacterial culture is maintained.

8.01 How Sludge Digestion Works (by William Garber)

The equations shown in Fig. 8.2 illustrate one way of outlining what happens in a digester. These equations indicate two general types of reactions:

1. Acid forming reactions which proceed at a rate dependent upon temperature, pH, and food conditions.

2. Methane fermentation reactions which proceed at a rate dependent upon temperature, pH, and food conditions.

You must try to operate an anaerobic sludge digester so that the rate of acid formation and methane fermentation are approximately equal; otherwise the reaction will get out of balance. The most common condition of unbalance that occurs is that the methane fermenters, which are sensitive anaerobes, fail to keep pace and the digester becomes acid because the rate at which acids are converted is too low.

The literature has been full of terms such as "Standard-Rate" and "High-Rate" digestion. These terms refer to digester loading and not to the rates of bacterial action. In "High-Rate" systems, mixing is used to obtain the best possible distribution of the substrate (food) and seed (organism) so that more bacterial reaction can occur.

RAW SLUDGE COMPLEX SUBSTRATE CARBOHYDRATES FATS PROTEINS + MICROORGANISMS "A" PRINCIPALLY ACID FORMERS SAPROPHYTIC FACULTATIVE → CO_2, H_2O. INTERMEDIATE DEGRADATION PRODUCTS + ORGANIC ACIDS CELLULAR AND OTHER INTERMEDIATE DEGRADATION PRODUCTS

ORGANIC ACIDS CELLULAR AND OTHER INTERMEDIATE DEGRADATION PRODUCTS + MICROORGANISMS "B" PRINCIPALLY METHANE FORMERS OBLIGATE(?) ANAEROBES → CH_4 METHANE + CO_2 CARBON DIOXIDE + OTHER END PRODUCTS H_2O, H_2S AND DEGRADATION PRODUCTS

Fig. 8.2 Reactions in a digester

Mixing is the most important factor in the so-called "High-Rate" processes, and it is considered to accomplish the following:

1. Utilize as much of the total content of a digester as possible.

2. Quickly distribute the raw sludge food throughout the volume of sludge in the tank.

3. Put the microorganisms in contact with the food.

4. Dilute the inhibitory by-products of microbiological reactions throughout the sludge mass.

5. Achieve good pH control by distributing buffering alkalinity throughout the digestion tank.

6. Obtain the best possible distribution of heat through the tank.

7. Minimize the separation of grit and inert solids to the bottom or floating scum material to the top.

A digester may be operated in one of three temperature zones or ranges, each of which has its own particular type of bacteria. The lowest range (in an unheated digester) utilizes psychrophilic (cold temperature loving) bacteria.[4] Temperature of the sludge inside tends to adjust to the outside temperature. However, below 50°F little or no bacterial activity occurs and the necessary reduction in sludge volatiles (organic matter) will not occur. When the temperature increases above 50°F, bacterial activity increases to a measurable rate and digestion starts again. The bacteria appear to be able to survive temperatures well below freezing with little or no harm. The psychrophilic upper range is around 68°F. Digestion in this range requires from 50 to 180 days, depending upon the degree of treatment (solids reduction) required. Few digesters are designed today to operate in this range, but there are many still in use, including most Imhoff tanks and similar unheated digesters with no mixing devices. Generally these digesters are not very effective in digesting sludge.

[4] Psychrophilic Bacteria (organisms) (sy-kro-FILL-lick). A group of bacteria that thrive in temperatures below 68°F.

The middle range of organisms are called the mesophilic (medium temperature loving) bacteria[5]; they thrive between about 68°F and 113°F. This is the most common operational range, with temperatures usually being maintained at about 95°F to 98°F. Digestion at that temperature may take from 5 to 50 days or more (normally around 25 to 30 days), depending upon the required degree of volatile solids reduction and adequacy of mixing. The so-called "High-Rate" processes are usually operated within the mesophilic temperature range. These are nothing more than procedures to obtain good mixing so that the organisms and the food can be brought together to allow the digestion processes to proceed as rapidly as possible. With the most favorable conditions the time may be no more than five days for an intermediate level of digestion.

The third range of organisms are called thermophilic (hot temperature loving) bacteria,[6] and they thrive above 113°F. The time required for digestion in this range falls between 5 and 12 days, depending upon operational conditions and degree of volatile solids reduction required. However, the problems of maintaining temperature, sensitivity of the organisms to temperature change, and some reported problems of poor solids-liquid separation are reasons why only a few plants have actually been operated in the thermophilic range.

You cannot merely raise the temperature of the digesters and have a successful operation in another range. The bacteria must have time to adjust to the new temperature zone and to develop a balanced culture before continuing to work. An excellent rule for digestion is never change the temperature more than one degree a day to allow the bacterial culture to become acclimated (adjust to the temperature changes).

Secondary digestion tanks are sometimes used to allow liquids (supernatant)[7] to separate from the solids, to provide a small amount of additional digestion, and to act as a "seed" source (the settled, digested sludge). However, digestion tanks generally have too small a "surface area to depth" ratio to be good sedimentation tanks. Separation of solids from liquids is more efficient in

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[5] Mesophilic Bacteria (mess-O-FILL-lick). A group of bacteria that thrive in a temperature range between 68°F and 113°F.

[6] Thermophilic Bacteria (thermo-FILL-lick). A group of bacteria that thrive in temperatures above 113°F.

[7] Supernatant (sue-per-NAY-tent). In a sludge digestion tank, the supernatant is the liquor between the surface scum and the settled sludge on the bottom of the tank.

lagoons or in tanks designed for separation. If a significant amount of digestion occurs in the secondary tank, the result may be poor separation of solids. Secondary digesters should be used for solids concentration and for a reservoir of alkalinity and seed sludge which may be returned to the primary digester when needed.

You have certain other items you can use for control in addition to mixing and temperature selection. These include:

1. Varying the sludge concentration or water added to the system.

2. Varying the rate and frequency of feeding, with continuous feed the most desirable.

3. Closely controlling grit and skimming in order that capacity of the tank is affected as little as possible by these materials.

4. Cleaning regularly to maintain capacity.

5. A good maintenance program to maintain the maximum degree of flexibility.

6. Maintaining records and laboratory control in order that process condition is known at all times.

Although digestion is a complex process and only a portion of its theory is understood, enough is known to allow you to exercise good operational control. For sludge digestion as for any of the wastewater processes, remember that for the most successful operation you need to do the following:

1. Understand the theory of the process so you know what you are basically trying to do.

2. Know your facilities thoroughly so that you can attain maximum flexibility of operation.

3. Keep careful records and use laboratory analyses to follow the process continually.

4. Maintain your facilities in the best possible condition at all times.

QUESTIONS

8.01A Why must raw sludge be digested?

8.01B What happens during digestion?

8.01C What are some of the important factors in controlling the rate of reproduction of acid-forming and methane bacteria in a digester?

8.1 COMPONENTS IN THE ANAEROBIC SLUDGE DIGESTION PROCESS

To understand and operate an anaerobic sludge digester, the operator must be familiar with the location and function of the various components of the digestion facility.

8.10 Pipelines and Valves

Raw sludge pipelines are usually constructed of cast iron or steel to withstand pumping pressures. In recent years glass-lined or epoxy-lined sludge lines have been used to alleviate the problem of grease deposits. These deposits cut capacity and may cause stoppages. Some plants use "go-devil" type cleaners and/or hot chemical solutions such as T.S.P. instead.

The valves used in sludge and scum lines are mostly of the plug type. They give positive control where a gate or butterfly valve may become blocked by rags or other material which will not allow the valve to seat. In some cases a gate or butterfly valve is indicated because a quick closing plug valve could result in water hammer and damage the pipeline.

CAUTION

NEVER START A POSITIVE DISPLACEMENT PUMP AGAINST A CLOSED VALVE, BECAUSE EXCESSIVE PRESSURE MAY RESULT IN DAMAGING THE LINE OR THE PUMP. ALL PUMPS SHOULD BE EQUIPPED WITH PRESSURE CUT-OFF DEVICES, BUT SOMETIMES THESE DEVICES FAIL OR ALLOW THE PRESSURE TO BUILD UP HIGH ENOUGH TO CAUSE DAMAGE. A SLUDGE LINE SHOULD NEVER BE ISOLATED BY CLOSING THE VALVES ON EACH END FOR SEVERAL DAYS BECAUSE GAS PRODUCTION CAN GENERATE SUFFICIENT PRESSURES TO CAUSE THE LINE TO FAIL. ALSO, THE SOLIDS WILL FORM AN ALMOST IMMOVABLE MASS IN THE LINE.

QUESTIONS

8.10A Why are plug type valves used in sludge lines?

8.10B Why should a positive displacement pump never be started against a closed valve?

8.10C Why should a sludge line never be closed at both ends?

8.11 The Digester

Digestion tanks may be cylindrical or cubical in shape. Most tanks constructed today are cylindrical. The floor of the tank is sloped so that sand, grit, and heavy sludge will tend to be removed from the tank. Most digesters constructed today have either fixed or floating covers.

A. Fixed Cover Tanks

A fixed cover tank has a stationary roof, generally slab, conical, or cone-shaped, and constructed of concrete or steel. Both types of covers are normally designed to maintain no more than an eight-inch water column of gas pressure on the tank roof (Fig. 8.3), but some are designed for pressures of 25 inches or more. The domed cover is designed to hold a larger volume of gas. Any type of mixing device may be used with a fixed cover tank, and the tank must be equipped with pressure and vacuum relief valves.

A fixed cover digester can have an explosive mixture in the tank when sludge is withdrawn if proper precautions are not taken to prevent air from being drawn into the tank. Each time a new charge of raw sludge is added, an equal amount of supernatant is displaced because the tank is maintained at a fixed level.

B. Floating Cover

A floating cover moves up and down with the tank level and gas pressure. Normally the vertical travel of the cover is about eight feet, with stops (corbels) or landing edges for down (lowering) control and

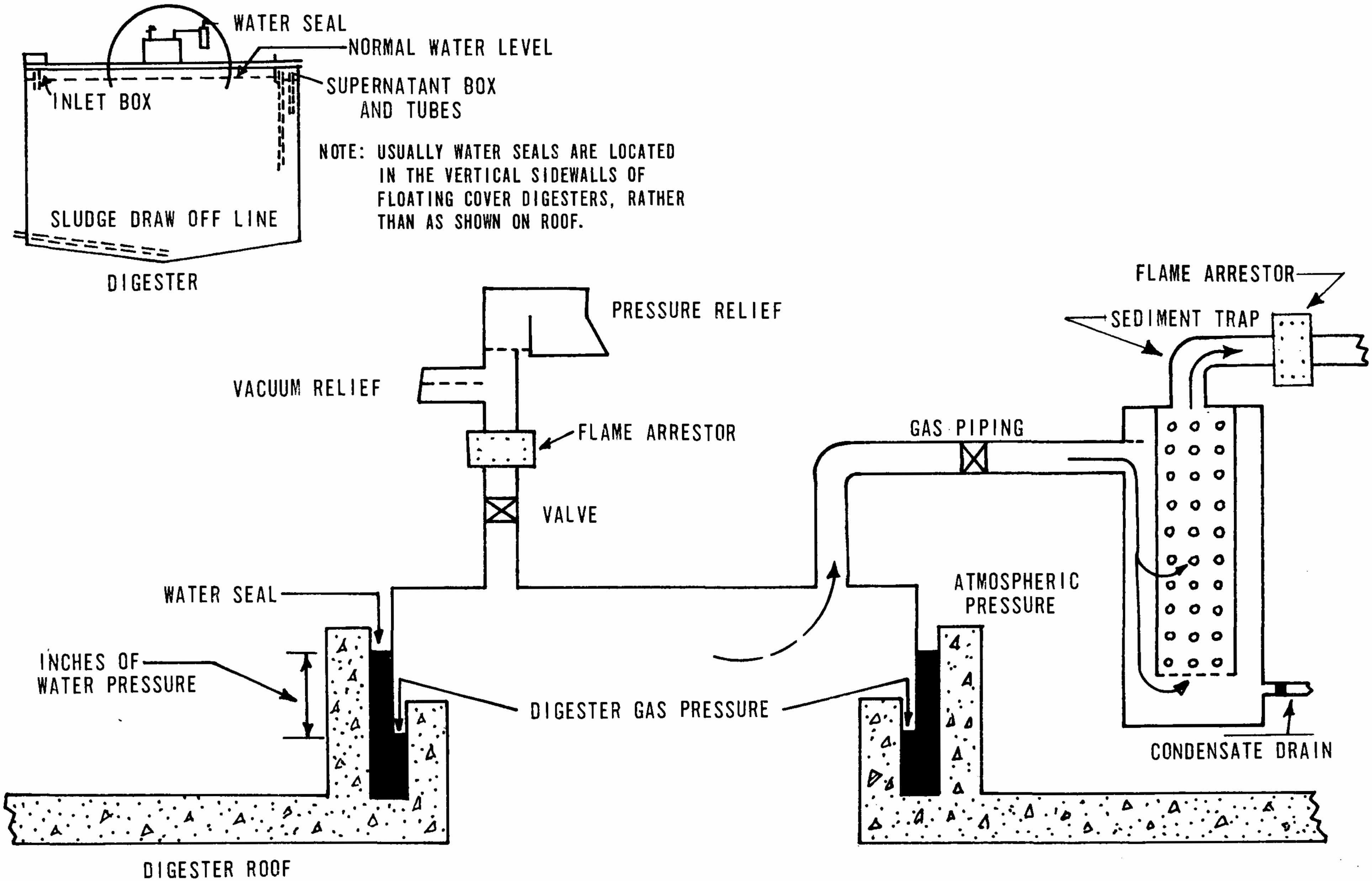

Fig. 8.3 Water seal on digester

maximum water level for upward travel. Maximum water level is controlled by an overflow pipe that must be kept clear to prevent damage to the floating cover by overfilling. Gas pressure is dependent upon the weight of the cover. The advantages of a floating cover include less danger of explosive mixtures forming in the digester, better control of supernatant withdrawal, and better control of scum blankets. Disadvantages include higher construction and maintenance costs.

C. Digester Depth

A typical operation depth for digesters is around 20 feet (side wall water level depth). The bottom slopes downward to the center of the tank. A gas space of two to three feet is usually provided above normal liquid sludge level, but some floating covers allow more room for gas storage.

D. Raw Sludge Inlet

Typically the raw sludge feed is piped to the top of the primary digester and admitted on the side opposite the supernatant overflow pipe (Fig. 8.4) to the secondary digester. Typically this line also carries any recirculated digester sludge in the system so that the raw sludge is immediately seeded with bacteria as it enters the tank.

E. Supernatant Tubes (Fig. 8.4)

On a fixed cover digester there may be three to five supernatant tubes set at different levels for supernatant removal. Normally only one tube is used at a time. The tube used is selected to return the supernatant liquor with the lowest quantity of solids back to the primary clarifier, or to sludge drying beds, provided space is available.

A single adjustable tube is also used at some plants. On the floating cover digester there is usually only one supernatant tube. This may be adjusted to pull supernatant liquor from various levels of the tank by raising or lowering the tube. In smaller plants the supernatant withdrawal may be done only once or twice a day, because the floating cover allows the tank to handle volume changes. An adjustable tube usually allows a supernatant with the least solids content to be selected. The digester should be visually checked a minimum of once per day for liquor levels to prevent overfilling and structural damage to the tank.

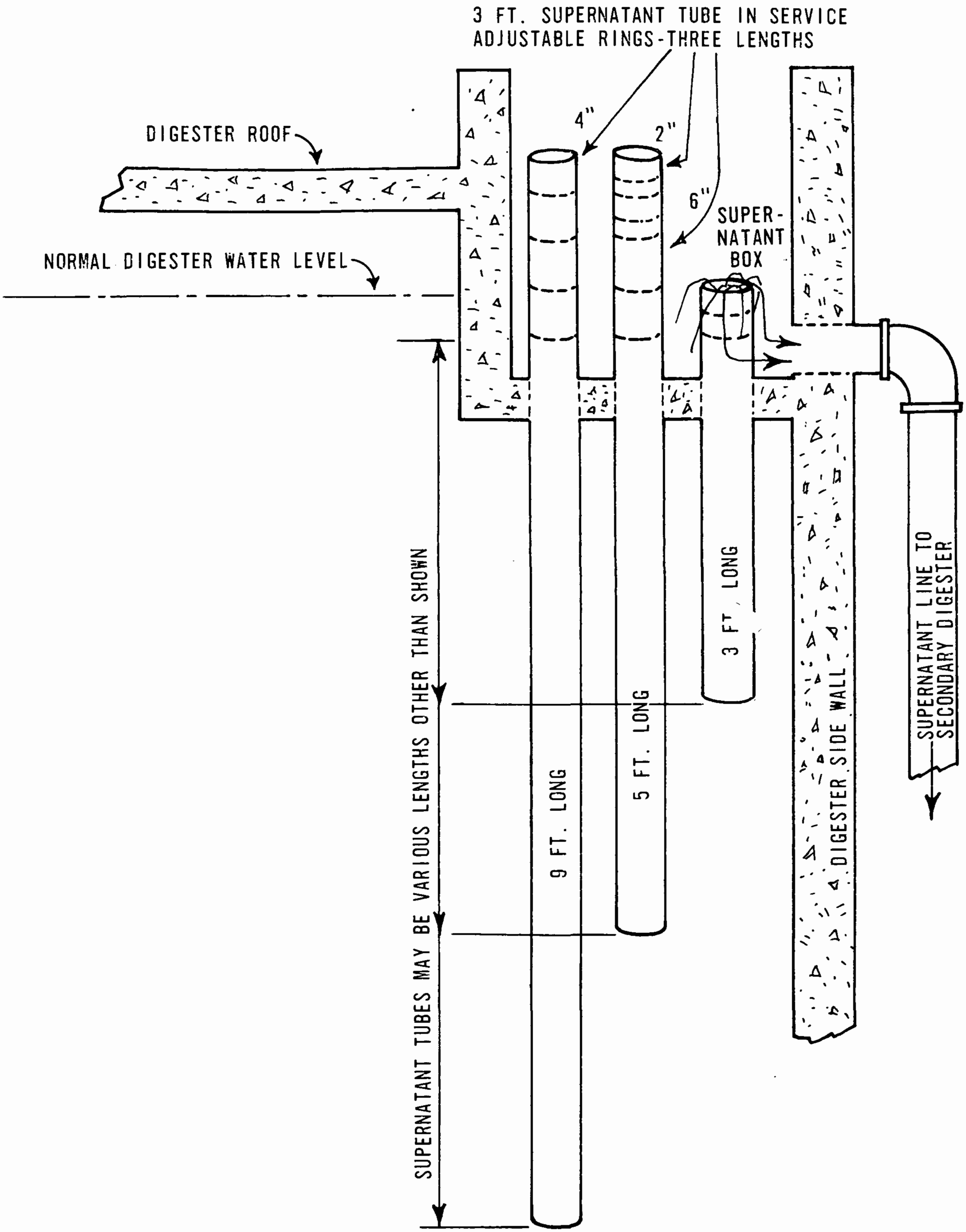

Fig. 8.4 Supernatant tubes and box

F. Sludge Draw-off Lines

The sludge draw-off lines are typically placed on blocks along the sloping floor of the digester. Sludge is withdrawn from the center of the tank. Very seldom are they placed under the floor of the digester because they would not be accessible in case of blockages. These lines are normally six inches in diameter and equipped with plug valves. The lines are used to transfer the digester sludge periodically to a sludge disposal system of either drying beds or some type of dewatering system. These lines also transfer seed sludge from the secondary digester to the primary digester and recirculate bottom sludge to seed and break up a scum blanket.

QUESTIONS

8.11A Why should you maintain no more than an eight-inch water column of gas pressure on the roof of a fixed cover digester?

8.11B Why must a fixed cover digester be equipped with pressure and vacuum relief valves?

8.11C What are the advantages of a floating cover in comparison with a fixed cover digester?

8.11D Why is it desirable to mix recirculated digester sludge with raw sludge?

END OF LESSON 1 OF 5 LESSONS

on

SLUDGE DIGESTION AND HANDLING

DISCUSSION AND REVIEW QUESTIONS

Chapter 8. Sludge Digestion and Handling

At the end of each lesson in this chapter you will find some discussion and review questions which you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson.

Write the answers to these questions in your notebook before continuing.

1. Briefly explain what happens when sludge is added to an anaerobic digester.
2. Why is it important to keep the contents of a digester well mixed?
3. Why should the floor of a digester be sloped?
4. Why do digesters have supernatant tubes?

8.12 Gas System (Fig. 8.5)[8]

The anaerobic digestion process produces 7 to 12 cubic feet of gas for every pound of volatile matter destroyed, depending upon the characteristics of the sludge. The gas consists mainly of methane (CH_4) and carbon dioxide (CO_2). The methane content of the gas in a properly functioning digester will vary from 65 to 70%, with carbon dioxide running around 30 to 35% by volume. One or two percent of the digester gas is composed of various other gases.

Digester gas (due to the methane) possesses a heat value of approximately 500 to 600 BTU[9] per cubic foot, whereas natural gas with a higher methane content may range from 900 to 1200 BTU per cubic foot.

Digester gas is utilized in plants in various ways: for heating the digesters, for heating the plant buildings, for running engines, for air blowers for the activated sludge process, or for electrical power for the plant.

WARNING

DIGESTER GAS CAN BE EXTREMELY DANGEROUS IN TWO WAYS. WHEN MIXED WITH OXYGEN IT CAN FORM **EXPLOSIVE MIXTURES**, AND IT ALSO CAN CAUSE **ASPHYXIATION** OR **OXYGEN STARVATION**. SMOKING, OPEN FLAMES, OR SPARKS **MUST NOT BE TOLERATED** AROUND THE DIGESTERS OR SLUDGE PUMPING FACILITIES.

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[8] Many figures in this section were made available courtesy of VAREC, Inc., 301 East Alondra Blvd., Gardena, California 90247. Mention of commercial products or manufacturers is for illustrative purposes and does not imply endorsement by Sacramento State College, EPA/WQO, or any other state or federal agency.

[9] BTU: British Thermal Unit. The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

The gas system removes the gas from the digester to a point of use, or to be burned in the waste gas burner as excess. The following items are components of the gas system.

A. Gas Dome

This is a point in the digester roof where the gas from the tank is removed. On fixed cover tanks there may also be a water seal (Fig. 8.3) incorporated to protect the tank structurally from excess positive pressure,[10] or vacuum created by withdrawal of sludge or gas too rapidly.

If gas pressure is allowed to build up to 11 inches of water column pressure, it will escape around the water seal to the atmosphere without lifting the roof. If sludge is drawn or gas used too rapidly, the vacuum could exceed eight inches and break the water seal, thus allowing air to enter the tank. Without the water seal, the vacuum could become great enough to collapse the tank. Air in the tank creates an explosive condition. In addition, sulphuric acid corrosion is often found where air is consistently in contact with the gas. The pipeline between the gas storage tank and the digester will protect the digester from water seal leaks, if the line is clear. When liquids are pumped into the digester, gas can go out the line to the storage tank and when liquids are pumped out of the digester, gas can return through the line.

QUESTIONS

8.12A What are the two main gaseous components of digester gas after gas production has become well established?

8.12B What are some uses of digester gas?

8.12C Why must the digester gas be controlled with extreme caution?

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[10] Positive Pressure. A positive pressure is a pressure greater than atmospheric. It is measured as pounds per square inch (psi) or as inches of water column. A negative pressure (vacuum) is less than atmospheric and is sometimes measured in inches of mercury.

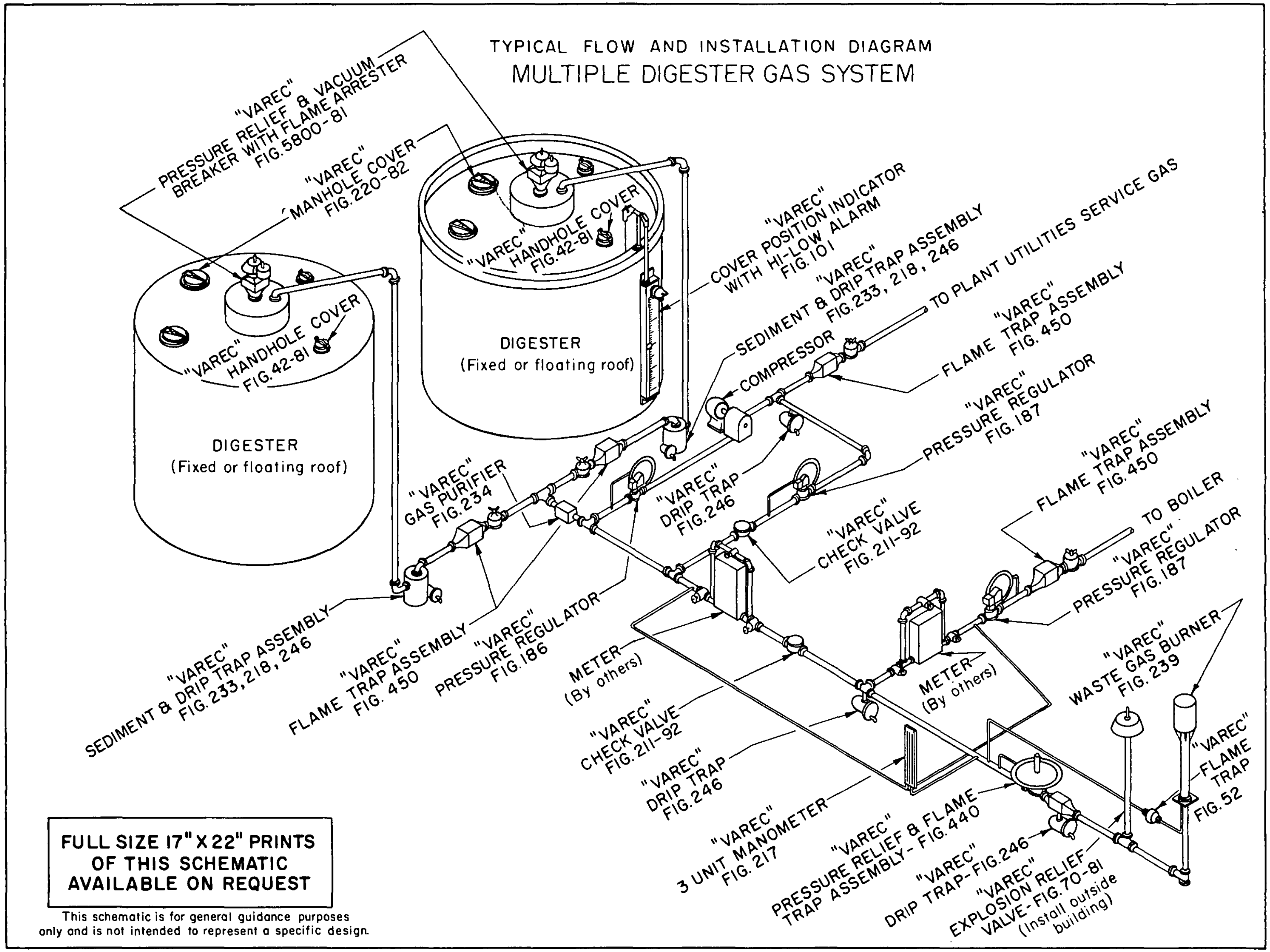


Fig. 8.5 Digester gas system
Courtesy of VAREC

B. Pressure Relief and Vacuum Relief Valves
(Fig. 8.6, VAREC Fig. No. 5800-81)

The pressure relief valve and the vacuum relief valve both are attached to a common pipe, but each works independently. The pressure relief valve is equipped with a seat and weighted with lead washer weights. Each weight is stamped with its equivalent water column height[11] such as 1" H_2O or 3" H_2O. There should be sufficient weights, combined with the weight of the pallet, to equal the designed holding pressure of the tank. The gas pressure is normally established between six inches and eight inches of water. If the gas pressure in the tank exceeds the pop-off setting, then the valve will open and vent to the atmosphere for a couple of minutes, through the pressure relief valve. This should occur before the water seal blows out. The water seal can be broken when a tank is overpumped or gas removal is too slow.

The vacuum relief valve operates similarly to the pressure relief valve except that it relieves negative pressures to prevent the tank from collapsing. Operating of either one of these valves is undesirable, because this allows the mixing of digester gas with air and can create an explosion outside the tank if the pressure relief valve opens and inside the tank if the vacuum relief opens.

WARNING

A GAS MIXTURE RATIO OF 5.7 TO 13.5% DIGESTER GAS TO AIR IS EXPLOSIVE (LOWER AND UPPER LIMITS). (FIGURE 8.7)

These two valves should be checked at least every six months for proper operation.

[11] Water Column Height. When pressure builds up in a digester, the gas pressure would force water up a tube of water connected to the outside of the digester. The higher the water column height, the greater the gas pressure.

PRESSURE RELIEF AND VACUUM BREAKER VALVE WITH FLAME ARRESTER

for Use on Digesters and Gas Holders

The "Varec" Figure No. 5800-81 unit consists of a Figure No. 2000-81 Pressure Relief and Vacuum Breaker Valve and a Figure No. 50-91 Flame Arrester. Maximum protection against excessive pressure and vacuum is afforded and accidental ignition of sludge gas within the digester and gas holder from external sources is eliminated.

Valve is light weight and corrosion resistant construction. Interior parts are readily accessible for inspection and maintenance purposes. Pallets are dead weight loaded and include replaceable synthetic rubber sludge gas resistant seat inserts to insure gas tight seating and long life service with minimum maintenance. Seat rings, pallets and guide posts are anodized for extra corrosion protection and are removable.

Flame arrester consists of a flame arresting bank assembly enclosed within a gas-tight housing. The bank consists of a multiple number of individual corrugated stamped sheets and is readily removable from the housing for inspection and cleaning purposes. The arrester is listed by Underwriters Laboratories and is approved by Associated Factory Mutual Laboratories.

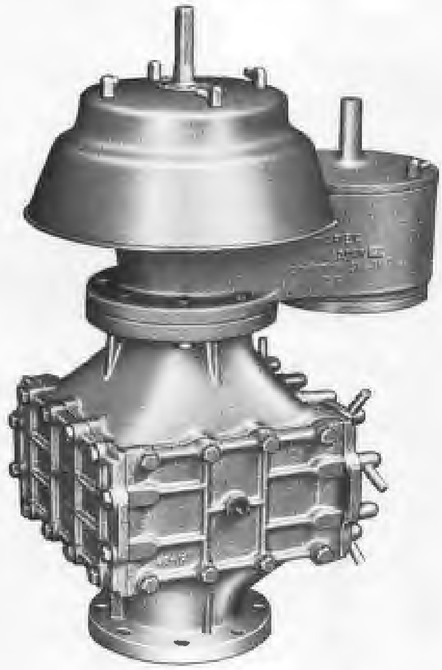


FIGURE NO. 5800-81

SETTINGS

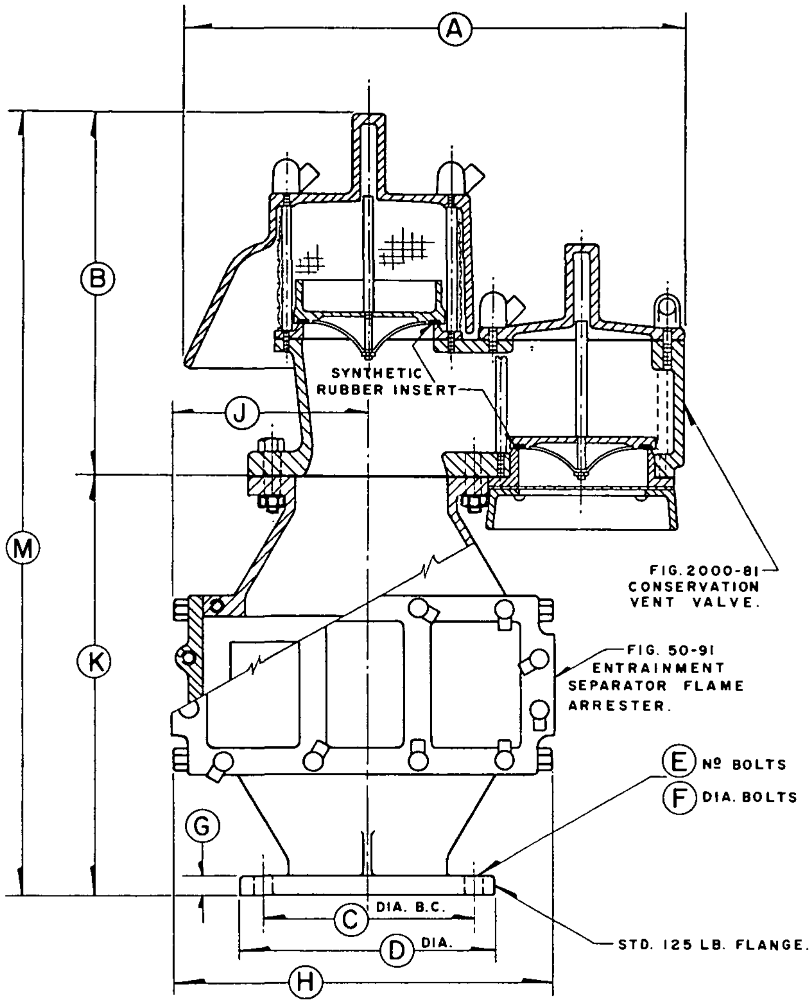
Valves are furnished with variable pressure settings from 2″ to 10″ of water in increments of 1″ of water. Vacuum setting is 2″ of water unless otherwise specified.

STANDARD MATERIALS OF CONSTRUCTION

Valve is substantially aluminum (impervious to the attack of sludge gas) throughout except for synthetic rubber pallet seat inserts and steel studs, nuts and screws.

Flame arrester bank is all aluminum and the housing consists of cast aluminum ends and cast iron side and cover plates. Gaskets are graphited asbestos.

FIG. Nº 5800-81

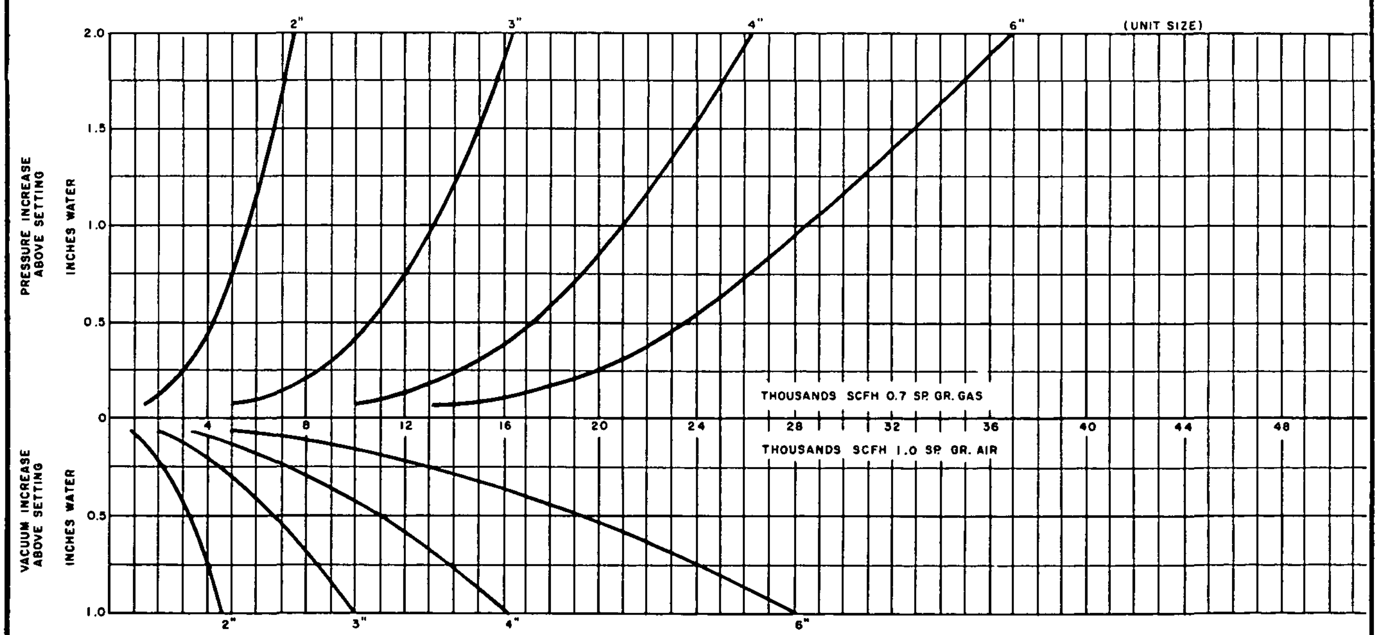


SIZES, DIMENSIONS AND APPROXIMATE SHIPPING WEIGHTS — FIG. 5800-81

SIZE	2″	3″	4″	6″
A	12½	16⅜	20	25
B	9¾	10⅝	14	17
C	4¾	6	7½	9½
D	6	7½	9	11
E	4	4	8	8
F	⅝	⅝	⅝	¾
G	⅝	¾	15/16	1
H	9	11¾	14½	16½
J	5⅛	6¾	8⅛	9¼
K	12⅝	13⅞	16⅝	21½
M	22⅜	24½	30⅝	38½
SHIP WT.-LBS.	65	100	150	250

LARGER SIZES AVAILABLE.

FLOW CURVES



An Explosive Gas Mixture was Accidentally Ignited,

The Digester Cover Blew Off,

And Landed on Top of a Pickup Truck.

Fig. 8.7 Results of digester explosion

QUESTIONS

8.12D How would you adjust the pressure relief valve to prevent pressures within the digester from exceeding the design pressure?

8.12E How could the water seal be broken in a digester?

8.12F Why is the operation of either the pressure relief valve or the vacuum relief valve undesirable?

C. Flame Arrestors (Fig. 8.8, VAREC Fig. No. 450)

A typical flame arrestor is a rectangular box holding approximately 50 to 100 corrugated aluminum plates with punched holes. If a flame should develop in the gas line, it would be cooled below the ignition point as it attempted to pass through the baffles, but gas could flow through with little loss in pressure.

To prevent explosions, flame arrestors should be installed:

1. Between vacuum and pressure relief valves and the digester dome.

2. After sediment trap on gas line from digester.

3. At waste gas burner.

4. Before every boiler, furnace, or flame.

Flame arrestors should be serviced every three months by valving the gas off, pulling one end plate, and sliding the baffle cartridge out of the housing. A build-up of scale, salts from condensate, and residue build-up on the plates restricts gas flow.

The cartridge in the flame arrestor is designed to slide open so the baffles may be separated and washed without complete dismantling. When the unit is reassembled it should be tested for leaks by swabbing a soapsuds solution over potential leaky areas and inspecting for bubbles.

D. Thermal Valves

Another protective device installed near a flame source and near the gas dome is the thermal valve. This valve is round, with a weighted seat attached to a stem. The stem sets on a fusible disk holding the seat up. If enough heat is generated by a flame, the fusible element melts and drops the stem and valve seat to cut off gas flow. Most valves are equipped with a wing nut on top of the valve body. If the wing nut is removed, it uncovers a glass tube which shows visually if the stem is up. If the stem cannot be seen, then the valve is closed, and no gas can flow. If this occurs, the valve is removed and heated in boiling water to remove the melted fusible slug. A new slug is installed (slightly larger than an aspirin tablet), the stem replaced on top of it, and the valve is ready for service. These valves should be dismantled at least once a year in order to be positive that the stem is free to fall and not gummed up with residue or scale from the gas.

Figure 8.9 (VAREC Fig. No. 440) shows a flame arrestor connected to a pressure relief valve.

QUESTIONS

8.12G How would you service a flame arrestor?

8.12H Why should you check the thermal valves at least once a year?

FLAME TRAP ASSEMBLY

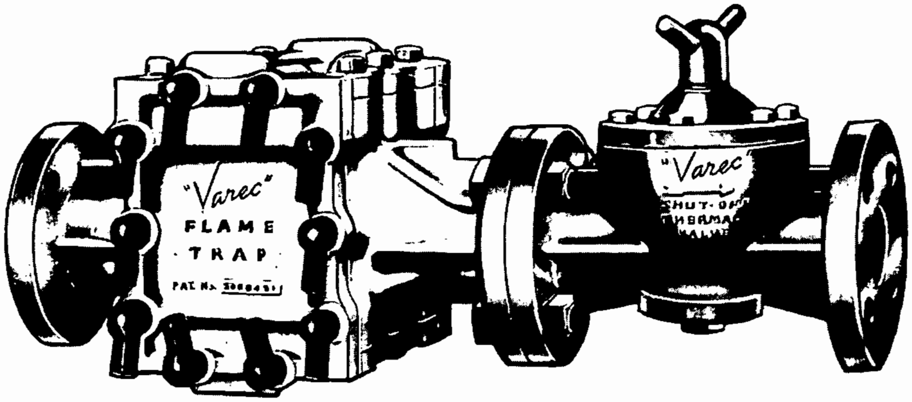


FIGURE NO. 450

Assembly consists of "Varec" Flame Trap Fig. No. 53-81 and Thermal Operated Shutoff Valve Fig. No. 430.

It is usually installed in all gas lines to gas utilization equipment, as close as possible to the points of combustion, and in lines leading from each digester and gasholder. May be installed in either horizontal or vertical pipelines.

It is designed to arrest and stop flame propagation — and to stop explosion waves, thus insuring protection of major equipment.

FEATURES

Simple and positive flame trap. The fusible element melts at 260° and stops gas flow within 15 seconds. Compression type fusible element prevents shutoff valve closing unless contacted by flame. Three extra fusible elements shipped with each unit.

Since this unit is manufactured of aluminum, it resists the attack of any of the corrosive elements common to sludge gas.

Indicator rod shows when valve is in normal open position.

The "Varec" Flame Trap Fig. No. 53-81 of this unit is listed by the Underwriters' Laboratories and approved by Associated Factory Mutual Laboratories.

Net free area through flame arresting bank is approximately four times corresponding pipe size. Each passageway has a net free area of approximately 0.042 sq. inches. By actual test these units have more flow capacity with less pressure drop than any known contemporary device.

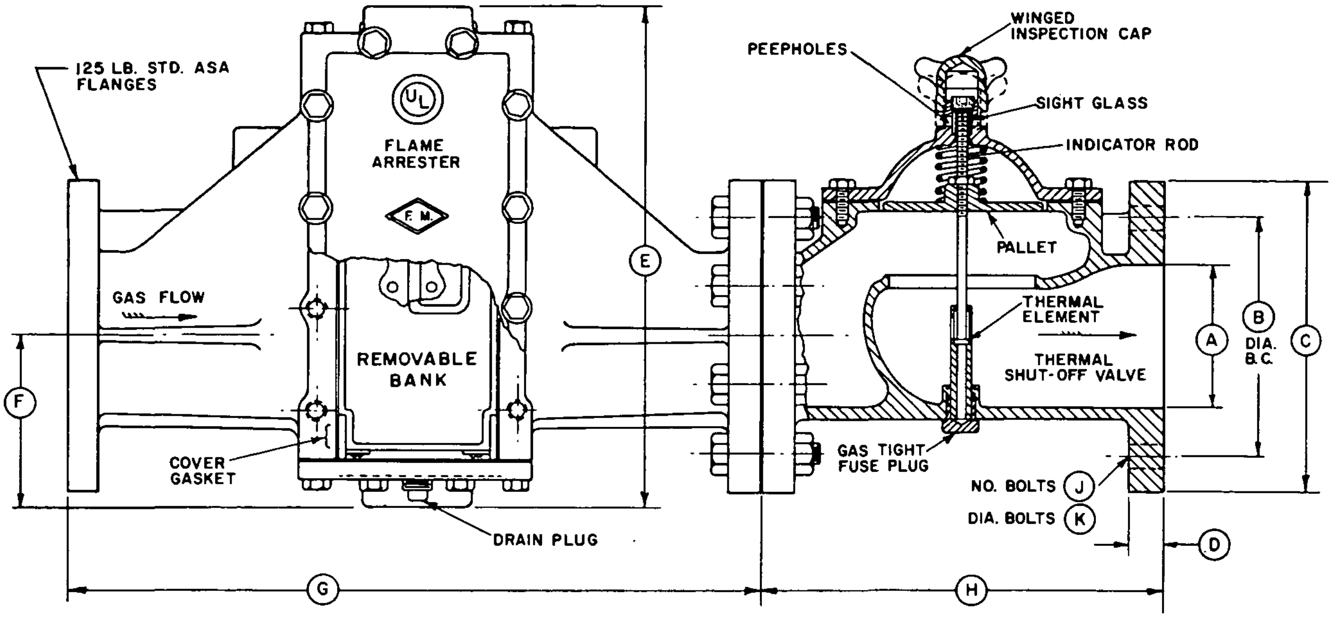
Flow capacity curves are shown on the following page to assist in selecting the correct size of equipment.

Flame Trap element is easy to inspect and clean. It has good vertical and horizontal drainage. Drip Trap connection is provided in case Unit is installed at low point in line.

MATERIALS OF CONSTRUCTION

Flame Trap Housing — aluminum and cast iron
Flame Trap Element — aluminum
Thermal Valve Body & Cover — aluminum
Guide Stem — stainless steel
Sight Glass — pyrex
Cover and cap gaskets — graphited asbestos
Sight glass gasket — synthetic rubber
Spring — stainless steel

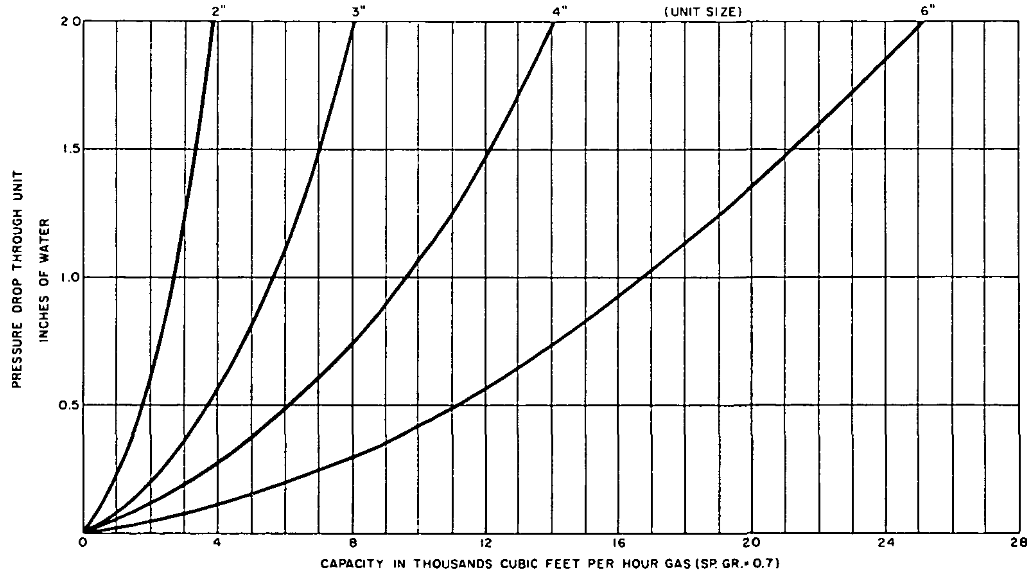
FIGURE NO. 450



SIZES, DIMENSIONS, WEIGHTS

SIZE	A	B	C	D	E	F	G	H	J	K	APPROX. WT. LBS. NET	APPROX. WT. LBS. SHIP
2"	2	4¾	6	⅝	8½	3½	14½	8¾	4	⅝	55	90
3"	3	6	7½	¾	10¾	4½	16	10	4	⅝	80	125
4"	4	7½	9	15/16	11¾	5	20	11⅜	8	⅝	100	150
6"	6	9½	11	1	14¼	5½	24⅜	15	8	¾	155	215

NOTE: Available in 8" size upon special order.



PRESSURE RELIEF AND FLAME TRAP ASSEMBLY

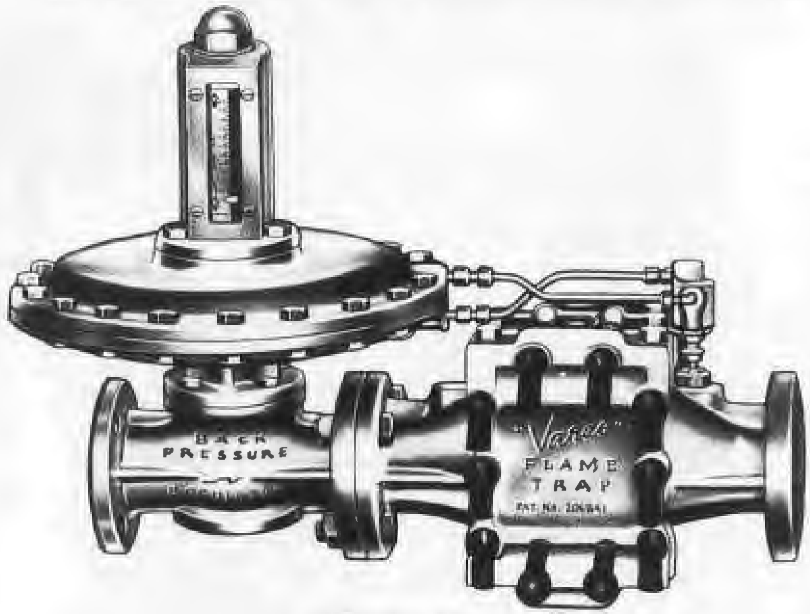


FIGURE NO. 440

Assembly consists of "Varec" Figure No. 386 Back Pressure Regulator, a "Varec" Figure No. 53-81 Flame Trap and a Thermal Shutoff Control unit.

It is usually installed in the waste gas line, just upstream of the waste gas burner.

It is designed to maintain a predetermined back pressure throughout the gas system so that only surplus gas is wasted, and to stop flame and explosion waves.

FEATURES

Simple, foolproof, sensitive in operation and a positive flame trap. The fusible element melts at 260°F. and stops gas flow within 15 seconds. Compression type fusible element prevents shutoff valve closing unless contacted by flame. Three extra fusible elements supplied with each unit.

Since the main bodies of the unit are constructed of aluminum and the stems, needle valve, and other important moving parts are of 18.8 stainless steel, this unit resists the attack of any of the corrosive elements common to sludge gas.

The "Varec" Flame Trap Fig. No. 53-81 of this unit is listed by the Underwriters' Laboratories and approved by Associated Factory Mutual Laboratories. The Flame Trap element is easy to inspect and clean. Drip Trap connection is provided in case unit is installed at a low point in line.

Net free area through flame arresting bank is approximately four times corresponding pipe size. Each passageway has a net free area of approximately 0.042 sq. inches. By actual test these units have more flow capacity with less pressure drop than any known contemporary device.

Flow capacity curves are shown on the following page to assist in selecting the correct size of equipment.

The Back Pressure Regulator unit is equipped with setting indicator so operator can easily adjust setting to requirements.

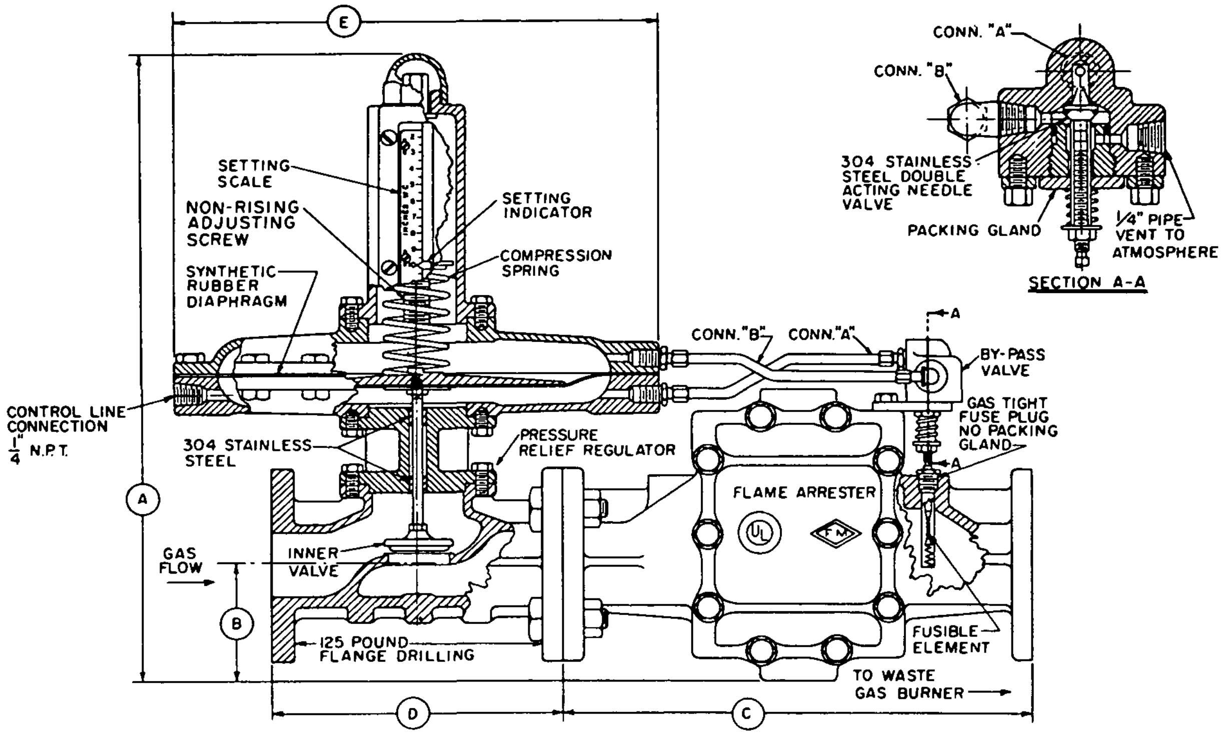
RANGE OF OPERATION

Range of operation is 2 to 12 inches water. Special springs available for higher operating pressures. Equipment supplied by factory set at 6 inches of water if not specified otherwise. Operator can adjust to his requirements.

MATERIALS OF CONSTRUCTION

- Regulator Body — cast aluminum
- Diaphragm Case — cast aluminum
- Bonnet — cast aluminum
- Spring — Cadmium-plated steel
- Diaphragm — corded synthethic rubber
- Cap — brass
- Thermal Shutoff Valve — aluminum, brass & stainless steel
- Flame Trap Housing — heavy cast aluminum ends and cast iron side and cover plates
- Flame Trap Element — aluminum

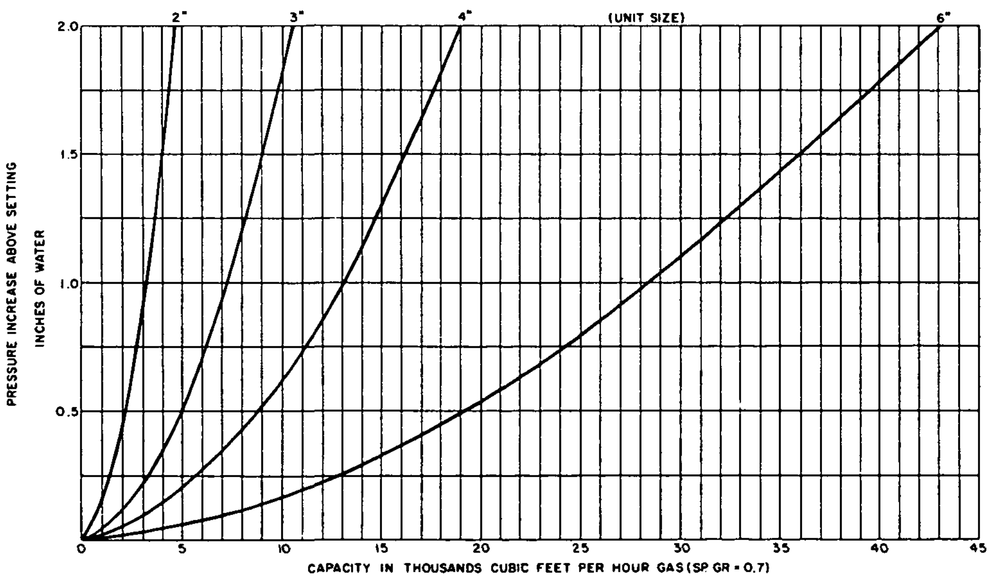
FIGURE NO. 440



SIZES, DIMENSIONS, WEIGHTS

Pipe Size	A	B	C	D	E	Net Wt. lbs.	Ship. Wt. lbs.
2"	19⅝"	3½"	14½"	8¾"	14½"	90	125
3"	22⅛"	4⅛"	16"	10 "	20½"	115	160
4"	23⅜"	4⅝"	20"	11¾"	20½"	150	200
6"	30 "	5¾"	24⅜"	15 "	26½"	210	260

NOTE: Available in 8" size upon special order.



E. Sediment Traps

A sediment trap is a tank 12 to 15 inches in diameter and two to three feet in length. It is usually located on top of the digester near the gas dome. The inlet gas line is near the top of the tank and on the side. The outlet line comes directly from the top of the sediment tank. The sediment trap is also equipped with a perforated inner baffle, and a condensate drain near the bottom. The gas enters the side at the top of the tank, passes down and through the baffle, then up and out the top. Moisture is collected from the gas in the trap, and any large pieces of scale are trapped before entering the gas system. The trap should be drained of condensate frequently but may have to be drained twice a day during cold weather, because greater amounts of water will be condensed.

F. Drip Traps--Condensate Traps
(Fig. 8.10, VAREC Fig. Nos. 245 and 246)

Digester gas is quite wet and in traveling from the heated tank to a cooler temperature the water condenses. The water must be trapped at low points in the system and removed, or it will impede gas flow and cause damage to equipment, such as compressors, and interfere with gas utilization. Traps are usually constructed to have a storage space of one to two quarts of water. All drip traps on gas lines should be located in the open air and be of the manual operation type. Traps should be drained at least twice a day and possibly more often in cold weather. Automatic drip traps are not recommended because many automatic traps are equipped with a float and needle valve orifice and corrosion, sediment, or scale in the gas system can keep the needle from seating. The resulting leaks may create gas concentrations with a potential hazard to life and equipment.

G. Gas Meters

Gas meters may be of various types, such as bellows, diaphragm, shunt flow, propeller, and orifice plate or differential pressure. They are described in detail in the metering section of Chapter 11, Maintenance.

H. Manometers

Manometers are installed at several locations to indicate gas pressure within the system in inches of a water column.

I. Pressure Regulators (Fig. 8.11, VAREC Fig. No. 387)

Pressure regulators are typically installed next to and before the waste gas burner. Such regulators are usually of the diaphragm type and control the gas pressure on the whole digester gas system. They are normally set at eight inches of water column by adjusting the spring tension on the diaphragm. Whenever an adjustment of a pressure setting is made, check the gas system pressure with a manometer for the proper range. If the gas pressure in the system is below eight inches of water column, no gas flows to the waste burner. When the gas pressure reaches eight inches of water column, the regulator opens slightly, allowing gas to flow to the burner. If the pressure continues to increase, the regulator opens further to compensate. The only maintenance this unit requires is on the thermal valve on the discharge side which protects the system from back flashes. This unit is spring loaded and controlled by a fusible element that vents one side of the diaphragm, thus stopping the gas flow when heated. Maintenance includes checking for proper operation of the regulator and of the fusible element. Gas regulators are also placed at various points in the system to regulate the gas pressure to boilers, heaters, and engines. Diaphragm conditions in the regulators should be checked at periodic intervals.

J. Waste Gas Burner (Fig. 8.12)

Waste gas burners are used to burn the excess gas from the digestion system. The waste gas burner is equipped with a continuous burning pilot flame, so that any excess gas will pass through the gas regulator and be burned. The pilot flame should be checked daily to be sure that it has not been blown out by wind. If the pilot is out, gas will be vented to the atmosphere creating an odorous and potentially explosive condition.

QUESTIONS

8.12I How frequently should you drain a sediment trap?

8.12J Why must drip or condensate traps be installed in gas lines?

8.12K What is a deficiency in automatic drip and condensate traps?

8.12L How would you adjust the gas pressure of the digester gas system?

8.12M Why should the pilot flame in the waste gas burner be checked daily?

DRIP TRAPS

Automatic

Varec Drip Traps are for collection and safe removal of condensate from gas lines and equipment. Drip traps should be installed at all low points in gas pipe systems where condensation will collect.

The Varec Figure No. 245 Automatic Drip Trap employs a float operated needle valve which automatically drains off collected condensate. This feature is particularly desirable where a closed discharge to drain is permissible and where condensate occurs too frequently for manual operation.

Standard construction is alum. body and cover, stainless steel ball float and needle valve assembly and graphited asbestos gasket. Available with ½", ¾", 1" NPT connections.

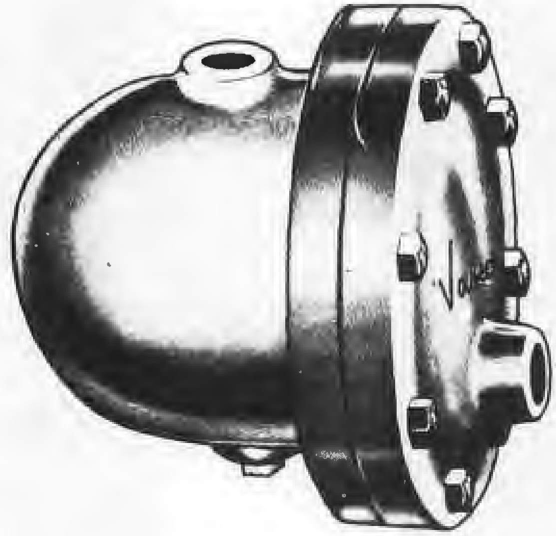


FIG. NO. 245 AUTOMATIC

Rotating Disc Type

The Varec Figure No. 246 Drip Trap is manually operated. Handle rotates disc from open inlet position to drain position. Ports and disc are so arranged that gas cannot escape regardless of disc position. Both ports and shaft are positively sealed by synthetic rubber "O" rings. Vent hole is provided to allow inflow of air to bowl while draining.

Standard construction is cast aluminum bowl and handle. Aluminum cover plate and disc are anodized. Other working parts are stainless steel. Heavy duty construction throughout. Available in 2½ quart capacity with 1" NPT connections.

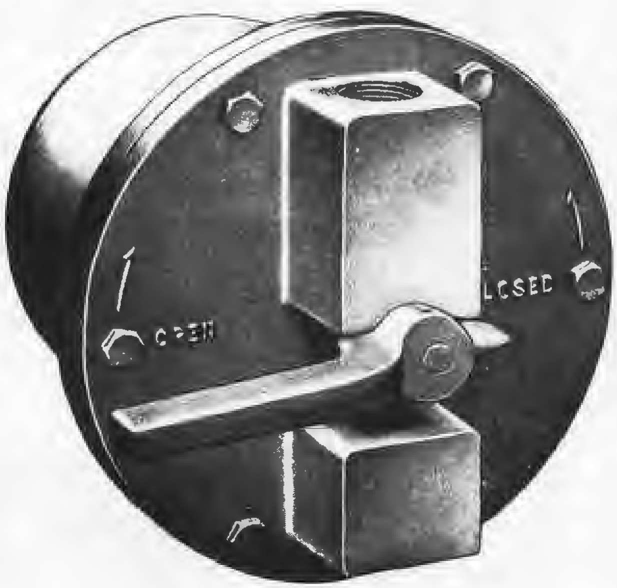


FIG. NO. 246
ROTATING DISC TYPE

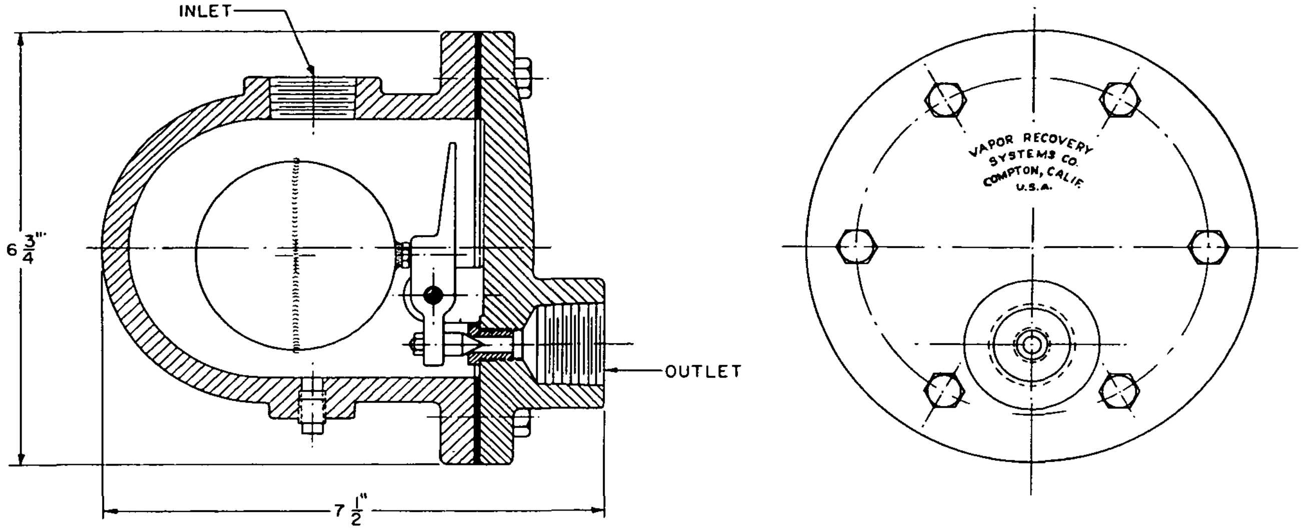


FIGURE NO. 245

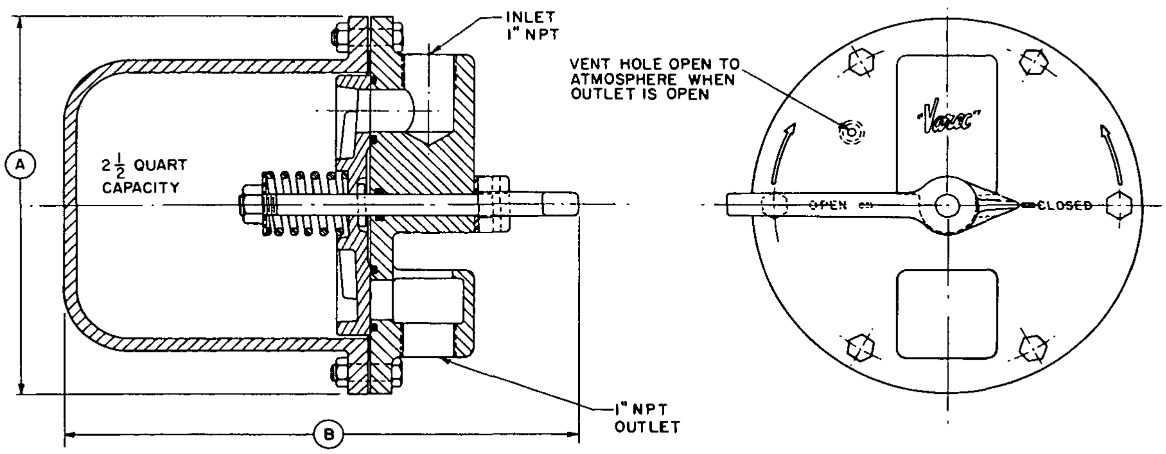


FIGURE NO. 246

SIZES, DIMENSIONS AND APPROXIMATE SHIPPING WTS. - FIG. NOS. 245 AND 246

FIGURE NO.	N. P. T. CONNECTION	A	B	APPROX. SHIPPING WEIGHTS - LBS.
245 AUTOMATIC	1/2", 3/4", 1"	—	—	23
246 MANUAL	1"	8 3/4	11 3/8	15

BACK PRESSURE
REGULATOR
SINGLE PORT

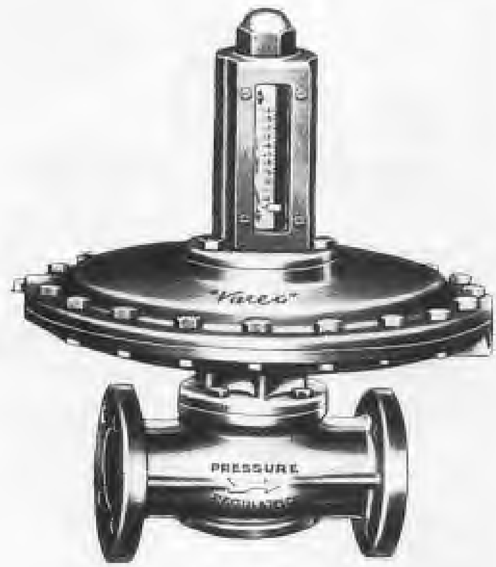


FIGURE NO. 386

The Figure No. 386 Regulator Valve is designed to control upstream pressure in sludge gas lines. Positive shut-off as well as accurate control is provided. Pointer type indicator, in weather-proof bonnet, facilitates setting adjustment. No weights or dismantling necessary to make adjustment.

Valve is the single port type operated by a spring loaded diaphragm.

Setting range is 2" W.C. to 12" W.C. as standard. Higher settings available (20" W.C. maximum) on special order.

MATERIALS OF CONSTRUCTION:

Heavy cast aluminum valve body, diaphragm housing and pallet, stainless steel operating shaft, heavy corded synthetic rubber diaphragm and cadmium plated steel spring.

PRESSURE (REDUCING)
REGULATOR
SINGLE PORT

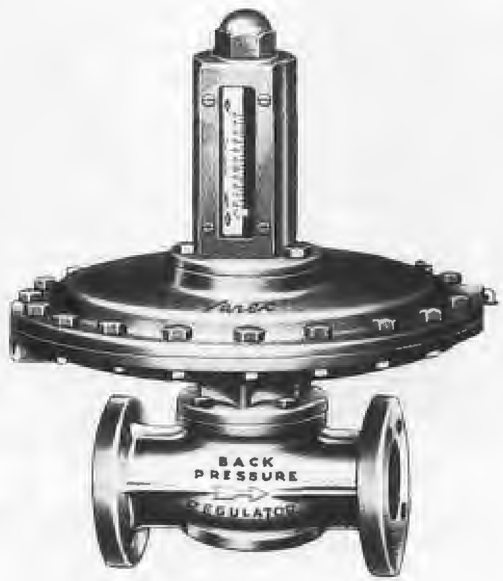


FIGURE NO. 387

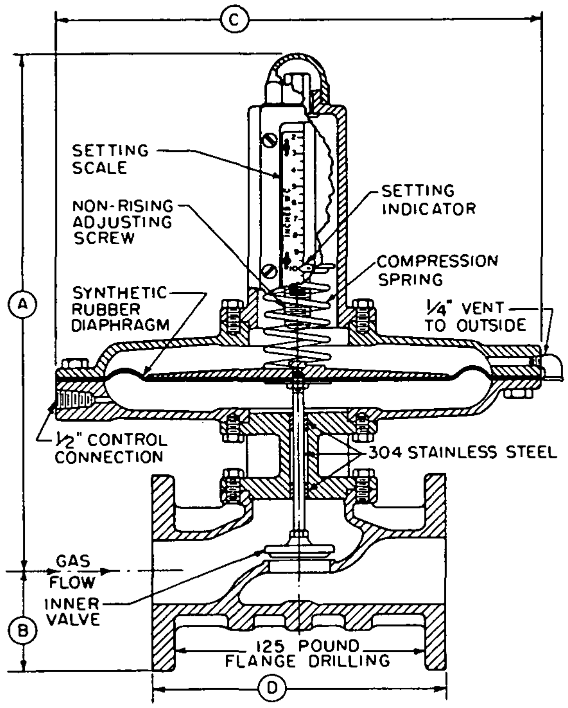
The Figure No. 387 Regulator Valve is designed to control downstream pressure in sludge gas lines. Positive shut-off as well as accurate control is provided. Pointer type indicator, in weather-proof bonnet, facilitates setting adjustment. No weights or dismantling necessary to make adjustment.

Valve is single port type operated by a spring loaded diaphragm.

Setting range is 2" W.C. to 12" W.C. as standard. Higher settings available (20" W.C. maximum) on special order.

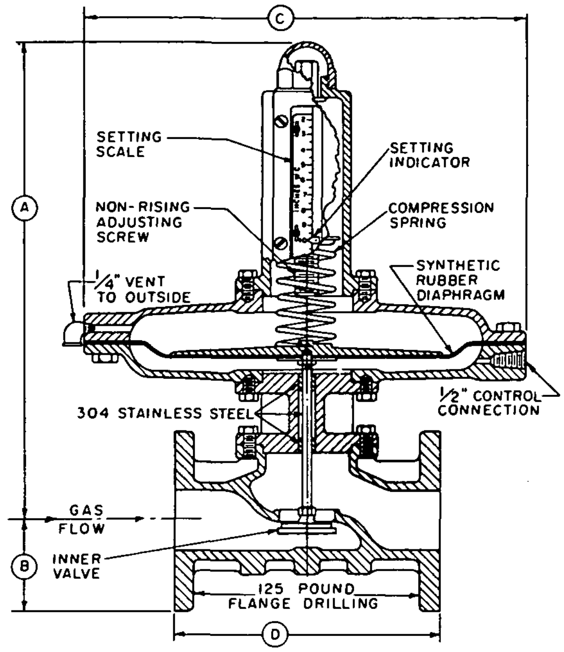
MATERIALS OF CONSTRUCTION:

Heavy cast aluminum valve body, diaphragm housing and pallet, stainless steel operating shaft, heavy corded synthetic rubber diaphragm and cadmium plated steel spring.



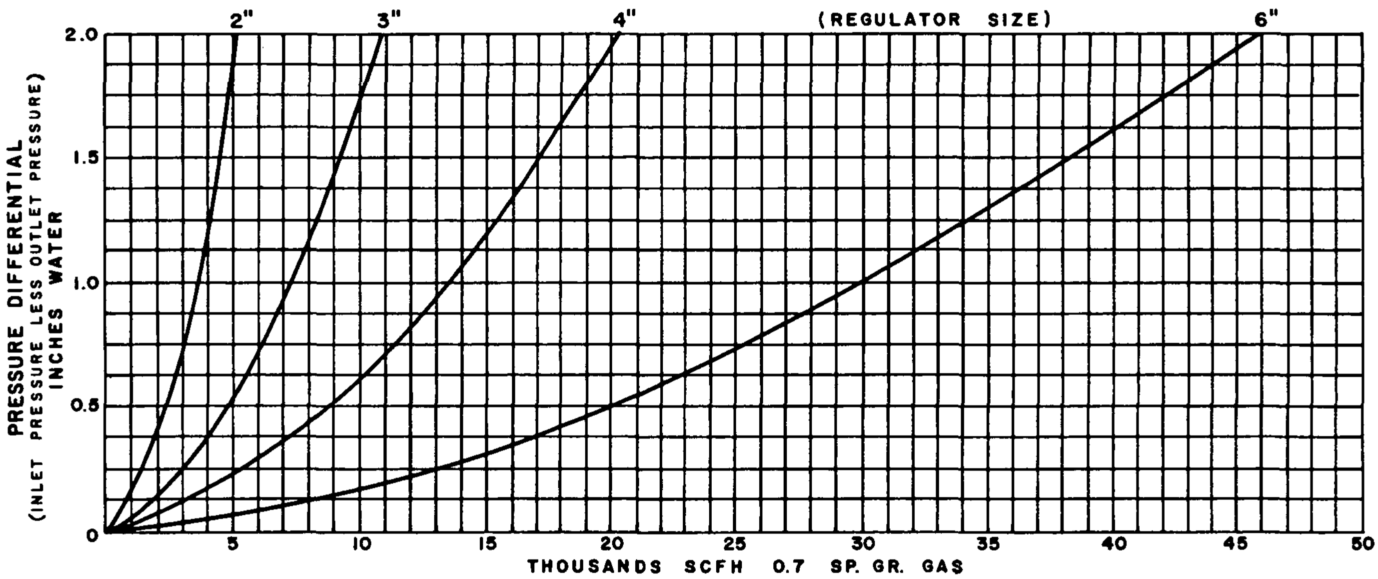
SECTIONAL ELEVATION

FIG. Nº 386



SECTIONAL ELEVATION

FIG. Nº 387



SIZES, DIMENSIONS, WEIGHTS

SIZES	A	B	C	D	Approx. Wt., lbs. Net	Approx. Wt., lbs. Ship.
2"	18½	3	14½	8¾	75	100
3"	20	3¾	14½	10	100	140
4"	23	4½	21	11⅜	130	175
6"	26	5½	21	15	160	220

NOTE: Available in 8" size upon special order.

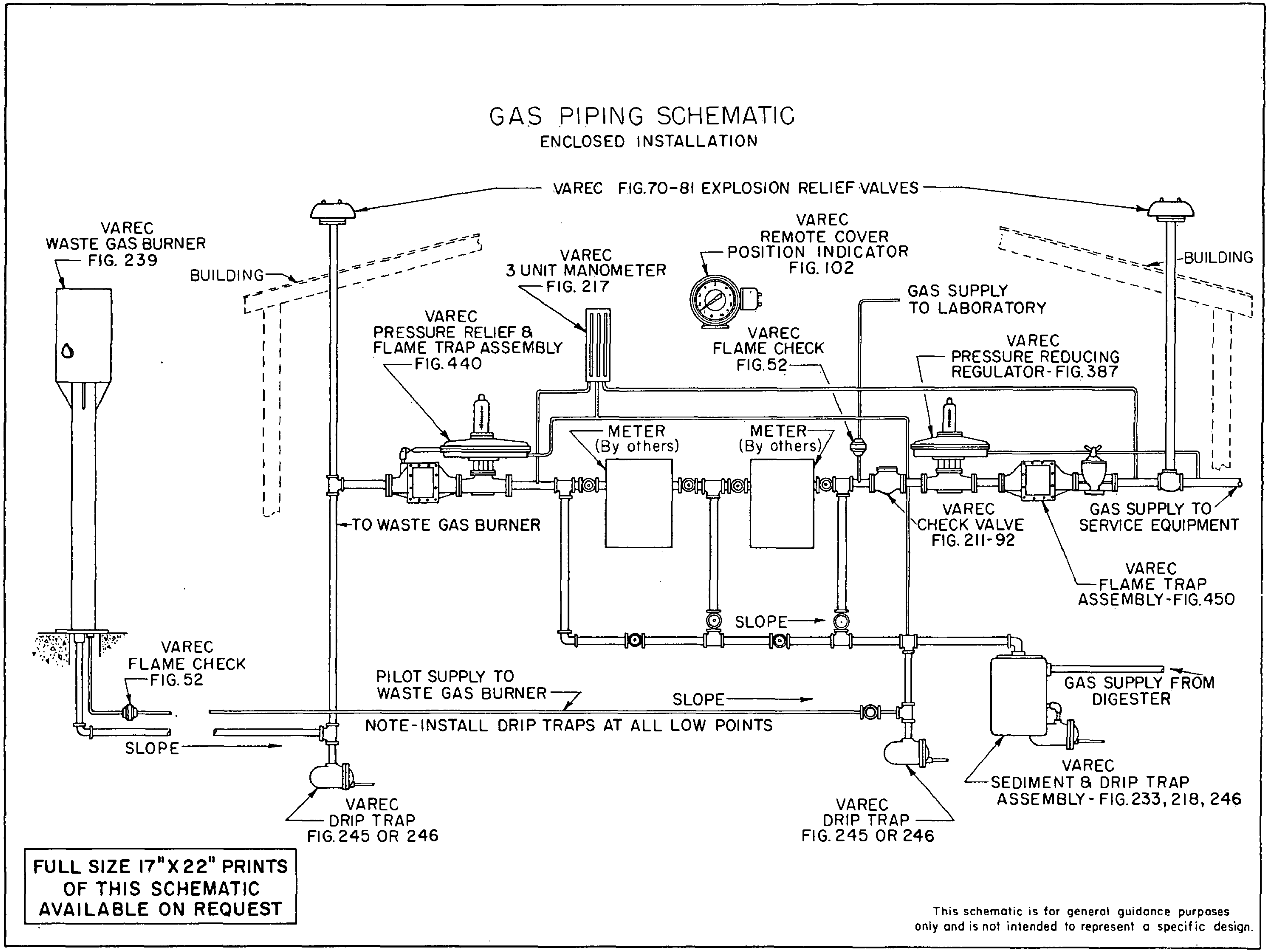


Fig. 8.12 Waste gas burner

Courtesy of VAREC

8.13 Sampling Well (Thief Hole)
(Fig. 8.13, VAREC Fig. Nos. 42-81 and 48-81)

The sampling well consists of a 3- or 4-inch pipe (with a hinged seal cap) that goes into the digestion tank, through the gas zone, and is always submerged a foot or so into the digester sludge. This permits the sampling of the digester sludge without loss of digester gas pressure, or the creation of dangerous conditions caused by the mixing of air and digester gas. However, caution must be used not to breathe gas which will always be present in the sample well and will be released when first opened. A sampling well is sometimes referred to as a "thief hole".

8.14 Digester Heating

Digesters can be heated in several ways. Newer facilities typically provide digesters that are heated by recirculating the digester sludge through an external hot water heat exchanger. Digester gas is used to fire the boiler, which is best maintained between 140 and 180°F for proper operation. The hot water is then pumped from the boiler to the heat exchanger where it passes through one jacket system, while the recirculating sludge passes through an adjacent jacket, picking up heat from the hot water. In some units the boiler and exchanger are combined and the sludge also is passed through the unit.

Circulation of 130°F water through pipes or heating coils attached to the inside wall of the digester is another method of heating digesters, although not too common in newer plants. This approach creates problems of cooking sludge on the pipes and insulating them, thus reducing the amount of heat transferred. Some facilities use submerged combustion of the gas with heat exchange between the hot gaseous products evolved and the liquid sludge.

Other plants inject steam directly into the digesters for heating. The steam is produced in separate boilers or is recovered in connection with vapor phase cooling of engines. Careful treatment of the evaporated water to prevent scaling of the system is necessary so the practice is generally confined to plants with good laboratory control.

QUESTIONS

8.13A Why should a digester have a special sampling well?

8.14A What causes a reduction in the amount of heat transferred from coils within the digester?

SAMPLING HATCH or HANDHOLE COVER

Non-sparking Gas-tight

VAREC Sampling Hatches or Handhole Covers are for use on digester covers or roofs. Insurance requirements are complied with in that this equipment is non-sparking, self-closing and gas-tight. Construction is non-corrosive in sludge gas service.

Above photo shows simplicity of operation

Figure No. 42-81 incorporates a standard 125 lb. A.S.A. flanged base for mounting. It is of extra heavy construction, basically of aluminum throughout. Specialty features are included such as a safety foot pedal for quick opening, a hand wheel which may be padlocked closed, and a synthetic rubber insert in cover to insure a gas-tight seal.

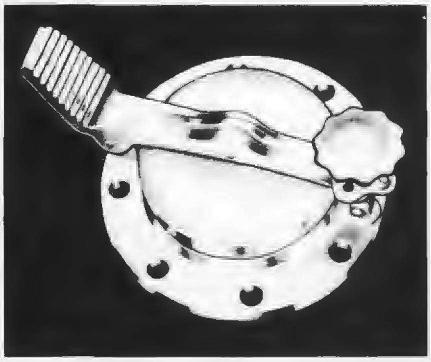


Figure No. 42-81
Flanged Base

Figure No. 48-81 is substantially same as Figure No. 42-81 in that it includes all the specialty features and is of same materials of construction. However, the base is for Standard Pipe Thread mounting.

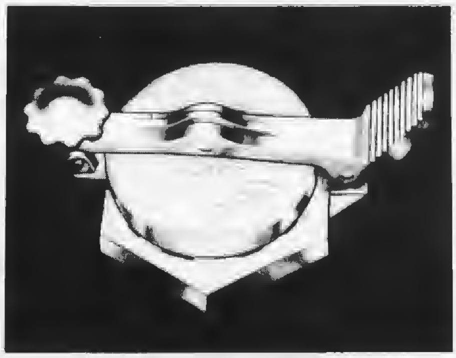


Figure No. 48-81
Screwed Base

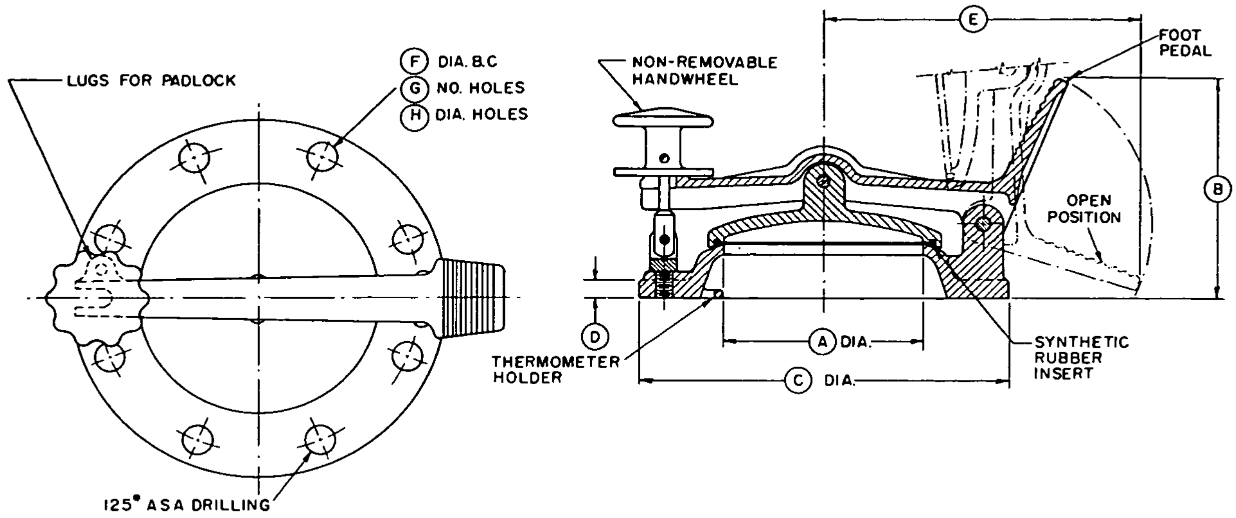


FIGURE NO. 42-81

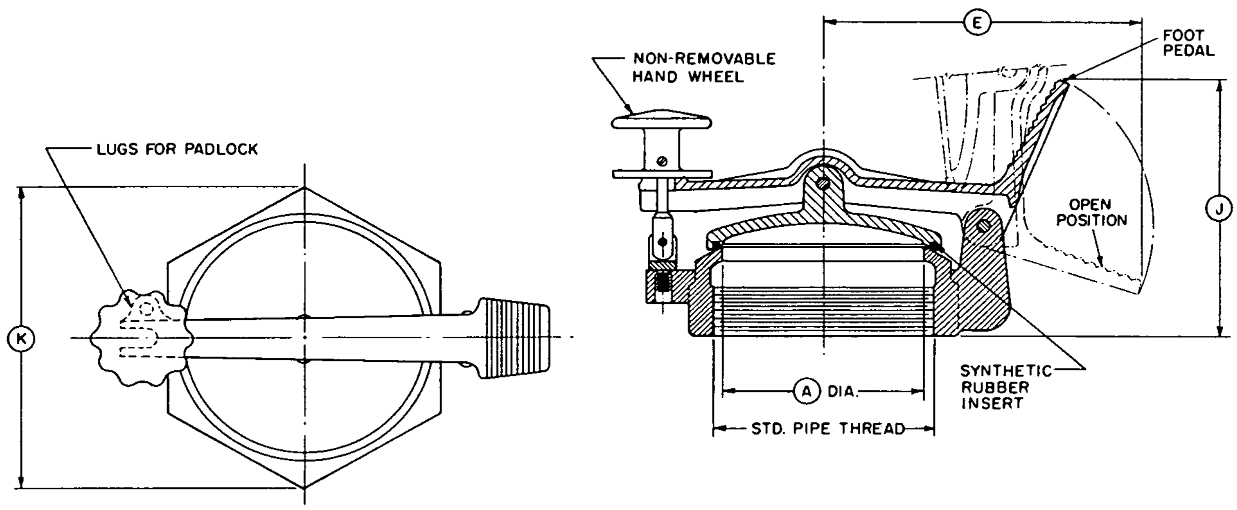


FIGURE NO. 48-81

SIZE	A	B	C	D	E	STD. 125-LB. DRILLING F	G	H	J	K	APPROX. SHIPPING WEIGHTS 42-81	48-81
2″	2	—	—	—	5¼	—	—	—	5	3	10	11
3″	3	4⅝	7½	½	6⅜	6	4	¾	5	5¼	12	17
4″	4	5¾	9	½	8⅛	7½	8	¾	6½	6⅜	15	25
6″	6	6¾	11	9/16	9¾	9½	8	⅞	8	9½	22	44
8″	8	6¾	13½	9/16	10⅞	11¾	8	⅞	7⅞	11½	31	60
10″	10	7	16	⅝	12	14¼	12	1	—	—	40	84

8.15 Digester Mixing

Mixing is very important in a digester. The ability of the mixing equipment to keep the tank completely mixed speeds digestion greatly.

Several important objectives are accomplished in a well-mixed digester.

a. Inoculation[12] of the raw sludge immediately with microorganisms.

b. Prevention of a scum blanket from forming.

c. Maintenance of homogeneous contents within the tank, including even distribution of food, organisms, alkalinity, heat, and waste bacterial products.

d. Utilization of as much of the total contents of the digester as possible and minimization of the build-up of grit and inert solids on the bottom.

A. Gas Mixing

This type of mixing is the most generally used in recent years, and various approaches have been patented by manufacturers. Gas is pulled from the tank, compressed, and discharged through gas outlets or orifices within the digester, or at some point several feet below the sludge surface. The gas rising to the surface through the digesting sludge carries sludge with it, creating a gas lift with a rolling action of the tank contents. The gas mixer may be operated on either a start and stop or a continuous basis, depending upon tank conditions. The components required for gas mixing include inlet and discharge gas lines, a positive displacement compressor, and a stainless steel gas line header in the digester. The gas header is equipped with a cross arm to hold a specified number of gas outlets, and may be mounted in a draft tube. The gas compressor is sized for the digester and may range from 30 to 200 cfm of gas.

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[12] Inoculation (in-NOCK-you-LAY-shun). Introduction of a seed culture into a system.

Work with "natural gas evolution" mixing at the Los Angeles County Sanitation District's plants has indicated that loadings of over 0.4 pounds of volatile solids per cubic foot per day were possible, but that if the loading dropped below 0.3 pounds immediate stratification occurred. In terms of gas recirculation, adequate mixing has been calculated from this study to be of the order of 500 cfm (cubic feet per minute) per 100,000 cubic feet of tank capacity if released at about a 15-foot depth. If released at a 30-foot depth, about 250 cfm per 100,000 cubic feet of tank capacity should be satisfactory. If hydraulic processes are used, either by recirculation or by draft tubes and propellers, then something like 30 HP per 100,000 cubic feet of tank capacity is required.

Maintenance requires that the condensate be drained from the lines at least twice a day, that the diffusers be cleaned to prevent high discharge pressures, and that the compressor unit be properly lubricated and cooled.

<u>QUESTIONS</u>

8.15A Why should a digester be kept completely mixed?

8.15B What maintenance is necessary for the proper operation of digester mixing by the use of gas?

B. Mechanical Mixing

Propeller mixers are found mainly on fixed cover digesters. Normally two or three of these units are supported from the roof of the tank with the props submerged 10 to 12 feet in the sludge. An electric motor drives the propeller stirring the sludge.

Draft tube propeller mixers are either single or multiple unit installations. The tubes are of steel and range from 18 to 24 inches in diameter. The top of the draft tube has a rolled lip and is located approximately 18 inches below the normal water level of the tank. The bottom of the draft tube may be straight or equipped with a 90° elbow. The 90° elbow type is placed so that the discharge is along the outside wall of the tank to create a vortex (whirlpool) action.

The electric motor driven propeller is located about two feet below the top of the draft tube. This type unit usually has reversible motors so the prop may rotate in either direction. In one direction the contents are pulled from the top of the digester and forced down the draft tube to be discharged at the bottom. By operating the motor in the opposite direction, the digested sludge is pulled from the bottom of the tank and discharged over the top of the draft tube to the surface.

If two units are in the same tank, an effective operation for breaking up a scum blanket is operating one unit in one direction and the other unit in the opposite direction, thereby creating a push-pull effect. The draft tube units are subject to shaft bearing failure due to the abrasiveness of sludge, and due to corrosion by hydrogen sulfide (H_2S) in the digester gas. Maintenance consists of lubrication and, if belt-driven, adjustment of belt tension.

A limitation of draft tube type mixers is digester water level. If the water level is maintained at a constant elevation, a scum blanket forms on the surface. The scum blanket may be a thick layer and the draft will only pull liquid sludge from under the blanket, not disturbing it. Lowering the level of the digester to just three or four inches over the top of the draft tube forces the scum to move over and down the draft tube. This applies mainly to single direction mixers.

Pumps are sometimes used to mix digesters. This method is common in smaller tanks. When external heat exchangers are employed, a larger centrifugal pump is used to recirculate the sludge and discharge it back into the digester through one or two directional nozzles at the rate of 200 to 1000 gpm.

The tank may or may not be equipped with a draft tube such that the pump suction may be from the top or valved from the bottom of the digester. Control of scum blankets with this method of mixing is dependent upon how the operator maintains the sludge level and where the pump is pulling from and discharging to the digester.

Maintenance of the pump requires normal lubrication and a good pump shaft sealing water system. The digested sludge is abrasive and pump packing, shafts, wearing rings, and impellers are rapidly worn. Another problem associated with pump mixing is the clogging of the pump impeller with rags, rubber goods, and plastic material. A pump may run for days not pumping due to clogging because the operator was not checking the equipment for proper operation.

Pressure gauges should be installed on the pump suction and discharge pipes. When a gauge reading different than normal occurs, the operator has an indication that some condition has changed that requires checking.

QUESTIONS

8.15C How would you break up a scum blanket in a digester with two or more draft tube propeller mixers?

8.15D Why should pressure gauges be installed on mixing pump suction and discharge lines?

END OF LESSON 2 OF 5 LESSONS

on

SLUDGE DIGESTION AND HANDLING

DISCUSSION AND REVIEW QUESTIONS

Chapter 8. Sludge Digestion and Handling

Write the answers to these questions before continuing with Lesson 3. The problem numbering continues from Lesson 1.

5. Why is digester gas considered dangerous?
6. What two purposes are served by the digester gas system?
7. Under what kind of circumstances will the pressure relief valve and vacuum relief valve operate?
8. Where should flame arrestors be installed in the digester gas system?
9. How would you test for gas leaks around a flame arrestor after it has been serviced?
10. Why must drip and condensate traps be drained regularly?
11. What means are used to mix the contents of digesters?

CHAPTER 8. SLUDGE DIGESTION AND HANDLING

(Lesson 3 of 5 Lessons)

8.2 OPERATION OF DIGESTERS

A digester can be compared with your own body. Both require food; but if fed too much, both become upset. Excess acid will upset both. Both like to be warm, with a body temperature of 98.6°F near optimum. Both have digestive processes that are similar. Both discharge liquid and solid waste. Both utilize food for cell reproduction and energy. If something causes upsets in a digester, just think how you would react if it happened to you and recall what would be the proper remedy. The remedies for curing upset digesters will be discussed throughout this chapter.

8.20 Raw Sludge and Scum

Raw sludge is normally composed of solids settled and removed from the primary and secondary clarifiers. Raw sludge contains carbohydrates, proteins, and fats, plus organic and inorganic chemicals that are added by domestic and industrial uses of water.

Solids are composed of organic (volatile) and inorganic material with the volatile content running from about 60% to 80% of the total, by weight. Some plants do not have grit removal equipment; so the bulk of the inert (inorganic) material such as sand, eggshells, and other debris will end up on the bottom of the digester occupying active digestion space. The rate of debris accumulation is predictable so that the amount is a function of the period of time between digester cleanings. Where cleaning has been neglected, a substantial portion of the active volume of the digester becomes filled with inert debris. Scum-forming products, such as kitchen grease, soaps, oils, cellulose, plastics, and other floatable debris, are generally all organic in nature but may create problems if the scum blanket in the digester is not controlled. Control is by providing adequate mixing and heat.

Several products end up in the digester that are not desirable because the bacteria cannot effectively utilize or digest them, and they cannot be readily removed by the normal process. These products include:

1. petroleum products and mineral oils
2. rubber goods
3. plastics (back sheets to diapers)
4. filter tips from cigarettes
5. hair
6. grit (sand and other inorganics)

Consequently, these items tend to accumulate in the digester and, without adequate mixing, may form a hard, floating mat and a substantial bottom deposit. On the other hand, a well-mixed tank may also present operational problems. For example, the material shredded by a comminuter or barminuter may become balled together by the mixing action and plug the digester supernatant lines.

Scum from the primary clarifiers is comprised mainly of grease and other floatable material. It may be collected and held in a scum box and then pumped to the digester once a day, or it may be added continuously or at a frequency necessary to maintain the proper removal of scum from the raw wastewater flow. Many operators prefer not to pump scum to the digesters, but to dispose of it by burning or burial. Scum may also refer to the floating and gas buoyed material found on the surface of poorly mixed digesters. This material may contain much cellulose, rubber particles, mineral oil, plastic, and other debris. It may become 5 to 15 feet thick in a digester, but should not occur in a properly operating digester. A thick scum layer will reduce the active digestion capacity of a digester.

8.21 Starting a Digester

When wastewater solids are first added to a new digester, naturally occurring bacteria attack the most easily digestible food available, such as sugar, starches, and soluble nitrogen. The anaerobic acid producers change these foods into organic acids, alcohols, and carbon dioxide, along with some hydrogen sulfide. The pH of the sludge drops from 7.0 to about 6.0 or lower. An "acid regression stage"[13] then starts and lasts as long as six to eight weeks. During this time ammonia and bicarbonate compounds are formed, and the pH gradually increases to around 6.8 again, establishing an environment for the methane fermentation or alkaline fermentation phase. Organic acids are available to feed the methane fermenters. Large quantities of methane gas are produced as well as carbon dioxide, and the pH increases to 7.0 to 7.2. Once alkaline fermentation is well established, strive to keep the digesting sludge in the 7.0 to 7.2 pH range.

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[13] Acid Regression Stage. A time period when the production of volatile acids is reduced. During this stage of digestion ammonia compounds form and cause the pH to increase.

If too much raw sludge is added to the digester, the acid fermenters will predominate, driving the pH down and creating an undesirable condition for the methane fermenters. The digester will go sour or acid again. When a digester recovers from a sour or acid condition, the breakdown of the volatile acids and formation of methane and carbon dioxide is usually very rapid. The digester may then foam or froth, forcing sludge solids through water seals and gas lines and causing a fairly serious operational problem. A sour digester usually requires 30 to 60 days to recover.

As noted at the beginning of this section, the first group of organisms must do its part before food is available to the next group. Once the balance is upset, so is the food cycle to the next group. When the tank reaches the methane fermentation phase, there is sufficient alkaline material to buffer the acid stage and maintain the process. Operational actions such as poor mixing, addition of excess food, excess water supplied to dilute the alkaline buffer, over-drawing digested sludge, or improper temperature changes can cause souring again.

The simplest way to start a digester is with seed sludge (actively digesting material) from another digester. The amount of seed to use is dependent upon factors such as mixing processes, digester sizes, and sludge characteristics, but amounts between 10 and 50% of the digester capacity have been used.

Example (seed volume based on tank capacity):

Calculate the volume of seed sludge needed for a 40-foot diameter digester with a normal water depth of 20 feet, if the seed required is 25% of the tank volume. Most digesters have sloping bottoms, but assume the normal side wall water depth represents the average digester depth:

Tank Diameter, D = 40 feet

Depth, H = 20 feet

$\frac{\pi}{4}$ = .785

$$\text{Tank Volume, cu ft} = \text{Area, sq ft} \times \text{Depth, ft}$$

$$= \frac{\pi}{4} D^2 \times H$$

$$= 0.785\ (40\ \text{ft})^2 \times 20\ \text{ft}$$

$$= 25{,}120\ \text{cu ft}$$

$$\begin{array}{r} 40 \\ \times 40 \\ \hline 1600 \end{array} \qquad \begin{array}{r} 1600 \\ \times 20 \\ \hline 32000 \end{array} \qquad \begin{array}{r} 0.785 \\ 32000 \\ \hline 1570000 \\ 2355 \\ \hline 25120.000 \end{array}$$

$$\text{Tank Volume, gal} = (25{,}120\ \text{cu ft})\ (7.5\ \text{gal/cu ft})$$

$$= 188{,}400\ \text{gal}$$

$$\begin{array}{r} 25120 \\ 7.5 \\ \hline 125600 \\ 175840 \\ \hline 188400.0 \end{array}$$

Seed required assumed to be 25% or 1/4 of the digester tank volume:

$$\text{Seed Volume, gal} = \frac{\text{Tank Volume, gal}}{4}$$

$$= \frac{188{,}400\ \text{gal}}{4}$$

$$= 47{,}100\ \text{gal}$$

$$\begin{array}{r} 47100 \\ 4\ \overline{)\ 188400} \\ 16 \\ \hline 28 \\ 28 \\ \hline 4 \\ 4 \end{array}$$

Therefore, 47,100 gallons of seed sludge would be needed. If seed sludge is not available, the tank may be started by filling the digester with raw wastewater and heating the tank to 85-95°F with natural gas or other fuel. Allow the bacteria to take the natural course of decomposition as earlier described. The time required for a start of this nature ranges from 45 to 180 days.

Rather than estimate the volume of seed sludge on the basis of digester capacity, a better approach is to determine the volume of seed necessary to maintain digestion under the expected initial loading. To use this approach, allow 0.03 to 0.10 pound of new volatile solids to be added per day per pound of volatile solids under digestion.

Example (seed volume based on raw sludge to be added):

Initially a new plant expects to pump 500 gallons of raw sludge per day to the digester. The raw sludge is estimated to contain 6% solids with a volatile content of 68%. Estimate the pounds of volatile solids needed by the digester and the gallons of seed sludge, assuming the seed sludge contains 10% solids with 50% volatile solids and weighs nine pounds per gallon. (Digested sludge containing 10% solids weighs more than water [8.34 lb/gal] without any solids.)

Find pounds of volatile matter pumped to digester per day.

$$\text{Volatile Matter Pumped, lbs/day} = (\text{Vol. of Sludge, gpd})(\text{Solids, \%})(\text{Volatile, \%})(8.34\ \text{lb/gal})$$

$$= (500\ \text{gal/day})(0.06)(0.68)(8.34\ \text{lb/gal})$$

$$= 170\ \text{lbs/day}$$

Select a digester loading between 0.03 and 0.10 pounds of new volatile solids added per day per pound of volatile solids in digester. Try 0.05 lb VM per day per pound under digestion.

Find pounds of seed volatile matter needed.

$$\frac{0.05\ \text{lb VM added/day}}{1\ \text{lb VM in digester}} = \frac{170\ \text{lb VM added/day}}{\text{Seed, lb VM}}$$

$$\text{Seed, lb VM} = \frac{(170\ \text{lb VM added/day})}{0.05\ \text{lb VM added/day}}\ \text{lb VM}$$

$$= 3400\ \text{lbs VM}$$

Find gallons of seed sludge needed.

$$\text{Seed Sludge, gal} = \frac{\text{Seed, lb VM}}{(9\ \text{lb/gal})(\text{Solids, \%})(\text{VM, \%})}$$

$$= \frac{3400\ \text{lb VM}}{(9\ \text{lb/gal})(0.10)(0.50\ \text{VM})}$$

$$= 7560\ \text{gal}$$

To start a digester, add the necessary seed sludge and fill the remainder of the tank with raw sludge and wastewater. Some operators do not fill a digester during start-up but this practice is not recommended. The reason is that the tank may develop an explosive mixture of gases if air is allowed into the partially-filled digester.

During the start-up of a digester, once production of a good, burnable gas is obtained the raw sludge feed rate can be gradually increased until the system is handling the total load.

QUESTIONS

8.20A What is (1) raw sludge? (2) scum?

8.21A What happens if you add too much raw sludge to the digester?

8.21B What causes a digester to foam and froth?

8.21C Calculate the recommended volume of seed sludge to start a digester 50 feet in diameter and 25 feet deep (average). Assume 700 gallons per day of raw sludge will be added, containing 6.5% solids and 70% volatile matter. Assume seed sludge contains 10% solids with 50% volatile solids and weighs nine pounds per gallon. Use a digester loading of 0.05 lb VM added per day per lb VM under digestion.

8.21D Why is it dangerous to start a digester when it is only partially full?

8.21E How could you determine when a new digester is ready for the raw sludge feed rate to be gradually increased to the full plant load?

8.22 Feeding

Food for the bacteria in the digester is the sludge from the primary and secondary clarifiers. Make every effort to pump as thick a sludge to the digester as possible. This may be accomplished by holding a blanket of sludge as long as possible in the primary clarifier, long enough to allow sludge concentration, but not long enough for sludge to start rising. In some plants concentration is accomplished in separate sludge thickening or flotation tanks.

Better operational performance occurs when the digester is fed several times a day, rather than once a day because you are avoiding temporary overloads on the digester and you are using your available space more effectively. If the plant is producing only 500 gallons of 6% sludge a day, one feeding may be allowable; however, for volumes much greater than 500 gallons a day, several pumpings a day should be used. This not only helps the digestion process, but maintains better conditions in the clarifiers, permits thicker sludge pumping, and prevents coning[14] in the primary clarifier hopper. On fixed cover digesters frequent feeding spreads the return of digester supernatant over the entire day instead of a return in one slug with possible upset of the secondary treatment system. Sludge is usually concentrated by holding a thick blanket on the bottom of the clarifier; but if sludge sets for a prolonged period, lowest layers may stick to the bottom and will no longer flow with the liquid. When pumping is attempted, liquid flows but solids remain in the hopper in a cone around the outlet.

It is never desirable to pump thin sludge or water to a digester. A sludge is considered thin if it contains less than 4% solids (too much water). Reasons for not pumping a thin sludge include:

1. Excess water requires more heat than may be available.

2. Excess water reduces holding time of the sludge in the digester.

3. Excess water forces seed and alkalinity from the digester, jeopardizing the system due to insufficient buffer[15] for the acids in the raw sludge.

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[14] Coning (CONE-ing). A condition that may be established in a sludge hopper during sludge withdrawal when part of the sludge moves toward the outlet while the remainder tends to stay in place. Development of a cone or channel of moving liquid surrounded by relatively stationary sludge.

[15] Buffer. A measure of the ability or capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water or wastewater for offering a resistance to changes in the pH. Buffer capacity is measured by titration with standard alkali and acid until the pH reaches some reference or end point (a pH of 4.5 or 8.5). The higher the volume (ml) of known reagent requirements, the higher the buffer capacity.

Sludge concentrations above about 12% solids will usually not digest well in conventional digestion tanks since adequate mixing cannot be obtained. This, in turn, leads to improper distribution of food, seed, heat, and metabolic products so that the souring and a stuck[16] digester results. However, most plants have difficulty in obtaining a raw sludge of 8% solids. Where a trickling filter or activated sludge process is used as the secondary system, sludges may have a solids range from 1 to 3%. A good activated sludge is likely to be oxidized to the point of negligible action in an anaerobic digester.

Feeding a digester must be regulated on the basis of laboratory test results in order to insure that the volatile acid/alkalinity reltaionship does not start to increase and become too high. See Section 8.4B.

QUESTIONS

8.22A How would you attempt to pump as thick a sludge as possible to a digester?

8.22B Why should sludge be pumped occasionally throughout the day rather than as one slug each day?

8.22C Why should the pumping of thin sludge be avoided?

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[16] Stuck. A "stuck" digester does not decompose the organic matter properly. Some operators refer to it as constipated. It is characterized by low gas production, high volatile acid/alkalinity relationship, and poor liquid-solids separation. A digester in a stuck condition is sometimes called a "sour" digester.

8.23 Neutralizing a Sour Digester

The recovery of a sour digester can be accelerated by neutralizing the acids with a caustic material such as soda ash, lime, or ammonia, or by transferring alkalinity in the form of digested sludge from the secondary digester. Such neutralization increases the pH to a level suitable for growth of the methane fermenters and provides buffering material which will help maintain the required volatile acids/alkalinity relationship and pH. When ammonia is added to a digester, an added load is eventually placed on the receiving waters. The application of lime will increase the solids handling problems. Soda ash is more expensive than lime, but doesn't add as much to the solids deposits. Transferring secondary digester sludge has the advantage of not adding anything extra to the system that was not there at an earlier time and, if used properly, will reduce both the effluent load and the solids handling problem.

If digestion capacity and available recovery time are great enough, it is probably preferable to simply reduce loading while heating and mixing so that natural recovery occurs. However, there are often conditions in which such neutralization is necessary.

When neutralizing a digester, the prescribed dose must be carefully calculated. Too little will be ineffective, and too much is both toxic and wasteful. In considering dosage with lime, the small plant without laboratory facilities could use as a rough guide a dosage of about one pound of lime added for every 1000 gallons of sludge to be treated. Thus, a 188,000-gallon digester full of sludge would receive 188 pounds of lime. A more accurate method is to add sufficient lime to neutralize 100% of the volatile acids in the digester liquor. (See Volatile Acids Test in Chapter 14, Laboratory Procedures and Chemistry.)

Example:

Volatile acids in digester sludge = 2300 mg/l. We should add lime equivalent to 2300 mg/l.

Lime Required, lbs = Volatile Acids, mg/l x Tank Volume, MG x 8.34 lbs/gal

= 2300 mg/l x 0.188 MG x 8.34 lbs/gal

= 2300 x 1.57 lbs

= 3611 lbs

The lime must be mixed into a solution before being added to the digester because dry lime would settle to the bottom in lumps which are not only ineffective but take up digester capacity and are difficult to remove when cleaning the digester. Use all of the mixing energy available while liming and thereafter in digester mixing. The easiest application point is through the scum box if one is available. Add small quantities of lime daily until the pH and volatile acid/alkalinity relationship (Section 8.4B) of the tank are restored to desired levels and gas production is normal.

In any case, use lime only if recovery by natural methods cannot be accomplished within the time available.

QUESTIONS

8.23A What happens when lime is added to a digester?

8.23B How much lime should be added to a 100,000-gallon digester, using the "rough guide" dosage in the previous section?

8.23C Why should lime be added in solution to the digester rather than in dry form?

8.23D For how long a time should you add lime to a digester?

8.24 Enzymes[17]

In recent years several products containing "commercial" enzymes or other biocatalysts (BUY-o-CAT-a-lists) have been marketed for starting digesters, controlling scum, or simply to maintain operation. Such biocatalysts or enzymes have never been shown to be effective in controlled tests and could, in fact, cause as much harm as good. A biological system such as found in the digesters develops a balanced enzyme and biocatalyst system for the conditions under which it is operating. The quantities of natural enzymes developed within the digesting sludge are many, many times greater than any amount you could either add or afford to purchase.

8.25 Foaming

Large amounts of foam may be generated during start-up by the almost explosive generation of gas during the time of acid recovery. Foaming is the result of active gas production while solids separation has not progressed far enough (insufficient digestion). It is encouraged during start-up by overfeeding. Foaming can be prevented by adequate mixing of the digester contents before foaming starts.

Bacteria can go to work very quickly when they have the proper environment. Almost overnight they can generate enough gas to

create a terrific mess of black foam and sludge. The foam not only plugs gas piping systems, but can exert excess pressures on digester covers, cause odor problems, and ruin paint jobs on tanks and buildings.

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[17] Enzymes (EN-zimes). Enzymes are substances produced by living organisms that speed up chemical changes.

To clean up the mess, first drop the level of the digester a couple of feet by withdrawing some supernatant. Next, cut off the gas system and flush it with water. Then hose the outside of the digester off as soon as possible or the paint will be stained a permanent grey. Drain and refill the water seal to remove the water fouled by the foaming. Use a strainer type skimming device to remove any rubber goods and plastic materials that have entered the water seal.

To control the foaming the best method is to stir the tank gently to release as much of the trapped gas from the foam as possible. Some operators even stop mechanical mixing equipment and stir with long, wooden poles. Try not to add too much water from the cleaning hoses as this reduces the temperature and dilutes the tank, which could create conditions for more foaming later. Do not feed the tank heavily, preferable not at all, until the foaming has subsided.

Foaming may occur when a thick sludge blanket is broken up, temperature changes radically, or the sludge feeding to the digester is increased. Avoid any conditions that give the acid formers the opportunity to produce more food than the methane fermenters can handle, because when the methane fermenters are ready, they may work too fast.

<u>If there had been adequate mixing, foaming problems would not have developed. Start mixing from top to bottom of the tank before foaming starts, not afterwards.</u>

8.26 Gas Production

When a digester is first started, extremely odorous gases are produced, including a number of nitrogen and sulphur compounds such as skatole, indole, mercaptans, and hydrogen sulfide. Many of these are also produced during normal digestion phases, but they are generally so diluted by carbon dioxide and methane that they are hardly noticeable. Their presence can be determined by testing if so desired.

During the first phases of digester start-up, most of the gas is carbon dioxide (CO_2) and hydrogen sulfide (H_2S). This combination will not burn and therefore is usually vented to the atmosphere. When methane fermentation starts and the methane content reaches around 60%, the gas will be capable of burning. Methane production eventually should predominate, generating a gas with 65% to 70% methane and 30% to 35% CO_2 by volume. Digester gas will burn when it contains 56% methane, but is not usable as a fuel until the methane content approaches 62%. When the gas produced is burnable, it may be used to heat the digester as well as for powering engines and for providing building heating.

QUESTIONS

8.24A What is the function of enzymes in digestion?

8.25A How would you attempt to control a foaming digester?

8.25B What preventive measures would you take to prevent foaming from recurring?

8.26A Why is the gas initially produced in a digester not burnable?

8.27 Supernatant and Solids

Plants constructed today are typically equipped with two separate digestion tanks or one tank with two divided sections. One tank is called the primary digester and is used for heating, mixing, and breakdown of raw sludge. The second tank, or secondary digester, is used as a holding tank for separation of the solids from the liquor. To accomplish such separation, the secondary tank must be quiescent (qui-ES-sent) (without mixing).

Most of the sludge stabilization work is accomplished in the primary digester, and 90% of the gas production occurs there. It is desirable to very thoroughly mix the primary tank, but it is undesirable to return the digested mixture to the plant as a supernatant. Therefore, when raw sludge is pumped to the primary digester, an equal volume is transferred to the secondary digester, and settled supernatant from the secondary digester is returned to the plant.

In the primary digester the binding property of the sludge is broken, allowing the water to be released. In the secondary digester the digested sludge is allowed to settle and compact, with some digestion continuing. When the solids settle they leave a light amber colored liquor zone between the top of the settled sludge and the surface of the digester. By adjusting or selecting the supernatant tube, the liquor with the least solids is returned to the plant.

The settled solids in the secondary digester are allowed to compact so that a minimal amount of water will be handled in the sludge dewatering system. These solids are excellent seed or buffer sludge in case the primary digester becomes upset. A reserve of 30 to 100 thousand gallons should always be held in the secondary digester. This represents a natural enzyme reserve and may save the system during a shock load. Primary and secondary sludge digesters should be operated as a complement to each other. If you need more seed or buffering capacity in the primary digester, it should be taken from the secondary digester.

The secondary tanks should be mixed frequently, preferably after sludge has been withdrawn and supernatant will not be returned to the plant. Usually secondary digesters are provided with mixers or recirculating pumps, preferably arranged for vertical mixing. This periodic mixing prevents coning of solids on the bottom of the tank and the formation of a scum blanket on the top. Mixing also helps the release of slowly produced gas that may float solids or scum.

If your plant has only one digester, stop mixing for one day before withdrawing digested sludge to drying beds.

8.28 Rate of Sludge Withdrawal

The withdrawal rate of sludge from either digester should be no faster than a rate at which the gas production from the system is able to maintain a positive pressure in the digester (at least two inches of water column). If the draw-off rate is too fast, the gas pressure drops due to volume expansion.

> WARNING: If continued, a negative pressure develops on the system (vacuum). This may create an explosive hazard by drawing air into the digester. If the primary digester has a floating cover, the sludge may be drawn down to where the cover rests on the corbels without danger of losing gas pressure.

Some operators prefer to pump raw sludge or wastewater to a digester during digested sludge drawoff to maintain a positive pressure. If gas storage lines permit it, return gas to the digester to maintain pressure in the digester.

QUESTIONS

8.27A What is the purpose of the secondary digester?

8.27B When raw sludge is pumped to the primary digester, what happens in the secondary digester?

8.27C How is the level of supernatant withdrawal selected?

8.28A How would you determine the rate of sludge withdrawal?

END OF LESSON 3 OF 5 LESSONS

on

SLUDGE DIGESTION AND HANDLING

DISCUSSION AND REVIEW QUESTIONS

Chapter 8. Sludge Digestion and Handling

Write the answers to these questions before continuing with Lesson 4. The problem numbering continues from Lesson 2.

12. What kinds of material or products frequently end up in digesters that are not desirable because bacteria cannot effectively utilize or digest them?

13. Why should seed sludge be added to a new digester?

14. Why should a digester be fed at regular intervals during the day, rather than once a day?

15. What are enzymes?

16. How can an operator attempt to prevent a digester from starting to foam?

17. Why should secondary digesters be mixed, if at all?

8.3 DIGESTER SLUDGE HANDLING

After sludge has passed through a digestion system, it must be dewatered and disposed of.

Small treatment plants are usually provided with sludge drying beds, while larger plants utilize mechanical dewatering and drying systems. Discharge by pipeline or barge to the ocean is sometimes used.

8.30 Sludge Drying Beds (See Fig. 8.14)

The drying process is accomplished through evaporation and percolation of the water from the sludge after it is spread on a drying bed. The drying bed is constructed with an underdrain system covered with coarse crushed rock. Over the rock is a layer of gravel, and then a layer of pea gravel covered with six to eight inches of sand.

Before sludge is applied, loosen the compacted sand layer by using a sludge fork with tines eight to twelve inches long. Stick the tines of the fork into the sand bed and rock it back and forth several times. This is to loosen the sand only, and care should be taken that the gravel and sand layer are not mixed. After the whole surface of the bed is loosened, rake it with a garden rake to break up the sand clods. Then level the bed by raking or dragging a 4" x 6" or 2" by 12" board on ropes to smooth the surface.

Sludge is then drawn to the bed from the bottom of the secondary digester. Draw the sludge slowly so as not to create a negative pressure in the digester and to prevent coning of sludge in the bottom of the digester. A thick sludge of 8% solids travels slowly, and if the draw-off rate is too fast, the sludge around the pipe flows out and the thicker sludge on the bottom moves too slow to fill the void. Consequently, the thinner sludge above the draw-off pipe moves in; and when it does, the supernatant level is reached, thus allowing almost nothing but water to go to the drying bed. The thin sludge and supernatant flowing down to the draw-off pipe washes a hole (shaped like a cone) in the bottom sludge. When this occurs it sometimes may be remedied by "bumping". This is accomplished by quickly closing and opening the draw-off valve on a gravity flow system, which creates a minor shock wave and sometimes washes the heavier sludge into the cone. If the digested sludge is pumped to the drying bed, quickly start and stop the pump using the power switch to create the "bumping" action.

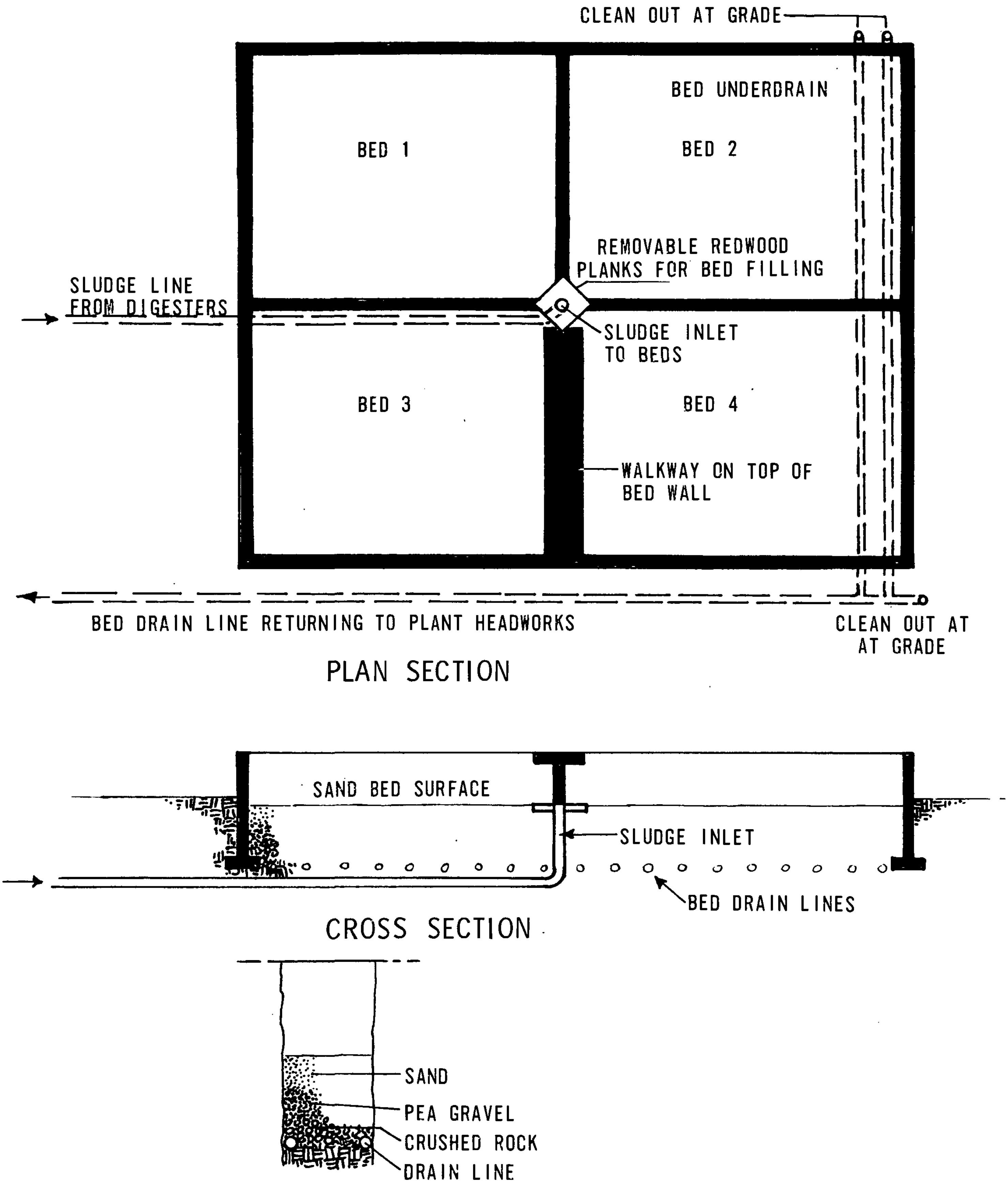


Fig. 8.14 Sludge drying bed

To draw sludge slowly is time consuming and requires frequent checks to be sure it does not thicken and stop flowing completely or cone and run too fast.

The sludge being drawn to the bed is sampled at the beginning of the fill, when the bed is half full, and just before the bed is filled to the desired level. The samples may be mixed together or analyzed separately for total and volatile solids.

The depth to which the sludge is applied is normally around 12 inches, but sometimes it is as deep as 18 inches in arid regions. If it is deeper, the time required for drying is too long. A bed filled with 20 inches of sludge would require approximately the same time to dry as a bed loaded with 14 inches, dried and removed and filled with another load 14 inches deep.

WARNING

NO SMOKING OR OPEN FLAMES SHOULD BE ALLOWED IN THE VICINITY WHERE SLUDGE IS BEING DRAWN FOR DRYING.
THE SLUDGE STILL CONTAINS SOME METHANE GAS. THIS IS SHOWN ON A FRESH BED OF SLUDGE BY THE NUMBER OF SMALL HOLES AND BUBBLES ON THE SURFACE OF THE SLUDGE. THERE HAVE BEEN CASES OF EXPLOSIONS AND FIRES CAUSED BY AN OPERATOR THROWING A LIGHTED MATCH OR CIGARETTE ONTO A DRYING BED OF SLUDGE FROM A DIGESTER.

After a bed of sludge is drawn, the sludge draw-off line should be flushed and cleared with water so the solids won't cement in the line and one end of the line left open for gas to escape, if it forms. Be sure to drain the line if freezing is a problem.

In warm weather, a good sand bed will have the sludge dry enough for removal within four weeks. The water separates from the sludge and drains down through the sand. Evaporation also dries the sludge and will cause it to crack.

When the sludge has formed cracks clear to the sand, it may then be removed by hand with forks. The one major drawback of sand beds is that heavy equipment, such as a skip loader, cannot be used because the weight could damage the underdrain system. Also, the scraping action could mix the sand with the gravel or remove some of the sand with the dried sludge which will have to be replaced.

Some operators lay 2" x 12" boards across the sand for wheelbarrows or light trucks and fork the sludge cake into them to haul to a disposal site. The dried sludge cake is normally three to six inches thick and is not heavy unless a large amount of grit was present in the sludge. The operator calculates the amount of cake in cubic feet by the depth of the dry sludge cake and surface area of the bed. The total dry pounds is arrived at from the total solids in the sludge samples when the sludge was drawn.

Dried sludge makes an excellent soil conditioner and a low-grade fertilizer. However, in many states air dried digested sludge may only be used on lawns, shrub beds, and orchards and cannot be used on root crop vegetables unless heat dried (at 1450°F), or unless it has been in the ground that the crop is to be planted in for over one year. It is always best to check with the state or local health department before dried sludge is used on a food crop.

If a bed of "green" sludge (partially digested) is accidentally drawn, it will require special attention. The water will not drain rapidly, odors will be produced, and the water held provides an excellent breeding ground for nuisance insects. Flies, rat-tail maggots, psychoda flies, and mosquitoes will breed profusely in this environment. An application of dry lime spread over the bed by shovel, and a spraying of a pesticide, is beneficial. The sludge from such a bed should never be used for fertilizer.

Dry sludge cake will burn at a slow smoldering pace, producing quite an offensive odor; therefore, don't allow it to catch fire.

WARNING

IF A SLUDGE POWDER OR DUST IS PRESENT AND KICKED INTO THE AIR IT WILL EXPLODE, SIMILAR TO A DUST EXPLOSION IN A FLOUR MILL. ONCE SLUDGE BEGINS BURNING IT IS EXTREMELY DIFFICULT TO EXTINGUISH. WATER SPRAYS ARE BEST USED IN EXTINGUISHING A SLUDGE FIRE.

QUESTIONS

8.30A How would you prepare a drying bed prior to applying sludge?

8.30B Why should sludge be drawn slowly from the digester?

8.30C What would you do if thin sludge suddenly started flowing onto the drying bed on a gravity flow system, indicating that a sludge cone had formed in the bottom of the digester?

8.30D Why should no smoking or open flames be allowed in the vicinity where sludge is being drawn?

8.30E What should you do to the sludge draw-off line after sludge is applied to the drying bed?

8.30F Why should heavy equipment such as skip loaders not be used to remove dried sludge from a sand drying bed?

8.30G What is the volume of dry sludge in a bed 100 feet long and 25 feet wide if the dried sludge is six inches thick? How many two cubic yard dump truck loads would be required to haul away this sludge?

8.30H If green sludge (partially digested) accidentally was applied to a drying bed, how would you handle this situation?

8.31 Blacktop Drying Beds (See Fig. 8.15)

This type of bed has become prevalent in the past few years and has several advantages if designed properly. It is made of blacktop or asphalt with both sides sloping gradually to the center to a one-foot wide drain channel. The drain channel runs the full length of the bed with a three- or four-inch drain line on the bottom. The drain line is covered with rock, gravel, and sand as in a sand bed. The drain line usually has a cleanout at the upper end, and a control valve on the discharge end.

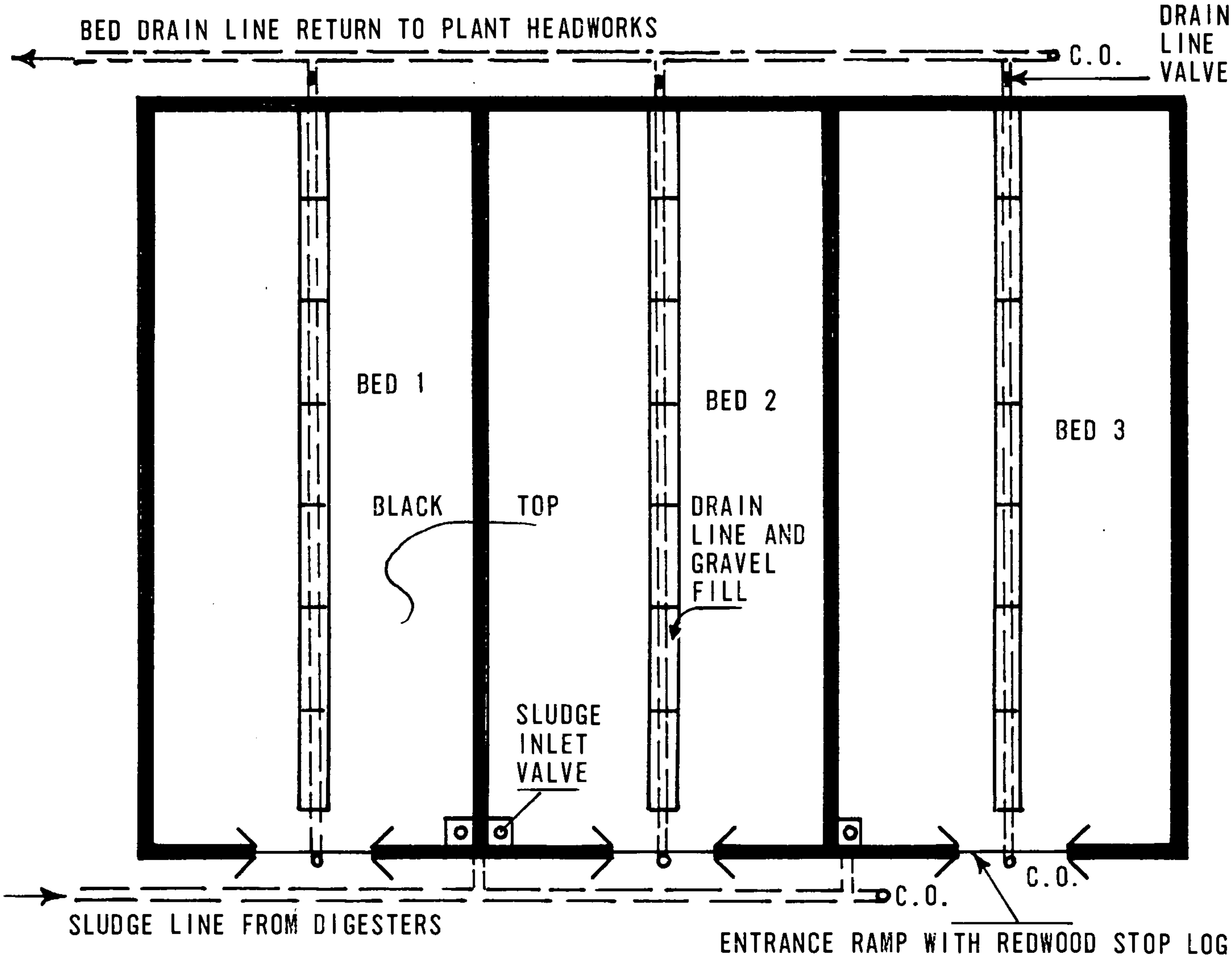
When the bed is to be used, the cleanout on the drain line is removed and the line is flushed with clear water and the cleanout cover replaced. It is recommended that the drain line valve be closed and the drain line and drain channel be filled with water to the top of the sand, so that the sand is not sealed with sludge. Sludge is then admitted to the bed. Some plants have operated successfully without pre-filling the collection system with water.

The depth the sludge is applied to the bed is between 18 and 24 inches.

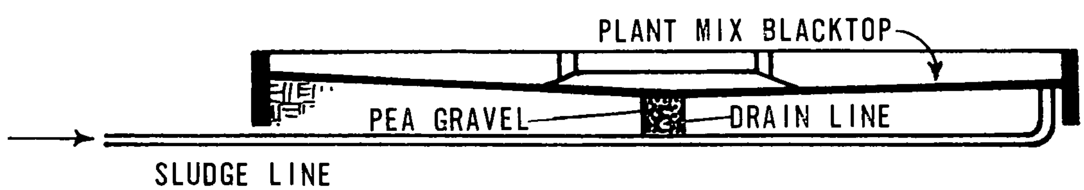
The sludge is sampled in the same way as when using a sand bed, except one additional sample is taken in a glass jar or beaker and set aside. By watching the jar of sludge, you can observe at some time during the first 24 to 36 hours that the sludge will rise to the top, leaving liquor on the bottom. This is primarily caused by the gas in the sludge. (Later, the sludge will again settle to the bottom and the liquor will be on the surface.) The drain valve on the drying bed should be opened when the sludge separates and rises to the top of the jar. The liquor collected in the sludge bed drains is normally returned to the primary clarifiers.

After the sludge has started to crack and has a crust, drying time may be reduced by driving a vehicle through the bed to mix the sludge. When the cake is dry a skip loader is used to clean the bed.

Blacktop beds may be able to handle two to three times as much sludge as sand beds in a given period of time.



PLAN VIEW



CROSS SECTION ONE BED

Fig. 8.15 Blacktop drying bed

8.32 Sludge Lagoons

Sludge lagoons are deep ponds that hold digested sludge and, in some instances, supernatant. Digested sludge is drawn to the lagoon periodically and may require a year or two to fill. When the lagoon is full, sludge is discharged into another lagoon while the first one dries. This drying period can require a year or two before the sludge is removed. Some large cities have used lagoons for many years, avoiding the use of covered secondary digestion tanks.

QUESTIONS

8.31A How would you attempt to reduce drying time in blacktop beds?

8.32A How does a sludge lagoon operate?

8.33 Withdrawal to Land

Wet sludge can be spread on land to reclaim the land or on farm land and ploughed in as a soil conditioner and fertilizer. Used with lagoons this gives a flexible system. This is an excellent method of sludge disposal wherever applicable, because it returns the nutrients to the land and completes the cycle as intended by nature.

Transporting sludge to the disposal site is accomplished by tank truck or pipeline. The application of wet sludge to the land depends upon the topography and the crop to be raised on that land. When applied to grass or low ground cover crops, application may be by spraying from the back of the tank truck while driving over the land, by the use of irrigation piping, or by shallow flooding.

The best method, but most costly, is leveling the land, constructing ridges and furrows, and then pumping the sludge down the furrows similar to irrigation practices used in arid regions. This method is not only capable of reclaiming land unsuitable for growing plants and trees, but may yield crops equal to or greater than those raised with commercial fertilizers.

Some precautions that must be practiced with this method of sludge disposal include:

1. Never apply partially digested ("green") sludge or scum.

2. Residential areas must not be located near land disposal sites.

3. Land disposal sites must not be located on a flood plain where the sludge may be washed into the receiving waters during flooding.

4. Domestic water wells must not be located on the land receiving the sludge.

5. Root crop vegetables must not be grown on the land.

6. Cooperation with the landowner as to application time, drying, and covering must be guaranteed.

7. Access to the land during wet weather must be provided.

8.34 Mechanical Dewatering

In plants where large volumes of sludge are handled and drying beds are not feasible, mechanical dewatering may be used. Mechanical dewatering falls into two methods: vacuum filters and centrifuges. Each is capable of reducing the moisture content of sludge to 60% to 80%, leaving a wet, pasty cake containing 20% to 40% solids. This cake may then be disposed of as land fill, barged to sea, dried in furnaces for fertilizer, or incinerated to ash in furnaces or wet oxidation units.

A. Vacuum Filters (Figs. 8.16 and 8.17)

For digested sludge to be dewatered by this method usually requires a conditioning of the sludge by the addition of chemicals. Elutriation (e-LOO-tree-a-shun) is the washing of the digested sludge in plant effluent in a suitable ratio of sludge to effluent. Elutriation may be accomplished in from one to three separate tanks, similar to small rectangular clarifiers. The sludge is pumped to the elutriation tank and mixed with plant effluent. Next this mixture is admitted to the other tanks to establish a counter-current wash. The sludge is then allowed to settle and is collected by flights and pumped to the next elutriation tank. After one to three washings it is then pumped to the conditioning tanks. The main purpose of the elutriation tanks is to remove the fine sludge particles which require large amounts of chemicals for coagulation. It also removes amino acids and salts which may have a small coagulant demand. After elutriation the sludge will react with the chemicals better and produce better cake. The elutriate (effluent from elutriation tanks) is returned to the primary clarifiers and may result in a very heavy recirculating load since it is chiefly fine solids. Many treatment plants have discontinued the practice of elutriation. Although the process saves approximately $1 per ton of dry solids handled on chemical costs, the costs are excessive for treating the elutriate (wash water) in the biological treatment processes.

Sludge conditioning is accomplished by the addition of various coagulants or flocculating agents such as ferric chloride, alum, lime, and polymers. In the conditioning tank the amount of chemical solution added is normally established by laboratory testing of sludge grab samples by adding various chemical concentrations to the grab samples to obtain a practical filtration rate by vacuum. This test establishes the operating rate for the chemical feed pumps or rotameters from the chemical head tanks, which is normally less than 10% of the dry sludge solids rate to the conditioning tank. (Both rates could be in pounds per 24 hours.) In this tank the

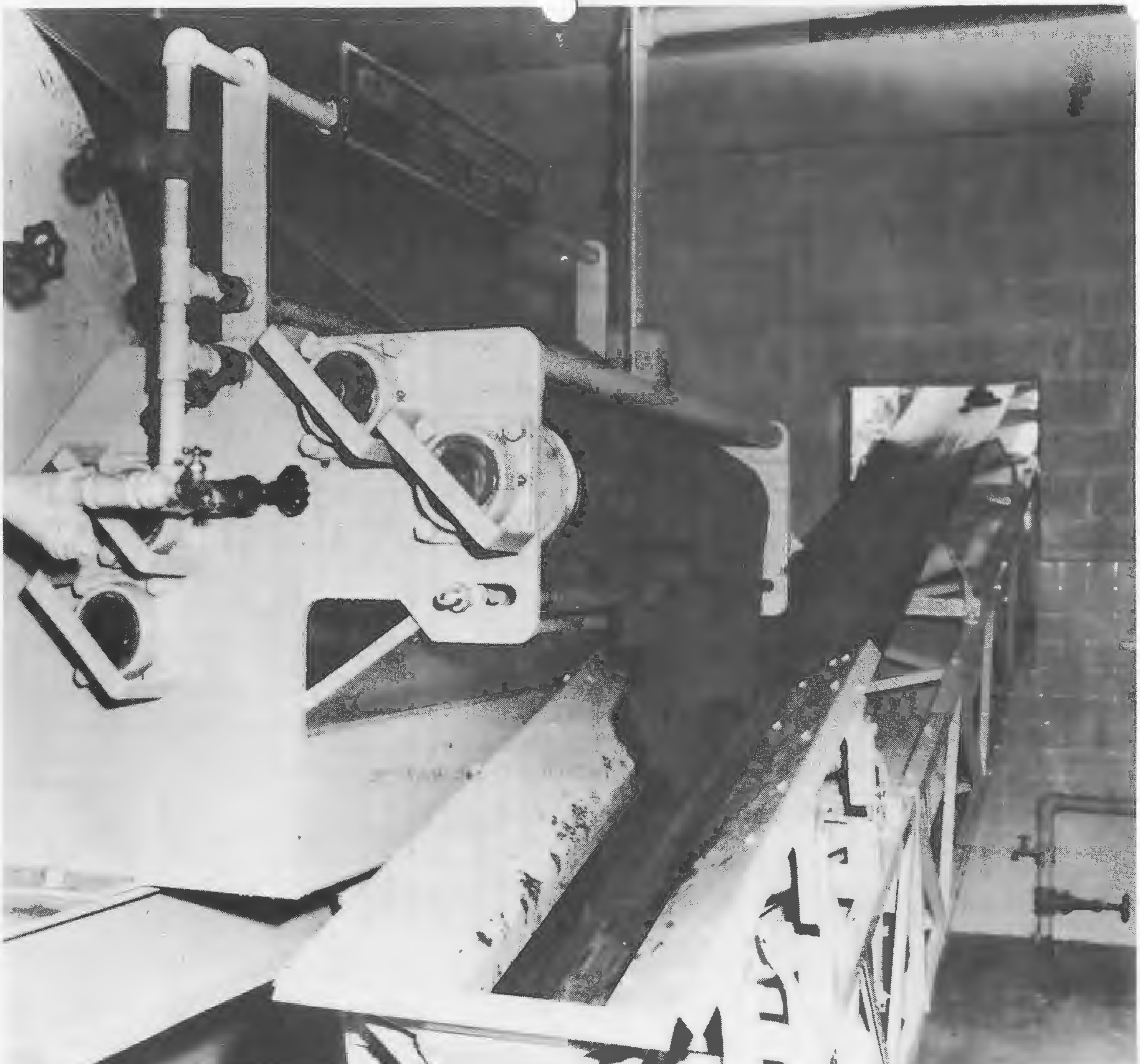


Fig. 8.16 Vacuum filter
Courtesy of Komline-Sanderson Engineering Corporation

chemical is mixed into the sludge by gentle agitation for several minutes. The conditioned sludge then flows to the filter bath where it is continuously and gently agitated. After operation has started, chemical feed is regulated according to cake appearance and behavior.

Filter drums are 10 to 18 feet in diameter, and 12 to 20 feet in length. They may use cloth blankets of dacron, nylon, or wool, or use steel coil springs in a double layer, to form the outer drum covering and filter media. The drum inside is a maze of pipe work running from a metal screen and wood surface skin, and connecting to a rotating valve port at each end of the drum.

Cloth blankets are stretched and caulked to the surface of the filter drums with short sections of 1/4" cotton rope at every screen section. The sides of the blanket are also stretched and stapled to the end of the drums. The nap[18] of the blanket should be out. After the blanket is stretched completely around the drum, it is then wrapped with two strands of 1/8" stainless steel wire, approximately 2" apart for the full length of the drum.

The installation of a blanket may require several days, and it lasts from 200 to 20,000 hours. The life of the blanket depends greatly on the blanket material, conditioning chemical, backwash frequency, and acid bath frequency. An improper adjustment of the scraper blade, or accidental tear in the blanket, will usually require its replacement.

Both cloth blankets and coil spring filters require a high pressure wash after 12 to 24 hours of operation, and in some instances, an acid bath after 1000 to 5000 operating hours.

The filter drum is equipped with a variable speed drive to turn the drum from 1/8 to 1 rpm. Normally, the lower rpm range is used to give the filter time to pick up sufficient sludge as it passes through the conditioned sludge tub under the filter. Normally less than 1/5 of the filter surface is submerged in the tub and pulling sludge to the blanket or springs by vacuum to form the cake mat. As that area passes through the conditioned sludge, the vacuum holds a layer 1/8 to 1/2 inch thick of sludge to the media, and continues to pull the water from the sludge to approximately 210 degrees from the bottom point of the filter after it leaves the vat. This is the drying cycle. At this point the vacuum is released and a light air pressure (3.0 psi) is applied to the inside of the blanket, lifting the sludge

[18] Nap. The soft fuzzy surface of the fabric.

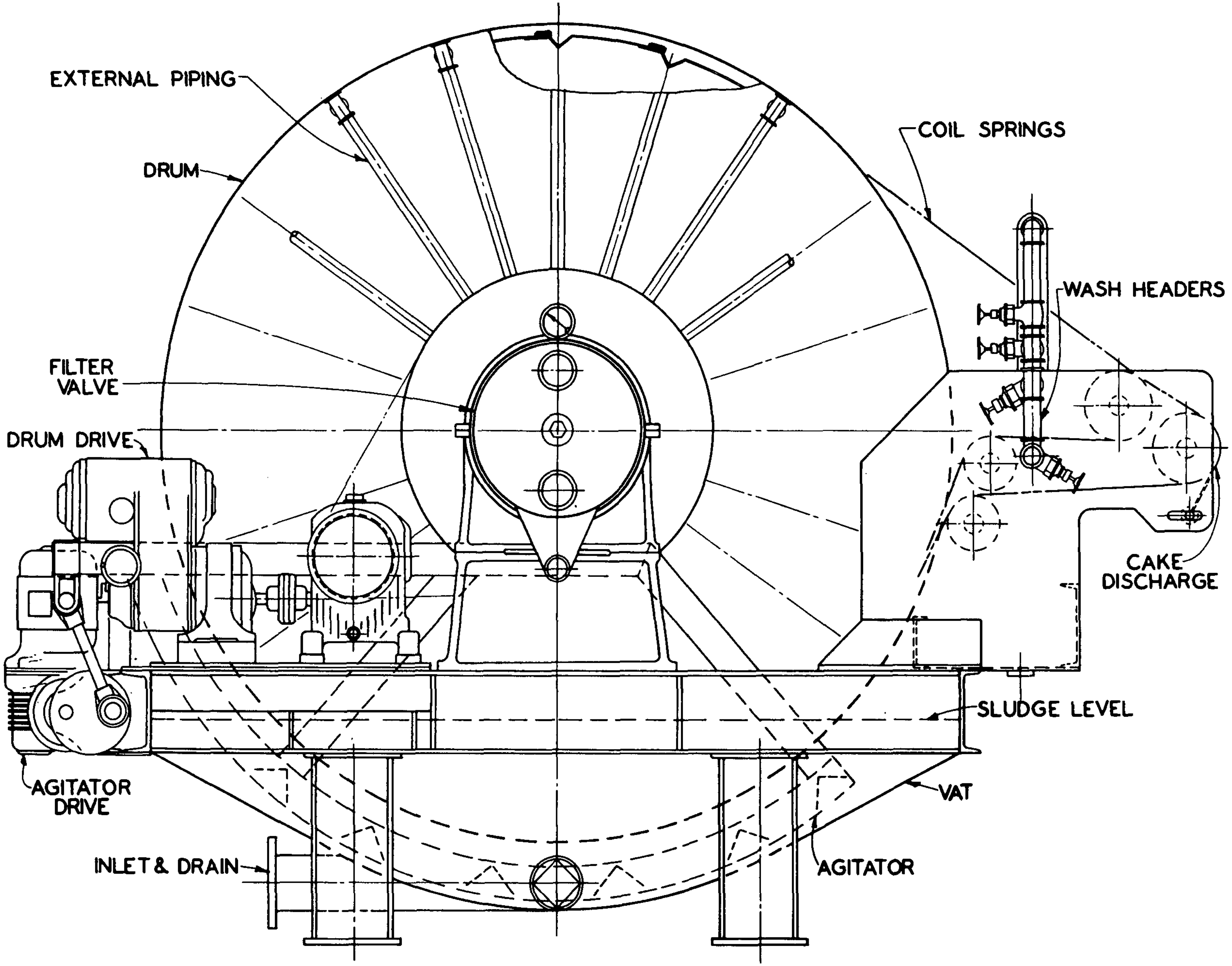


Fig. 8.17 Coilfilter elevation

Courtesy of Komline-Sanderson Engineering Corporation so that it falls from the blanket into a hopper or conveyor belt. The drum then rotates past a scraper blade to remove sludge that did not fall. The applied air is then phased out as that section starts into the filter tub, and vacuum is applied in order to pick up another coating of sludge.

The thickness of the sludge cake and moisture content depend upon the sludge, chemical feed rate, drum rotation speed, mixing time, and condition of the blanket or coil springs. A filter may blank out (lose sludge cake) for any of the above reasons or due to the loss of vacuum or filtrate pumps. Filtrate is the liquor separated from the sludge by the filter; it is returned to the primary clarifiers.

QUESTIONS

8.33A What are some of the advantages of applying sludge to land?

8.34A How is sludge disposed of in many large plants or areas where drying beds are not feasible?

8.34B How would you prepare digested sludge for drying by vacuum filtration?

8.34C How would you determine the chemical feed rate to condition sludge?

8.34D What factors influence the life of a filter blanket?

B. Centrifuge

Centrifuges are gaining in popularity for dewatering raw or primary sludges for furnaces or incineration units. Their use on digested sludge is becoming more widespread and is expected to replace vacuum filters as the prime digested sludge dewatering device. Most digested sludges are conditioned with polymers before being fed to a centrifuge.

Centrifuges are various sized cylinders that rotate at high speeds. The sludge is pumped to the center of the bowl where centrifugal force established by the rotating unit separates the lighter liquid from the denser solids. The centrate[19] is returned to the primary clarifiers, and the sludge cake is removed to a hopper or to a conveyor for disposal.

The feed rate, pool depth, centrifuge rpm, and other factors determine the condition of the discharge cake or slurry and the quality of centrate. The centrate usually contains a high amount of suspended solids that become difficult to handle in the primary clarifiers and digesters. A large amount of grit in the sludge greatly increases the wear rate on the centrifuge. Similar to the wash water from the elutriation process, centrate from vacuum filters also exerts a difficult load on biological treatment processes.

QUESTIONS

8.34E Centrifuges are commonly used to dewater what types of sludges?

8.34F How would you regulate the condition of the sludge cake from a centrifuge?

END OF LESSON 4 OF 5 LESSONS

on

SLUDGE DIGESTION AND HANDLING

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[19] Centrate. The liquor leaving the centrifuge after most of the solids have been removed.

DISCUSSION AND REVIEW QUESTIONS

Chapter 8. Sludge Digestion and Handling

Write the answers to these questions before continuing with Lesson 5. The problem numbering continues from Lesson 3.

18. What kind of sludge should be placed on a sand drying bed?
19. What precautions should be taken when applying sludge to a drying bed?
20. What are the advantages of a blacktop drying bed over a sand drying bed?
21. Why have some plants discontinued elutriation?
22. What are some of the operational problems encountered in using a centrifuge to dewater sludge?

8.4 DIGESTER CONTROLS AND TEST INTERPRETATION

NOTE: See Chapter 14, Laboratory Procedures and Chemistry, for testing procedures.

A. Temperature

A thermometer is usually installed in the recirculated sludge line from the digester to the heat exchanger. This thermometer will accurately measure the temperature of the digester contents when circulation is from bottom to top. The temperature from the digester is recorded and should be maintained between about 95 and 98°F for mesophilic digestion. Never change the temperature more than 1°F per day. Accurate temperature readings also may be taken from the flowing supernatant tube or from the heat exchanger sludge inlet line. The same temperature should be maintained at all levels of the tank.

B. Volatile Acid/Alkalinity Relationship

The volatile acid/alkalinity relationship is the key to successful digester operation. As long as the volatile acids remain low and the alkalinity stays high, anaerobic sludge digestion will occur in a digester. Each treatment plant will have its own characteristic ratio for proper sludge digestion (generally less than 0.1). When the ratio starts to increase, corrective action must be taken immediately. This is the first warning that trouble is starting in a digester. If corrective action is not taken immediately or is not effective, eventually the CO_2 content of the digester gas will increase, the pH of the sludge in the digester will drop, and the digester will become sour.

A good procedure is to measure the volatile acid/alkalinity relationship at least twice a week, plot the volatile acid/alkalinity relationship against time, and watch for any adverse trends to develop. Whenever something unusual happens, such as an increased solids load from increased waste discharges or a storm, the volatile acids/alkalinity relationship should be watched closely. Chapter 14, Laboratory Procedures and Chemistry, contains a procedure for measuring volatile acids by titration which gives satisfactory results for operational control.

The volatile acid/alkalinity relationship is an indication of the buffer capacity of the digester contents. A high buffer capacity is desirable and is achieved by a low ratio which exists when volatile acids are low and the alkalinity is high (120 mg/l volatile acids/2400 mg/l alkalinity). Excessive feeding of raw sludge to the digester, removal of digested sludge, or a shock load such as produced by a storm flushing out the collection system may unbalance the volatile acid/alkalinity relationship.

A definite problem is developing when the volatile acid/alkalinity relationship starts increasing. Once the relationship reaches the vicinity of 0.5/1.0 (1000 mg/l volatile acids/2000 mg/l alkalinity), serious decreases in the alkalinity usually occur. At a relationship of 0.5/1.0 the concentration of CO_2 in digester gas will start to increase. When the relationship reaches 0.8 or higher, the pH of the digester contents will begin to drop. When the relationship first starts to increase, ample warning is given for corrective action to be taken before problems develop and digester control is lost.

Response to an Increase in Volatile Acid/Alkalinity Ratio:

When the ratio starts to increase, extend mixing time of digester contents, control heat more evenly, and decrease sludge withdrawal rates. Mixing should be vertical mixing from the bottom of the tank to the top of any scum blanket. If possible, some of the concentrated sludge in the secondary digester should be pumped back to help correct the ratio. In addition, the primary digester should not be operated as a continuous overflow unit when raw sludge is added, but it should be drawn down to provide room for some sludge from the secondary digester too. During heavy rains when extra solids are flushed into the plant, it may be necessary to add some digested sludge to the primary digester. Use the volatile acid/alkalinity ratio as a guide to determine the amount of digested sludge that should be returned to the primary digester for control purposes.

C. Digester Gas (CO_2 and Gas Production)

This is a useful test to record. The change of CO_2 in the gas is an indicator of the condition of the digester. Good digester gas will have a CO_2 content of 30 to 35%. The volatile acid/alkalinity relationship will start to increase before the carbon dioxide (CO_2) content begins to climb. If the CO_2 content exceeds 42%, the digester is considered in poor condition and the gas is close to the burnable limit (44 to 45% CO_2).

Gas production in a properly operating digester should be constant if feed is reasonably constant. If the volume produced gradually starts falling, trouble of some sort is indicated.

D. pH

pH is normally run on raw sludge, recirculated sludge, and supernatant. This information is strictly for the record and not for plant control. The raw sludge, if stale, will be acid and run in the range of 5.5 to 6.8. Digester liquors should stay around 7.0 or higher. pH is usually the last indicator to change and gives little warning of approaching trouble. It is therefore the least desirable control method.

QUESTIONS

8.4A Where would you obtain the temperature of a digester?

8.4B Why is the volatile acid/alkalinity relationship very useful in digester control?

8.4C What should be done when the volatile acid/alkalinity relationship starts to increase?

8.4D Why is pH a poor indicator of approaching trouble in a digester?

E. Solids Test

Samples are collected of the raw sludge, recirculated sludge, and supernatant. Each sample is tested for total solids and volatile solids.

The information from these tests is used to determine the pounds of solids handled through the system, the digester loading rates, and the percent of reduction of the organic matter destroyed by the digester. All of these tests are necessary for the maintenance of close digester operation.

F. Volume of Sludge

Volumes of sludge are needed to determine the pounds of solids handled through the system. In smaller plants which use a positive displacement pump, the volume of raw sludge is determined by the volume the pump displaces during each revolution. For instance, a 10-inch piston pump with a 3-inch stroke will discharge one gallon per revolution. These pumps are equipped with a counter on the end of the shaft and are seldom operated faster than 50 gpm.

Example

Calculate the volume pumped per stroke (revolution) by a piston pump with a 10-inch diameter piston and the stroke set at three inches.

$$\text{Volume of Cylinder, cu ft} = \text{Area, sq ft} \times \text{Depth, ft}$$

$$= 0.785\ D^2H$$

$$\frac{10''}{12''/\text{ft}} = 0.833 \text{ or } 0.83 \text{ ft}$$

$$\frac{3''}{12''/\text{ft}} = 0.25 \text{ ft}$$

$$= 0.785 \times (0.83 \text{ ft})^2 \times 0.25 \text{ ft}$$

$$= 0.785 \times 0.69 \text{ ft} \times 0.25 \text{ ft}$$

$$= 0.785 \times 0.17$$

$$= 0.133 \text{ cu ft}$$

.83	.69	.785
.83	.25	.17
249	345	5495
664	138	785
.6889	.1725	.13345

Volume of Cylinder, gal	= 0.133 cu ft x 7.48 gal/cu ft	7.48 .133
	= 0.995 gals/stroke	2244 2244 748
	= 1.0 gal/stroke (approximately)	0.99484

This is the maximum volume that can be pumped per stroke with this unit. Slow or incomplete valve closures are likely to reduce this amount. You may check it by taking the delivery volume and dividing it by the number of strokes to fill a drying bed or tank.

Units:

The piston travels the depth of the cylinder each stroke. We could have written our original equation in volume per stroke by indicating depth as distance per stroke.

Volume, cu ft/stroke = Area, sq ft x Depth, ft/stroke

Therefore, if the pump counter recorded 2800 revolutions, ideally the pump handled a total of 2800 gallons for that period of time, which is normally a 24-hour period.

If a centrifugal pump is provided, it would be necessary to determine the volume pumped within the system. Thus by determining how long it took to pump one foot of sludge to the digester, the volume per minute could be determined. The quantity of sludge pumped per day is an important variable, and the operator should make a real effort to determine the quantity. The volume of sludge pumped to the digester should be approximately the same each day.

QUESTIONS

8.4E Why would you run a solids test on digester sludge?

8.4F Calculate the volume of sludge pumped per stroke by a 12-inch diameter piston pump with the stroke set at four inches.

8.4G If a piston pump discharges 1.2 gallons per stroke and the counter indicates 2000 revolutions during a 24-hour period, estimate how many gallons were pumped during that day.

8.4H Why would you want to know the volume of sludge pumped per day?

G. Raw Sludge

If the 2800 gallons of raw sludge pumped by the piston pump contained 6.5% total solids and had a volatile content of 68%:

1. How many pounds of dry sludge were handled?

2. What part is subject to digestion (volatile solids)?

Example

Sludge Pumped	=	2800 gallons
Solids	=	6.5%
Volatile	=	68%

Dry Solids, lbs = Gals Pumped x % Solids as decimal x 8.34 lbs water/gal

= 2800 gals x 0.065 x 8.34 lbs/gal

$$\begin{array}{r} 2800 \\ \underline{.065} \\ 14000 \\ \underline{16800} \\ 182.000 \end{array}$$

= 182 gals x 8.34 lbs/gal of solids

182 x 8.34 = 1517.88

= 1518 lbs during pumping period

Volatile Solids, lbs = % Volatile as decimal x Total Solids, lbs

= 0.68 x 1518 lbs

= 1032 lbs of volatile solids during pumping period

H. Recirculated Sludge

Laboratory tests indicate that the dry solids in a recirculated digested sludge sample was 4.5% and contained 54.2% volatile content. This indicates that the process is reducing the volatile content of the sludge, but the 4.5% solids content is lower than that of the raw sludge being pumped to the digester. The reduction is a result of the conversion of a substantial portion of the volatile solids in the raw sludge to methane, carbon dioxide, and water. Therefore, the reduction in solids comes from some of the solids being converted to gas and some of the solids being washed out in the supernatant.

The reduction of volatile solids that has occurred in the primary digester is arrived at mathematically by the following formula:

$$P = \frac{R - D}{R - (R \times D)} \times 100\% = \frac{In - Out}{In - (In \times Out)} \times 100\%$$

P = Percent Reduction of Volatile Matter

In = R = Percent Volatile Matter in Raw Sludge

Out = D = Percent Volatile Matter in Digested Sludge

Example:

In = 68% Volatile Matter in Raw Sludge

Out = 54.2% Volatile Matter in Digested Sludge

$$P = \frac{In - Out}{In - (In \times Out)} \times 100\%$$

$$= \frac{0.68 - 0.54}{0.68 - (0.68 \times 0.54)} \times 100\%$$

$$= \frac{0.14}{0.68 - 0.37} \times 100\%$$

$$= \frac{0.14}{0.31} \times 100\%$$

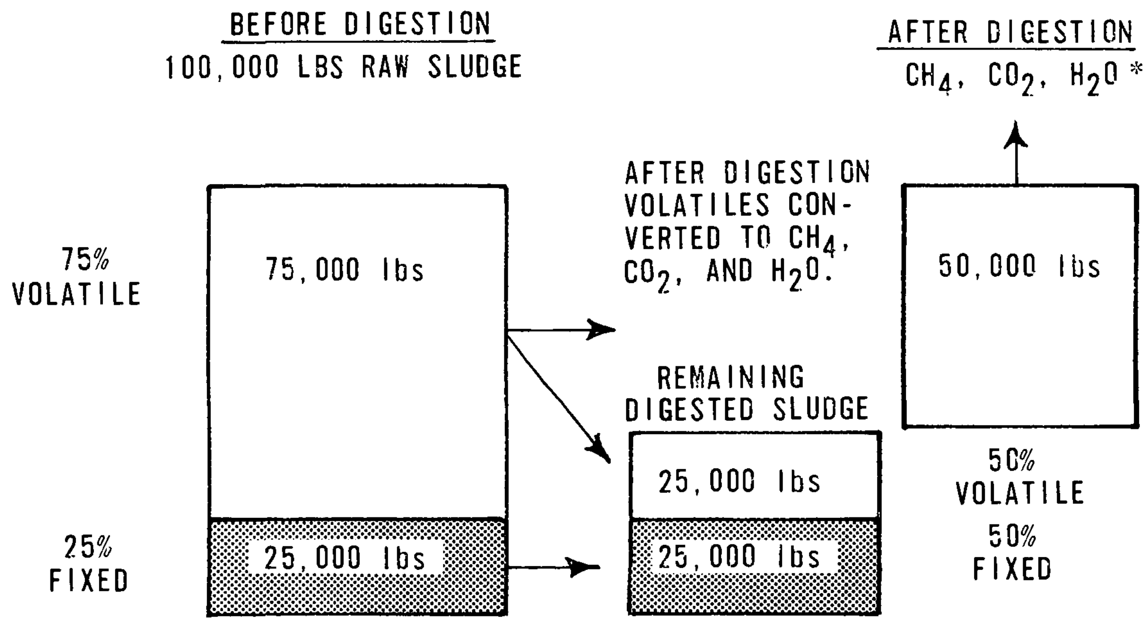
$$= 0.45 \times 100\%$$

$$= 45\%$$

$$\begin{array}{r} 0.68 \\ -0.54 \\ \hline 0.14 \end{array} \qquad \begin{array}{r} 0.54 \\ 0.68 \\ \hline 432 \\ 324 \\ \hline 0.3672 \\ \text{or } 0.37 \end{array} \qquad \begin{array}{r} 0.68 \\ -0.37 \\ \hline 0.31 \end{array}$$

$$\begin{array}{r} .45 \\ .31 \,/\, \overline{.14\,00} \\ 12\;4 \\ \hline 1\;60 \\ 1\;55 \end{array}$$

What is actually happening in the calculation of the percent reduction of volatile matter may be visualized by the following example. Start with 100,000 pounds of raw sludge solids consisting of 75% volatile (organic) solids and 25% fixed (inorganic) solids. After digestion, 50,000 pounds of volatile matter has been converted to methane, carbon dioxide, and supernatant water containing recycle solids, nitrogen, and a COD. The remaining digested sludge consists of 25,000 pounds volatile matter and 25,000 pounds of fixed solids.



* SUPERNATANT WATER CONTAINING RECYCLE SOLIDS, NITROGEN AND A COD.

Check 1:

$$\text{Percent Reduction of Volatile Matter} = \frac{(\text{Reduction of Vol. Solids, lbs}) \times 100\%}{\text{Starting Amt of Vol. Solids, lbs}}$$

$$= \frac{(75{,}000 \text{ lbs} - 25{,}000 \text{ lbs}) \times 100\%}{75{,}000 \text{ lbs}}$$

$$= \frac{50{,}000 \times 100\%}{75{,}000}$$

$$= 66.7\%$$

Check 2:

$$P = \frac{\text{In} - \text{Out}}{\text{In} - (\text{In} \times \text{Out})} \times 100\%$$

$$= \frac{0.75 - 0.50}{0.75 - (0.75 \times 0.50)} \times 100\%$$

$$= \frac{0.25}{0.375} \times 100\%$$

$$= 66.7\%$$

I. Secondary Digested Sludge

Laboratory results indicate that a total digested sludge solids sample was 9.6% solids and 42.8% volatile content. The raw sludge solids volatile content was 68%. The overall percent reduction, P, could then be arrived at by using the formula,

$$P = \frac{\text{In} - \text{Out}}{\text{In} - (\text{In} \times \text{Out})} \times 100\%$$

$$= \frac{(0.68 - 0.43) \times 100\%}{0.68 - (0.68)\ (0.43)}$$

$$= \frac{0.25 \times 100\%}{0.68 - 0.29}$$

$$= \frac{0.25}{0.68} \times 100\%$$

$$= 0.64 \times 100\% = 64\%$$

If sludge is drawn from the secondary digester, the total pounds of dry solids may be calculated by using the 9.6% solids results for that example and the volume of the withdrawn sludge.

Thus,

Volume Secondary Digester Sludge in Gallons x Solids, % x Weight of Sludge, lb/gal[20]

= Total Solids, lbs

Total Solids, lbs x Volatile Solids, % = Volatile Solids, lbs

By subtracting from the raw sludge figures, the pounds reduction of total and volatile solids can be found.

QUESTIONS

8.4I During a 24-hour period, 3000 gallons of 5% total solids sludge with a volatile content of 70% was pumped to a digester. Calculate the pounds of: (1) solids, and (2) volatile material pumped.

8.4J Calculate the reduction in volatile solids if the percent volatile entering the digester is 70% and the percent leaving is 45%.

$$P = \frac{\text{In} - \text{Out}}{\text{In} - (\text{In} \times \text{Out})} \times 100\%$$

[20] A gallon of water weighs 8.34 pounds. A gallon of digested sludge will weigh slightly more due to solids. The best way to find the weight is to weigh a gallon of the sludge.

J. Digester Supernatant

The total solids test is run on the digester supernatant to determine the solids load returned to the plant. The total solids in the digester supernatant should be kept below 1/2 of 1% (0.005 or 5000 mg/l). High solids content in the supernatant usually indicates that too much seed or digested sludge is being withdrawn from the digester. This kind of withdrawal could increase the volatile acid/alkalinity relationship which is also undesirable.

Another simple method for checking supernatant is to draw a sample into a 1000 ml graduate and let it stand for four or five hours. The sludge on the bottom of the graduate should be below 50 ml, with an amber colored liquor above it. If supernatant solids are allowed to build too high, an excessive solids and BOD load is placed on the secondary system and primary clarifier. Sludge withdrawn from the secondary digester or supernatant removal tubes should be changed to a different level in the digester where the liquor contains the least amount of solids when the supernatant load becomes too heavy on the plant.

Plants should be designed to allow all sludge solids and liquids to go to a lagoon or some such system for final or ultimate disposal, rather than returning them to the plant.

K. Computing Digester Loadings

Digester loadings are reported as pounds of volatile matter per cubic foot or 1000 cubic feet of digester volume per day. The loading rate should be around 0.15 to 0.35 pounds of volatile solids per cubic foot in a heated and mixed digester. For an unmixed or cold digester, the loading rate should not exceed 0.05 pounds of volatile matter per cubic foot, assuming that each cubic foot contains approximately 0.5 pounds of predigested solids.

Going back to the 40-foot diameter and 20-foot water depth digester described earlier, a raw sludge volume was pumped of 2800 gallons, at 6.5% solids and 68% volatile matter. It was determined that there were 1032 pounds of volatile solids added to the digester per day.

Example

$$\text{Digester Loading, lbs vol. matter/cu ft/day} = \frac{\text{lbs of Vol Matter Added per Day}}{\text{Volume of Digester, cu ft}}$$

$$= \frac{1032 \text{ lbs of Vol. Matter/day}}{25{,}120 \text{ cu ft}}$$

$$= 0.041 \text{ lbs Vol. Matter/cu ft/day}$$

```
              .041
25120 / 1032.000
        1004 80
          27 200
          25 120
```

This would be a light loading, but it is not uncommon in small, new plants.

The pounds of solids that should remain in the digester to maintain a suitable environment must be determined too. To retain a favorable volatile acid/alkalinity relationship of around 0.1, at least ten pounds of digested sludge should be retained in the digester for every pound of volatile matter added to the digester.

$$\text{Digested Sludge in Storage, lbs} = \text{Vol. Mat. Added, lbs/day} \times \frac{\text{10 lbs Dig. Sludge in Storage}}{\text{1 lb Vol. Mat. Added per Day}}$$

$$= 1032 \text{ lbs/day} \times \frac{\text{10 lbs Storage}}{\text{1 lb Added/Day}}$$

$$= 10{,}320 \text{ lbs old sludge in storage on a dry solids basis}$$

The actual amount of sludge retained will depend on digester conditions and the volatile acid/alkalinity ratio.

Sometimes data are reported as pounds of volatile matter destroyed per cubic foot or 1000 cubic feet of digester capacity per day. Using the same data from above and starting from the beginning with 2800 gallons, at 6.5% solids, and 68% volatile, assume a volatile solids reduction of 50%.

Example

Volatile Matter Destroyed, lbs/day/cu ft

$$= \frac{\text{Volume of Sludge Pumped, gal/day} \times \text{\% Solids} \times \text{\% Volatile} \times \text{\% Reduction} \times 8.34\ \text{lbs/gal}}{\text{Volume of Digester, cu ft}}$$

$$= \frac{\overbrace{2800\ \text{gals/day} \times 0.065}^{\text{Volume of Solids}} \times 0.50 \times 8.34\ \text{lbs/gal}}{25{,}120\ \text{cu ft}}$$

$$\begin{array}{r} .50 \\ \underline{.68} \\ 400 \\ \underline{300\ } \\ .3400 \end{array}$$

$$= \frac{2800\ \text{gpd} \times 0.065 \times 0.34 \times 8.34\ \text{lbs/gal}}{25.120\ \text{cu ft}}$$

$$\begin{array}{r} .065 \\ \underline{.34} \\ 260 \\ \underline{195\ } \\ .02210 \end{array}$$

$$= \frac{2800 \times 0.022 \times 8.34}{25{,}120\ \text{cu ft}}$$

$$\begin{array}{r} 2800\ \text{gpd} \\ \underline{.022}\ \phantom{\text{gpd}} \\ 5600\ \phantom{\text{gpd}} \\ \underline{5600\ }\ \phantom{\text{gpd}} \\ 61.600\ \phantom{\text{gpd}} \end{array}$$

$$= \frac{61.6 \times 8.34}{25{,}120\ \text{cu ft}}$$

$$\begin{array}{r} 8.34 \\ \underline{61.6} \\ 5004 \\ 834\ \\ \underline{5004\ \ } \\ 513.744 \end{array}$$

$$= \frac{513.7\ \text{lb/day}}{25{,}120\ \text{cu ft}}$$

$$25120 \,\overline{)\,513.70}^{\ .024}$$

= 0.0204 lbs/day/cu ft

or

= 20.4 lbs/day/1000 cu ft

L. Computing Gas Production

Digester gas data should be recorded in cubic feet produced per day by the digestion system, as recorded daily from the gas meter. The carbon dioxide (CO_2) content should normally be tested once or twice a week. (See Chapter 14, Laboratory Procedures and Chemistry.) Gas production should range between 7 and 12 cubic feet for each pound of volatile matter destroyed in the digesters.

Assume that the gas meter readings have averaged 6000 cubic feet of gas per day. Using the data from the calculation of volatile matter destroyed in pounds per day of 513.7, compute gas produced per pound of volatile matter destroyed.

Example

Gas Produced, cu ft/lb of vol. matter destroyed

$$= \frac{\text{Gas Produced, cu ft/day}}{\text{lbs of Volatile Matter Destroyed, lb/day}}$$

$$= \frac{\text{6000 cu ft gas/day}}{\text{513.7 lbs Volatile Matter Destroyed/day}}$$

$$= \text{12 cu ft gas/lb vol. matter destroyed}$$

```
         11.67
513.7 / 60000
        5137
         8630
         5137
         34930
         30822
          41080
```

QUESTIONS

8.4K Why would you run a total solids test on the digester supernatant?

8.4L What would you do if the total solids were too high in the digester supernatant?

M. Solids Balance, by F. Ludzack

What comes into a treatment plant must go out. This is the basis of the solids balance concept. If you measure what comes into your plant and can account for at least 90 percent of this material leaving your plant as a solid (sludge), liquid (effluent), or gas (digester gas), then you have control of your plant and know what's going on in the treatment processes. This approach provides a good check on your metering devices, sampling procedures, and analytical techniques. It is an eye opener when tried for the first time and advanced operators are urged to calculate the solids balance for their plant.

Using the data from Section G, Raw Sludge, page 8-88, the following example will illustrate the solids balance concept on a digester and drying bed.

INPUT TO DIGESTER

2800 gallons of raw sludge with solids content, 6.5% and volatile solids content, 68%

DIGESTER OUTPUT or INPUT TO DRYING BED

Digested solids with solids content, 4.5% and volatile solids content, 54%

Calculate the pounds of total solids, water, volatile and inorganic solids pumped into the digester.

Total solids to digester.

$$\text{Dry Solids, lbs} = \text{Gals pumped} \times \text{\% Solids as decimal} \times 8.34 \text{ lbs water/gal}$$

$$= 2800 \text{ gals} \times 0.065 \times 8.34 \text{ lbs/gal}$$

$$= 1518 \text{ lbs solids}$$

Total water and solids to digester.

$$\text{Water \& Solids, lbs} = \frac{\text{Total Solids, lbs}}{\text{\% Solids as decimal}}$$

$$= \frac{1518 \text{ lbs}}{0.065}$$

$$= 23{,}400 \text{ lbs}$$

Water to digester.

Water, lbs = Water & Solids, lbs - Solids, lbs

= 23,400 lbs - 1518 lbs

= 21,882 lbs

or

= 21,900 lbs

Volatile Solids to digester.

Volatile Solids, lbs = Total Solids, lbs x % Solids as decimal

= 1518 lbs x 0.68

= 1032 lbs

Inorganic Solids to digester.

Inorganic Solids, lbs = Total Solids, lbs - Volatile Solids, lbs

= 1518 lbs - 1032 lbs

= 486 lbs

Calculate the percent reduction in volatile matter in the digester to find the pounds of gas produced during digestion.

Percent reduction of volatile matter

$$P = \frac{\text{In} - \text{Out}}{\text{In} - (\text{In} \times \text{Out})} \times 100\%$$

$$= \frac{0.68 - 0.54}{0.68 - (0.68 \times 0.54)} \times 100\%$$

$$= 45\%$$

Gas out of digester

Gas, lbs = Volatile Solids, lbs x % reduction as a decimal

= 1032 lbs x .45 lbs

= 465 lbs

Determine the pounds of total, volatile, and inorganic solids removed from the digester to the drying bed as digested sludge.

Volatile Solids to drying bed

$$\text{Volatile Solids, lbs} = \text{Volatile solids to digester, lbs} - \text{Volatile solids out as gas, lbs}$$

$$= 1032 \text{ lbs} - 465 \text{ lbs}$$

$$= 567 \text{ lbs}$$

Total solids to drying beds

$$\text{Total Solids, lbs} = \frac{\text{Volatile Solids, lbs}}{\text{\% Volatile Solids as a decimal}}$$

$$= \frac{567 \text{ lbs}}{0.54}$$

$$= 1050 \text{ lbs}$$

Inorganic solids to drying beds

$$\text{Inorganic Solids, lbs} = \text{Total Solids, lbs} - \text{Volatile Solids, lbs}$$

$$= 1050 \text{ lbs} - 567 \text{ lbs}$$

$$= 483 \text{ lbs}$$ (Note: Almost same as 486 lbs to digester)

Total solids and water to drying bed

$$\text{Water \& Solids, lbs} = \frac{\text{Total Solids, lbs}}{\text{\% Solids as decimal}}$$

$$= \frac{1050 \text{ lbs}}{0.045}$$

$$= 23{,}400 \text{ lbs}$$ (Note: Same volume as put into digester because of thinner sludge going out.)

Find total pounds of water to drying bed and compare amounts of water into and out of digester.

Water to drying bed

Water, lbs = Water & Solids, lbs - Solids, lbs

= 23,400 lbs - 1050 lbs

= 22,350 lbs

or say = 22,400 lbs

Compare amounts of water in and out of digester.

Water Change, lbs = Water Out, lbs - Water In, lbs

= 22,400 lbs - 21,900 lbs

= 500 lbs drawdown in digester

In this case more water was withdrawn in the thin sludge than was added with the thick sludge. No supernatant was withdrawn from the digester or recycled. All of the recycle material must come from the dewatering operation.

DRYING BED OUTPUT

Dried residue removed, 2 lbs water/1 lb solids or 33% solids

Determine the pounds of water removed with the dried solids and the pounds of drainage water recycled to the plant.

Water in solids

Water in Solids, lbs = Total Solids, lbs x 2 lbs water/lb solids

= 1050 lbs x 2 lbs water/lb

= 2100 lbs

Drainage water recycled to plant

$$\text{Recycle Water, lbs} = \text{Water to Drying Bed, lbs} - \text{Water in Solids, lbs}$$

$$= 22{,}400 \text{ lbs} - 2{,}100 \text{ lbs}$$

$$= 20{,}300 \text{ lbs} \qquad \text{(less evaporation)}$$

Estimate pounds of solids recycled to plant based on constituents in drainage or recycled water. Assume the recycled water contained 3500 mg COD/1 which is equivalent to 3500 lbs COD per million pounds of recycled water. The 20,300 pounds of recycled water amounts to approximately 0.02 million pounds.

Find the pounds of COD recycled.

$$\text{COD, lbs} = 3500 \text{ lbs COD/M lbs water} \times \text{M lbs water recycled}$$

$$= 3500 \text{ lbs COD/M lbs} \times 0.02 \text{ M lbs}$$

$$= 70 \text{ lbs}$$

Convert the recycled COD load to pounds of recycled solids assuming 1.4 pounds of COD in each pound of recycled solids.

$$\text{Recycle Solids, lbs} = \frac{\text{COD, lbs}}{\text{COD, lbs/Solids, lbs}}$$

$$= \frac{70 \text{ lbs COD}}{1.4 \text{ lb COD/lb Solids}}$$

$$= 50 \text{ lbs}$$

Convert the recycled TKN (Total Kjeldahl Nitrogen) load in the recycled water to pounds of solids assuming a concentration of 600 mg TKN/1.

$$\text{Recycle Solids, lbs} = 600 \text{ lbs TKN/M lbs water} \times \text{M lbs water recycled}$$

$$= 600 \text{ lbs/M lbs} \times 0.02 \text{ M lbs}$$

$$= 12 \text{ lbs}$$

Estimate total recycle solids

Total Recycle Solids, lbs = Recycle COD Solids, lbs + Recycle TKN Solids, lbs

= 50 lbs + 12 lbs

= 62 lbs

SUMMARY

Constituent	Input to Digester	Input to Drying Bed	Recycle to Plant
Total Solids, lbs	1,518	1,050	62
Volatile Solids, lbs	1,032	567	
Inorganic Solids, lbs	486	483	
Water, lbs	21,900	22,400	20,300
Gas Out, lbs		465	

To complete the solids balance, the quantity of water actually recycled and its solids content should be compared with the calculated values. Another helpful solids balance is to compare calculated and actual digester inputs and outputs on an annual basis.

8.5 OPERATIONAL CHECKS AND SAMPLING SCHEDULE

Items listed below are provided to help you keep your digester in a healthy condition.

8.50 Daily

A. Raw Sludge Pump

1. Raw sludge volume pumped in past 24 hours. (Pump counter reading or meter reading.)
2. Pumps operating properly (check motor, pump, packing, suction, and discharge pressures while pump is operating).
3. Visual check of raw sludge being pumped.
4. Sludge line valve positions.
5. Pump time clock operation.

B. Recirculated Digester Sludge
(Check in mixing line or heat exchanger.)

1. Temperature of recirculated sludge.
2. Boiler and heat exchanger temperature and pressures.
3. Boiler and heat exchanger operation.
4. Recirculated sludge pump operation (check motor, pump, packing, suction, and discharge pressures while pump is operating).

C. Digesters

1. Drain gas line condensate traps and sedimentation trap.
2. Record digester gas pressure and/or floating cover position.
3. Read gas meter.
4. Check supernatant tubes for operation and hose down supernatant box.

5. Record level of water seal on fixed cover digester.

6. Check operation of mixing equipment.

7. Examine waste gas burner for proper operation.

8.51 Weekly

A. Sludge and Gas System Valves

Exercise all sludge and gas system valves by opening and closing.

B. Supernatant Tubes

Check all supernatant tubes for operation and sample each for clearest supernatant to be returned to plant.

C. Supernatant Box

Hose down supernatant box and flush supernatant line to plant.

D. Lubricate Equipment

Lubricate the equipment.

8.52 Monthly

A. Scum Blanket

Check digester for scum blanket build-up.

B. Digester Structure

Examine digester structure for cracks and possible gas leaks.

C. Gas Piping System

Inspect gas piping system for leaks.

8.53 Quarterly

A. Gas Safety Devices

Clean and check digester gas safety devices.

8.54 Semiannually

A. Manometers

Clean and refill gas manometers.

B. Water Seals

Flush and refill digester dome water seals.

8.55 Three to Eight Years

A. Clean and Repair Digester

Dewater digester and clean out, repair, and paint as required.

8.56 Digester Sampling Schedule

A. Daily

1. Temperature.

2. Carbon dioxide content of digester gas.

B. Twice Per Week (Minimum)

1. Recirculated sludge.

   a. Volatile Acids
   b. Alkalinity
   c. Calculate Volatile Acid/Alkalinity Relationship

C. Weekly

1. Raw sludge.

   a. pH
   b. Total Solids
   c. Volatile Solids

2. Recirculated sludge.

   a. pH
   b. Total Solids[21]
   c. Volatile Solids[21]

3. Supernatant

   a. pH
   b. Total Solids
   c. Volatile Solids

D. Monthly to Quarterly

1. Sound digester by sampling from bottom up at five-foot intervals and test for:

   a. Total Solids
   b. Volatile Solids

2. Use sample results from (1) to determine:

   a. Sludge concentrations at various levels in the digester.

   b. Depth of grit accumulation at bottom of digester. (A gradual build-up of grit will occur, and you should estimate the date when the digester will have to be cleaned.)

   c. Quantity of sludge available and condition of sludge to be drawn to drying beds.

   d. Presence of scum blanket and its thickness.

   e. On mixed tanks as primary digesters the effectiveness of digester mixing equipment in mixed primary digesters.

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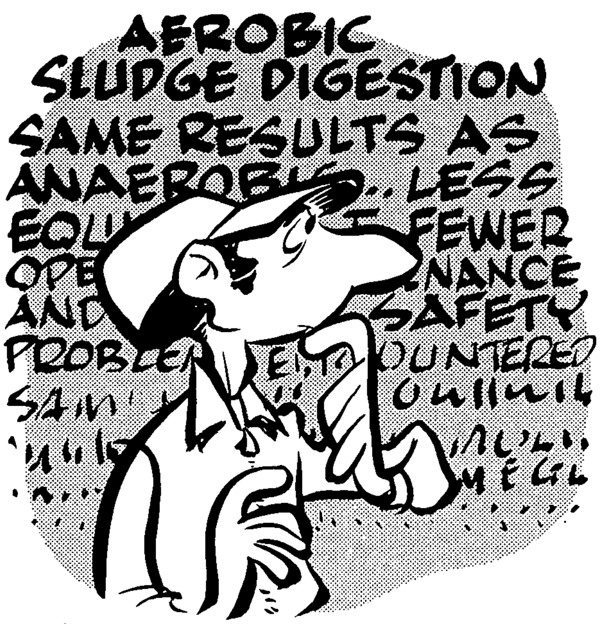
[21] Collect raw sludge samples daily at the start, middle, and end of the pumping cycle. Once a week prepare a composite sample by mixing the daily samples together and run total and volatile solids tests.

8.6 AEROBIC SLUDGE DIGESTION

8.60 Introduction

Aerobic digestion of solids occurs, whether intentional or not, in any of the conventional secondary treatment processes. In the extended aeration process, the aerobic digestion process is continued almost to the maximum obtainable limit of volatile matter reduction. A separate aerobic digester is intended mainly to insure that residual solids from aerobic biological treatment processes are digested to the extent that they will not cause objectionable odors during disposal. The aerobic digester is a separate operation following other processes to extend decomposition of solids and regrowth of organisms to a point where available energy in active cells and storage of waste materials are sufficiently low to permit the material to be considered stable enough for discharge to some ultimate disposal operation. Neither aerobic nor anaerobic sludge digestion completes the oxidation of volatile materials in the digester.



Important comparisons between aerobic and anaerobic sludge digestion are summarized in the following sections.

Anaerobic Sludge Digestion

1. Does not use aeration as part of the process.

2. Works best on fresh wastes that have not been treated by prior stabilization processes.

3. Uses putrefaction as a basic part of the process.

4. Tends to concentrate sludge and improves drainability.

5. Produces methane gas that provides energy for other operations.

6. Generates major digestion products consisting of solids, carbon dioxide, water, methane, and ammonia.

7. Produces liquids that may be difficult to treat when returned to the plant.

8. Generates sludges that need additional stabilization before ultimate disposal.

Aerobic Sludge Digestion

1. Has lower equipment costs, but operating costs are higher.

2. Tends to produce less noxious odors.

3. Produces liquids that usually are easier to treat when returned to the plant.

4. Generates major digestion products consisting of residual solids, carbon dioxide, water, sulfates, and nitrates. Most of these products are close to the final stabilization stage.

5. May achieve nitrogen removal by stopping aeration long enough to allow the conversion of nitrates to nitrogen gas. Aeration must be restarted before sulfates are converted to sulfides (H_2S).

6. Tends to work better on partially stabilized solids from secondary processes that are difficult to treat by the anaerobic digestion process.

7. Produces a sludge that has a higher water content. Aerobic sludges are difficult to concentrate higher than 4 percent solids.

8. Uses oxygenation and mixing provided by aeration process equipment.

9. Has less hazardous cleaning and repairing tasks.

10. Works by aerobic decay which produces less odors when operated properly.

8.61 Process Description

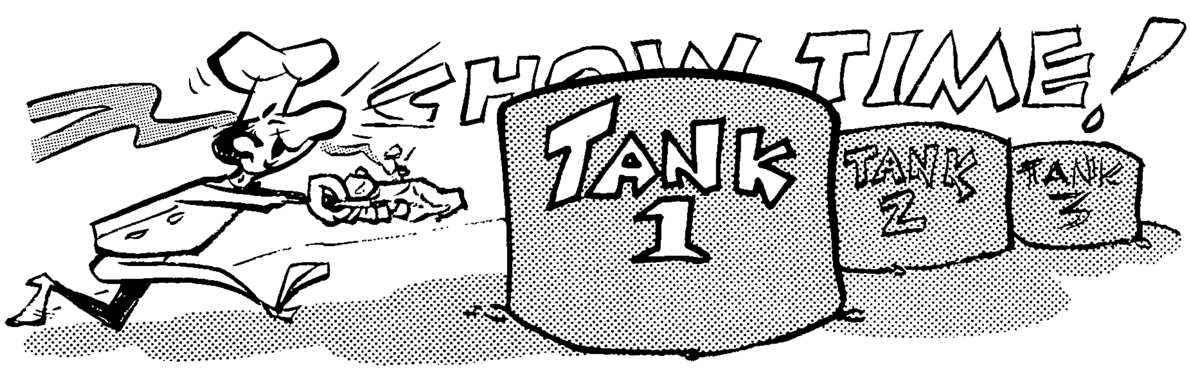
Aerobic digestion tanks may be either round or rectangular, eighteen to twenty feet deep, with or without covers, depending on geographical location and climatic conditions. The tanks use aeration equipment (mechanical or diffused air) to maintain aerobic conditions. Each tank has a sludge feed line at mid-depth of the tank, a sludge draw-off line at the bottom of the tank, and a flexible, multilevel supernatant draw-off line to remove liquor from the upper half of the tank.

Covers are used in colder climates to help maintain the temperature of the waste being treated. Covers should not be used if they reduce evaporative cooling too much and the liquid contents become too warm. When the liquid becomes too warm offensive odors may develop and the process effluent will have a very poor quality.

Aerobic digestion requires the waste solids to be held at least twenty days in the digester. Detention time depends on the origin of the sludge being treated. Twenty days will provide sufficient digestion time for sludges from an extended aeration process where the sludges are already well digested. Sludges from a contact stabilization process require more than twenty days. When temperatures are very low the sludge may have to be held until the weather warms in the spring.

8.62 Operation

Aerobic digesters are operated under the principle of extended aeration from the activated sludge process, relying on the mode or region called endogenous[22] respiration. Aerobic digestion consists of continuously aerating the sludge without the addition of new food, other than the sludge itself, so the sludge is always in the endogenous region. Aeration continues until the volatile suspended solids are reduced to a level where the sludge is reasonably stable, does not create a nuisance or odors, and will readily dewater.



[22] Endogenous (en-DODGE-en-us): A diminished level of respiration in which materials previously stored by the cell are oxidized.

To place aerobic digesters (assume this plant has three aerobic digesters) in series into service, fill the first digester with primary effluent to within three feet of the normal water level and start the aeration equipment. Divert to the aerobic digestion process whenever sludge is pumped. Waste aerobic sludge from the secondary clarifier will provide the seed to start the process. Maintain a dissolved oxygen level near 1.0 mg/l in the aerobic digester.

Pump raw primary and secondary sludges to the aerobic digester in the same manner sludge is pumped to an anaerobic digester, except sludge concentrations in the range of 1.5 to 4 percent are commonly pumped to the aerobic digester.

When the aerobic digester has filled to normal water level, turn off the aeration equipment and allow the solids to settle to the bottom of the tank. This will leave a supernatant above the solids. Don't leave the aeration equipment off too long because odors will start to develop.

After the solids have settled, adjust the flexible, multi-level supernatant line to draw-off a foot or two of water from the upper portion of the tank. Sufficient water is removed from the digester in order to accomodate another 24-hour flow of sludges from the primary and secondary clarifiers. Restart the aeration equipment when sufficient water has been removed.

Water withdrawn from the aerobic digester may be discharged to a pond or returned to the primary clarifier. If the water is returned to the primary clarifier, the clarifier should be capable of handling the extra flow. Primary effluents frequently have undesirably high solids levels.

Next day, repeat the process of stopping aeration, allowing settling, and removing a portion of the supernatant liquor to make room for another day's pumping of sludge. After a week or two the solids level will build-up to occupy approximately fifty percent of the tank volume during the settling period with a suspended solids concentration of 10,000 to 15,000 mg/l.

Place the second aerobic digestion tank in service at this time. Fill the second aerobic digester with primary or secondary effluent to within three feet of the normal water level. Transfer a foot or so of sludge from the bottom of the first digester to the second one, leaving sufficient room in the first to accept another 24-hour period of sludge pumping. Start the aeration equipment in both digesters.

On the next day supernatant should be removed only from the second digester to the primary clarifier. Transfer enough supernatant from the first aerobic digester to allow enough room for one day's sludge pumping. When the second aerobic digestion tank attains the desirable solids level, place the third aerobic digester into service.

After all three tanks are in operation, the aeration equipment is seldom stopped in the first tank. Remove supernatant from the second and third tanks only. Withdraw solids from the third tank for disposal to drying beds or mechanical dewatering as required. The water levels in the tanks should be kept equal when the tanks are operated in a series.

New sludge is introduced into the first tank. All of the tanks receive organisms and their stored materials as food. When starting with new cell mass containing negligible silt, up to about 40 percent of the volatile material can be digested. By the time the sludge reaches the third tank most of the food has been used by the organisms, but they still require energy. Under these conditions they use their own cell material to the extent that only their empty shells remain.

The greatest oxygen demand is exerted in the first tank, and the demand decreases as the sludge is moved to the second and third tanks. Usually sufficient oxygen is being supplied in the third tank if the sludge is kept mixed and not allowed to settle to the bottom of the digester. Dissolved oxygen levels in the tanks should be maintained at or above 1.0 mg/l.

8.63 Operational Records

Successful operation requires the operator to record the following information:

Daily

1. Volume of raw and secondary sludges transferred to the aerobic digesters.

2. Pounds of solids transferred and volatile content.

3. Volume of supernatant liquor withdrawn from last digestion tank.

Weekly

1. Supernatant solids and volatile solids content in digesters.

When Sludge is Withdrawn

1. Volume of sludge withdrawn for dewatering.

2. Pounds of solids dewatered and volatile content.

3. Pounds of volatile solids destroyed during digestion.

8.64 Operational Problems

A. Scum

The aerobic digesters will have to be skimmed periodically to remove floating grease and other material that will not digest. This material should be disposed of by incineration or burial with the scum collected from the primary clarifier.

B. Odors

Odors should not be a problem in aerobic digestion unless insufficient oxygen is supplied or a shock load reaches the aerobic digestion tanks. If an odor problem does occur, a very effective cure is to recycle sludge from the bottom of the second or third tank back to the first tank. This is also good practice in activated sludge plants that have bulking problems because sludge from the last aerobic digester responds very quickly when returned to an aerator.

C. Floating Sludge

Floating sludge may become quite thick in the second and third tanks when aeration is stopped during removal of the supernatant. To avoid clogging, the supernatant draw-off line should be installed so the withdrawal point is from two to six feet below the water surface. The floating sludge is a problem only during supernatant removal. Scum and solids must be removed from the supernatant to prevent interference with other treatment processes and degradation of the plant effluent.

8.65 Maintenance Problems

Usually this process requires very little maintenance. Routinely hose the side walls of open tanks for appearance and fly control.

A. Diffuser Maintenance

If diffused air is used for aeration, only open orifice or nozzle type diffusers should be installed because of the daily stopping of air flow during supernatant removal.

B. Aeration Equipment

Aeration equipment should be operated continuously except when settling is needed for supernatant removal. Both settling and supernatant removal should be accomplished in 0.5 to 1.5 hours.

QUESTIONS

8.6A Why do some plants have aerobic digesters?

8.6B What are some of the advantages of aerobic digestion in comparison with anaerobic digestion?

8.6C What dissolved oxygen levels should be maintained in aerobic digesters?

8.7 ADDITIONAL READING

a. MOP 11, pages 39-88.

b. New York Manual, pages 85-116.

c. Texas Manual, pages 303-396 and 413-444.

d. Sewage Treatment Practices, pages 63-79.

e. Anaerobic Sludge Digestion, WPCF Manual of Practice No. 16, Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016. Price $1.50 to members; $3.00 to others. Indicate your member association when ordering.

f. Dague, Richard R., Digester Control, J. Water Pollution Control Federation, Vol. 40, No. 12, p 2021 (December 1968).

g. Sludge Dewatering, WPCF Manual of Practice No. 20, Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016. Price $3.00 to members; $6.00 to others. Indicate your member association when ordering.

END OF LESSON 5 OF 5 LESSONS

on

SLUDGE DIGESTION AND HANDLING

DISCUSSION AND REVIEW QUESTIONS

Chapter 8. Sludge Digestion and Handling

Write the answers to these questions before continuing. The problem numbering continues from Lesson 4.

23. Why is temperature measured in a digester?

24. Why should the temperature in the digester not be changed by more than one degree per day?

25. What is the first warning that trouble is developing in an anaerobic digester?

26. How would you try to stop and reverse an increasing volatile acid/alkalinity relationship?

27. What is the percent reduction in volatile matter in a primary digester if the volatile content of the raw sludge is 69% and the volatile content of the digested sludge is 51%?

$$P = \frac{\text{In} - \text{Out}}{\text{In} - (\text{In} \times \text{Out})} \times 100\%$$

28. How often should the volatile acid/alkalinity relationship in a digester be checked?

SUGGESTED ANSWERS

Chapter 8. Sludge Digestion and Handling

8.01A Raw sludge must be digested so wastewater solids may be disposed of without creating a nuisance.

8.01B During digestion the organic solids are broken down to other stable products, thus reducing the solids volume and releasing the water from the solids.

8.01C Some of the important factors in controlling sludge digestion include regulation of food supply (organic solids), temperature, mixing, and volatile acid/alkalinity relationship.

8.10A Plug type valves are used in sludge lines because they are less apt to become fouled up by rags than other types of valves.

8.10B A positive displacement pump will continue to build pressure with each revolution until the safety devices shut the pump off, the motor stalls and overheats, or either the pump or the pipe breaks.

8.10C A sludge line should never be sealed at both ends because sludge in it can produce gas and create pressures high enough to break the line or valves.

8.11A Normally the digester roof is designed to contain a maximum operating pressure. If the pressure is exceeded, the water seal could be broken, allowing air to enter the tank and form an explosive mixture of gases. High gas pressures may cause structural damage to the tank in severe cases.

8.11B Fixed cover digesters must be equipped with pressure and vacuum relief valves to break a vacuum or bleed off excessive pressure to protect the digester from structural damage.

8.11C Floating cover. Advantages: Fluctuates with sludge level and gas pressure in digester. Less danger of explosive mixtures than in fixed cover digester. Better control of supernatant withdrawal and scum blankets.

8.11D Mixing recirculated digester sludge with raw sludge provides immediate seeding of the raw sludge with anaerobic bacteria from the digester.

END OF ANSWERS TO QUESTIONS IN LESSON 1.

8.12A The two main gaseous components of digester gas are methane and carbon dioxide.

8.12B Digester gas is used to mix digesters; for fuel to heat digesters and plant buildings; and to run engines on pumps, blowers, and generators.

8.12C Digester gas must be handled with extreme caution due to its ability to burn and explode.

8.12D The pressure relief valve is adjusted by placing the correct amount of lead weights on the pressure relief pallet and then checking the digester pressure with a water manometer to insure the proper setting.

8.12E The water seal in a digester could be broken by either excessive gas pressure or a vacuum in the tank.

8.12F The operation of either the pressure or vacuum relief valves can create an explosive condition due to digester gas mixed with air.

8.12G a. Cut off the gas flow in that line.

b. Put out all flames and pilot lights in the area.

c. Remove end housing and slide out cartridge containing flame arrestor baffles.

d. Clean the baffles in solvent and dry.

e. Reinstall cartridge and replace end plate.

f. Return pressure to gas line and soap test for gas leaks.

8.12H Thermal valves should be checked at least once a year to make sure that the stem and valve seat are clean and the valve will operate when needed.

8.12I A sediment trap should be drained as often as necessary to prevent water from entering the gas lines, which may be from one to three times per day.

8.12J Drip or condensate traps should be installed to keep water out of the gas lines which would restrict gas flows.

8.12K Automatic drip and condensate traps may stick open, venting gas to atmosphere and creating a hazardous condition.

8.12L The gas pressure of the digester system may be adjusted by connecting a manometer to the gas system and adjusting the regulator to hold eight inches water column of gas pressure on the digester.

8.12M The pilot flame in the waste gas burner should be checked daily to prevent unburned waste gas from being vented to the atmosphere and creating a potentially hazardous condition.

8.13A A digester should have a special sampling well in order that the tank contents may be sampled at various depths without venting the digester gas to atmosphere.

8.14A If the temperature of the hot water in the heating coils of this type of heating system is maintained too high, it will cook the sludge onto the coils, thus acting as insulation and reducing the heat transferred.

8.15A Complete mixing greatly speeds the digestion rate by providing the bacteria with greater access to the organic material, and retards or prevents formation of scum blankets.

8.15B Maintenance consists of compressor lubrication, condensate drainage from the gas lines, and prevention of high back pressure due to plugged diffusers.

8.15C An effective operation for breaking up scum in digesters with draft tube mixers is to operate one unit (tube) as a top suction and the other unit as a bottom suction. The direction of flow in the tubes should be reversed each day.

8.15D Pressure gauges should be installed because if a change in the pressures is noted, then this is an indication that the pump is not functioning properly and the desired mixing may not be taking place in the digester.

END OF ANSWERS TO QUESTIONS IN LESSON 2.

8.20A Raw sludge is normally composed of solids settled and removed from the clarifiers or sedimentation tanks. Scum is composed mainly of grease and other floatable material.

8.21A If too much raw sludge is added to the digester, the acid fermentation predominates, which lowers the pH of the sludge and slows down the methane fermenters.

8.21B A digester will usually foam and froth when large amounts of material have been converted by the acid formers as food for the methane bacteria group, which in turn produces large volumes of gas causing the digester to foam.

8.21C Find pounds of volatile matter pumped to digester per day.

$$\text{Volatile Matter Pumped, lbs/day} = (\text{Vol. Sludge, gpd})(\text{Solids, \%})(\text{Volatile, \%})(8.34\ \text{lb/gal})$$

$$= (700\ \text{gal/day})(0.065)(0.70)(8.34\ \text{lb/gal})$$

$$= 265\ \text{lb/day}$$

Find pounds of seed volatile matter needed.

$$\frac{0.05\ \text{lb VM Added/day}}{1\ \text{lb VM in Digester}} = \frac{265\ \text{lb VM Added/day}}{\text{Seed, lb VM}}$$

$$\text{Seed, lb VM} = \frac{(265\ \text{lb VM Added/day})\ \text{lb VM}}{0.05\ \text{lb VM Added/day}}$$

$$= 5300\ \text{lbs VM}$$

Find gallons of seed sludge needed.

$$\text{Seed Sludge, gal} = \frac{\text{Seed, lb VM}}{(9\ \text{lb/gal})(\text{Solids, \%})(\text{VM, \%})}$$

$$= \frac{5300\ \text{lb VM}}{(9\ \text{lb/gal})(0.10)(0.50\ \text{VM})}$$

$$= 11{,}800\ \text{gal}$$

8.21D It is hazardous to start a digester when it is only partially full due to explosive conditions created by a mixture of air and methane in partially full digesters.

8.21E A new digester is ready for the raw sludge rate to be gradually increased to the full plant load when it is producing a burnable gas.

8.22A As thick a sludge as possible may be pumped to the digester by operating the sludge pump for several minutes each hour to clear the sludge hopper, and at a rate not to exceed 50 gpm.

8.22B a. Better performance of primary clarifier.

b. Raw sludge will be well mixed in digester.

c. Less chance of pumping thin sludge or water to the digester.

d. Supernatant is returned to the plant throughout the day, rather than in one large slug.

8.22C The pumping of thin sludge should be avoided because too much water pumped to the digester increases heating requirements, reduces digester holding time, washes buffer and seed sludge out of the digester, and imposes a heavier supernatant load on the plant.

8.23A Lime is added to a digester in an attempt to neutralize the acids and increase the pH to 7.0.

8.23B Assume a dosage of one pound of lime per 1000 gallons of digester sludge.

$$\text{Lime Dose, lbs} = \frac{\text{Digester Sludge Volume, gal}}{\text{1000 gals/lb lime}}$$

$$= \frac{\text{100,000 gal}}{\text{1000 gals/lb lime}}$$

$$= \text{100 lbs of lime}$$

8.23C Lime must be mixed into a slurry before being added to a digester or it will settle to the bottom in lumps which will harden and be ineffective.

8.23D Lime should be added daily until the volatile acids/alkalinity relationship, gas production, and pH levels are restored.

8.24A Bacteria secrete enzymes that help break down compounds that the bacteria in the digester may use as food.

8.25A To control a foaming digester, stop feeding, lower the sludge level by a foot or two for room, start mechanical mixers, and wash away the foam with a hose.

8.25B To prevent foam from recurring:

a. Maintain temperature in digester.

b. Feed sludge at regular, short intervals.

c. Exercise caution when breaking up scum blankets.

d. Don't overdrain sludge from digester.

e. Keep contents of digester well mixed from top to bottom at all times.

8.26A The gas initially produced in a digester is not burnable because it contains mostly CO_2. Generally digester gas will burn when the methane content reaches 50%, but for use as a fuel the methane content should be at least 60%.

8.27A The purpose of the secondary digester is to allow separation of the sludge from the water, to store digested sludge, and to allow more complete digestion. This reserve of digested sludge is needed to act as seed sludge or buffer sludge to be transferred to the primary digester if it becomes upset.

8.27B When raw sludge is pumped to the primary digester, usually an equal volume of sludge from the primary digester is transferred to the secondary digester and supernatant is displaced from the secondary digester back to the plant.

8.27C The level of supernatant withdrawal is selected on a fixed cover digester by selecting the supernatant tube that reaches the clearest supernatant zone in the digester. On floating cover tanks, the supernatant draw-off line is raised or lowered to the clearest supernatant zone in the digester.

8.28A The rate of sludge withdrawal can be determined by watching the gas pressure on the digester that the sludge is being drawn from and not letting the gas pressure drop below two inches of water column.

END OF ANSWERS TO QUESTIONS IN LESSON 3.

8.30A Prior to applying sludge to a drying bed the operator should loosen the sand, break the clods, and level the sand bed.

8.30B Sludge should be drawn slowly from the digester to prevent (1) coning of the sludge and (2) causing a negative pressure in the digester.

8.30C To eliminate a sludge cone you should open and close the valve rapidly to "bump" the sludge in the tank. If the sludge remains thin, stop drawing it.

8.30D Flames and smoking should not be allowed due to the presence of methane gas which is flammable.

8.30E After sludge has been applied to the drying beds, the draw-off line should be flushed with water so the solids won't cement in the line and one valve left open so any gas produced will not rupture the line. The line should be drained if freezing is a problem.

8.30F Heavy equipment should not be used to remove dried sludge from a sand drying bed because the equipment may damage the underdrain system, mix the sand and gravel in the bed, or remove sand that will have to be replaced.

8.30G

$$\text{Volume, cu ft} = \text{Length, ft} \times \text{Width, ft} \times \text{Depth, ft}$$

$$= 100 \text{ ft} \times 25 \text{ ft} \times 0.5 \text{ ft}$$

$$= 1250 \text{ cu ft}$$

$$\text{Volume, yards} = \frac{1250 \text{ cu ft}}{27 \text{ cu ft/cu yd}}$$

$$= 46.3 \text{ cubic yards of dry sludge}$$

$$\text{No. of Trucks} = \frac{\text{Volume, yds}}{\text{Truck Capacity, yds/truck}}$$

$$= \frac{46.3 \text{ yds}}{2 \text{ yds/truck}}$$

$$= 23.15 \text{ trucks}$$

$$= 23 \text{ or } 24 \text{ trucks}$$

8.30H If green sludge were applied to a drying bed, then the operator should apply dry lime and if allowable, an insecticide to control odors and insects. The sludge should be burned or buried when dried.

8.31A To reduce drying time in a blacktop drying bed, obtain a separate sample of the sludge applied to the bed. When the sludge goes to the surface of the sample, open the drain line and slowly bleed off the lower liquor. When the sludge begins to dry and crack, mix the bed, thereby exposing wet sludge.

8.32A A sludge lagoon is filled and then sludge is diverted to another lagoon. The sludge in the full lagoon is tilled, dried, and removed.

8.33A Applying sludge to land improves the condition of the soil and returns nutrients to the soil.

8.34A Mechanical dewatering (vacuum filters and centrifuges) is used to prepare sludge for disposal in large plants or areas where drying beds are not feasible.

8.34B Digested sludge can be prepared for vacuum filtration by washing by elutriation and conditioning with a coagulant.

8.34C The chemical feed rate to condition sludge is determined by sampling and adding various dosages of flocculant to the samples and running filterability tests with a Buchner funnel.

8.34D The life of a filter blanket is influenced by care, maintenance, and the type of material.

8.34E Centrifuges are used to dewater raw or primary sludges and digested sludges for incinerators or furnaces.

8.34F The condition of the sludge from a centrifuge is regulated by the sludge feed rate, bowl speed, and if chemical conditioners are used, by dosage rates and pool depth.

END OF ANSWERS TO QUESTIONS IN LESSON 4.

8.4A The temperature of a digester may be obtained from the digester recirculation sludge line which carries sludge from the digester to the heat exchanger or from the operating supernatant tube.

8.4B The volatile acid/alkalinity relationship is useful in digester control because it is the first indicator that the digestion process is starting to get out of balance and that corrective action is necessary.

8.4C When the volatile acid/alkalinity relationship starts increasing, the operator should reduce the raw sludge feed, maintain heat at the regular level, and thoroughly mix the tank contents. If the volatile acids continue to increase, add seed sludge from the secondary digester.

8.4D pH is a poor indicator because it is usually the last indicator to change, and by the time it changes significantly the digester is already in serious trouble.

8.4E Solids tests are run on digester sludge to determine the pounds of sludge, the pounds of volatile sludge available to the bacteria, the pounds of volatile sludge destroyed or reduced, the digester loading rates, reductions, and the amount of solids handled through the system.

8.4F
$$\begin{aligned}
\text{Volume, cu ft} &= \text{Area, sq ft} \times \text{Depth, ft} \\
&= \frac{\pi D^2}{4} \times \text{Depth, ft} \\
&= 0.785 \times \left(\frac{12''}{12''/\text{ft}}\right)^2 \times \frac{4''}{12''/\text{ft}} \\
&= 0.785 \times 1 \text{ sq ft} \times 0.33 \text{ ft} \\
&= 0.259 \text{ cu ft} \\
\text{Volume, gal} &= 0.259 \text{ cu ft} \times 7.48 \text{ gals/cu ft} \\
&= 1.93732 \text{ or } 1.9 \text{ gals/stroke}
\end{aligned}$$

8.4G
$$\begin{aligned}
\text{Gallons} &= 1.2 \text{ gals/rev} \times 2000 \text{ rev/day} \\
&= 1.2 \text{ gals} \times 2000\text{/day} \\
&= 2400 \text{ gals/day}
\end{aligned}$$

8.4H 1. Gallons pumped per day.
2. Pounds of dry solids/day to the digester.
3. Estimated gallons of supernatant returned to the plant.
4. Volume of sludge for ultimate disposal.

8.4I Dry Solids, lbs = Gals Pumped x % Solids x 8.34 lbs/gal

= 3000 gals x 0.05 x 8.34 lbs/gal

= 1251 pounds

Volatile Content, lbs = % Volatile x lbs Dry Solids

= 0.70 x 1251 lbs Dry Solids

= 875.70 pounds

8.4J Find % reduction, P.

$$P = \frac{\text{In} - \text{Out}}{\text{In} - (\text{In} \times \text{Out})} \times 100\%$$

$$= \frac{0.70 - 0.45}{0.70 - (0.70 \times 0.45)} \times 100\%$$

$$= \frac{0.25}{0.70 - 0.315} \times 100\%$$

$$= \frac{0.25}{0.385} \times 100\%$$

$$= 0.65 \times 100\%$$

= 65% reduction of volatile matter

8.4K Total solids tests are run on the digester supernatant to estimate the solids load being returned to the plant.

8.4L If the total solids reached 0.5 of 1%, sludge should be drawn or supernatant withdrawal level changed.

8.6A Aerobic digestion is commonly used to handle waste activated sludge because of the operational problems encountered when a waste aerobic activated sludge with a low solids content is placed in an anaerobic digester.

8.6B Advantages of aerobic digestion in comparison with anaerobic digestion include fewer operational, maintenance, and safety problems. Aerobic digesters do not require mixing, heating, and gas handling facilities. Potentially explosive methane gas is not produced and close operational control of the volatile acids/alkalinity relationship is not necessary.

8.6C Dissolved oxygen levels in aerobic digesters should be above 1.0 mg/l.

END OF ANSWERS TO QUESTIONS IN LESSON 5.

OBJECTIVE TEST

Chapter 8. Sludge Digestion and Handling

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one answer to each question.

1. The environment in an anaerobic digester may be controlled by regulating the:
    1. Air supply
    2. Food supply
    3. Domestic water supply
    4. Temperature
    5. Mixing

2. Material not readily decomposed in digesters includes:
    1. Rubber goods
    2. Fruit
    3. Plastic
    4. Hair
    5. Grit

3. Sludge should be pumped from the primary clarifier to the digester several times a day to:
    1. Keep the pump from becoming clogged
    2. Prevent temporary overloading of the digester
    3. Maintain better conditions in the clarifier
    4. Permit thicker sludge pumping
    5. Prevent coning

4. Digester gas may be used as a fuel when the methane content exceeds:
    1. 25%
    2. 35%
    3. 50%
    4. 65%
    5. 75%

5. The following precautions must be taken when applying sludge to a drying bed:

   1. Withdraw the sludge slowly from the digester
   2. Loosen sand before applying sludge
   3. Make sure the bed is covered with sludge
   4. Never smoke in the vicinity where the sludge is being drawn
   5. When finished, flush the draw-off line and leave one end open

6. High volatile acid/alkalinity relationship in a digester may be caused by:

   1. Overloading the tank with organic material
   2. Pumping too thin a raw sludge
   3. Filling the tank too full
   4. Withdrawing supernatant
   5. Adding lime

7. Useful digester control tests include:

   1. BOD
   2. pH
   3. Volatile acid/alkalinity relationship
   4. DO
   5. Temperature

8. Laboratory tests indicate that the volatile content of a raw sludge was 71% and after digestion the content is 53%. The percent reduction in volatile matter is:

   1. 25%
   2. 50%
   3. 54%
   4. 60%
   5. 68%

9. Calculate the volatile matter destroyed (lbs/day/cu ft) in a 20,000 cubic foot digester receiving 2400 gallons per day of raw sludge. The solids content is 5%, the volatile content 71%, and the volatile solids are reduced 50% by digestion:

   1. .015
   2. .018
   3. .020
   4. .023
   5. .025

10. A positive displacement pump should never be started against a closed valve because:

    1. It will pump nothing
    2. Excessive pressure may damage the line, the pump, or the motor
    3. The sludge will spill
    4. The valve will swing open
    5. The power driver will stall and overheat

11. Digester gas may be used to:

    1. Heat digesters
    2. Supply oxygen to activated sludge aeration tanks
    3. Digest solids
    4. Run engines
    5. Gas rats around the plant

12. Flame arrestors should be installed:

    1. Between vacuum and pressure relief valves and the digester dome
    2. After sediment trap on gas line from digester
    3. At waste gas burner
    4. Before every boiler, furnace, or flame
    5. In the vent of the waste gas burner

13. The pilot flame in the waste gas burner should be checked daily to:

    1. Make sure it has not been blown out by the wind
    2. Prevent valuable gas from escaping
    3. Prevent odorous gas from escaping
    4. Prevent explosive conditions from developing
    5. Make sure proper temperatures are maintained in the digester

14. The contents of a primary digester should be mixed to:

    1. Distribute food in the tank
    2. Allow solids separation
    3. Prevent formation of a scum blanket
    4. Warm up the sludge
    5. Keep the temperature the same throughout the tank

15. Successful digester operation depends on:

    1. Understanding what's happening in the digester
    2. Keeping all the digested sludge out of the digester
    3. Analysis and application of information from laboratory tests
    4. Cleaning the digester at regular intervals to maintain capacity
    5. Regularly checking the skimmer

16. Sludge pumped to the digester should be as thick as possible:

    1. To reduce heat requirements in the digester
    2. So the sludge will settle to the bottom of the digester
    3. So large amounts of digested sludge will not be displaced to the secondary digester
    4. So a scum blanket won't be formed in the digester
    5. None of these

17. The temperature of a digester should not be changed more than one degree per day to:

    1. Avoid excessive heat losses
    2. Avoid overloading the heat exchanger
    3. Allow the walls of the digester time to expand and contract
    4. Allow the organisms in the digester time to adjust to the temperature change
    5. Allow time for heating gas to be produced in the digester

18. The function of the water seal on the gas dome of the digester is to keep:

    1. Air from entering the digester
    2. Digester gas from escaping the digester
    3. Insects and rodents out of the digester
    4. Sludge from leaking out of the digester
    5. Foam inside the digester

19. Sludge or gas should not be removed too rapidly from the digester because:

    1. The sludge drying beds may become overloaded
    2. If a vacuum develops in the tank it may collapse
    3. If a vacuum develops in the tank air may be drawn in and form an explosive mixture
    4. The water seal could break
    5. The waste gas burner may become overloaded

20. A scum blanket in a digester may be broken up by:

    1. Vigorously mixing the digester contents
    2. Burning
    3. Use of long poles
    4. An ax
    5. Rolling back the blanket

21. The purpose of the secondary digester is to allow:

    1. For more sludge digestion
    2. An opportunity for more mixing
    3. Storage for seed sludge
    4. The liquids and solids in digested sludge to separate
    5. The designer to make more money

22. What could be happening if gas production in a digester starts decreasing?

    1. The volatile acid/alkalinity relationship is increasing
    2. The raw sludge volume fed to the digester is decreasing
    3. The raw sludge volume fed to the digester is excessive
    4. The scum blanket is breaking up
    5. The volatile acid/alkalinity relationship is decreasing

23. Sludge should be withdrawn slowly from a digester to prevent:

    1. Coning
    2. Supernatant from overloading the plant
    3. Forming a vacuum in the digester
    4. The possibility of an explosive gas mixture developing in the digester
    5. The possibility of the digester cover collapsing

24. What would you do if the volatile acid/alkalinity relationship started to increase in a digester?

    1. Increase time of mixing
    2. Maintain constant temperature throughout the digester
    3. Decrease sludge withdrawal rates
    4. Return some digested sludge
    5. Reduce volume of raw sludge pumped to digester

25. After sludge has been applied to the drying bed, the sludge draw-off line should be:

    1. Closed at both ends to keep out rodents and insects
    2. Open at one end to allow gas to escape
    3. Washed out
    4. Left full of sludge
    5. Filled with plant effluent

Please write on your IBM answer sheet the total time required to work all five lessons and this objective test.

APPENDIX

Monthly Data Sheet

CLEANWATER, USA

WATER POLLUTION CONTROL PLANT

MONTHLY RECORD ________ 19___

DIGESTION

OPERATOR: ______________

DATE	DAY	RAW SLUDGE					RECIRCULATED SLUDGE						GAS			SLUDGE DISPOSAL						REMARKS
		GALLONS PER DAY	% SOLIDS	% VOLATILE	pH	SCUM GAL./DAY	TEMP. °F	% SOLIDS	pH	VOL. ACIDS MG/L	ALKALINITY MG/L	MIXING HRS.	GAS PROD. FT^3/DAY	FT^3/M.G. FLOW	% CO_2	GALS. TO BED	BED NO.	% SOLIDS	% VOL. SOL.	LBS. DRY SOLIDS	CU. YDS. CAKE REM.	
1	S	12850	2.4	80.7	5.9		91	1.3	6.9	103	1450	24	31080									
2	M	12280				1090	91					24	37170									
3	T	11990					91					24	26800									
4	W	12020					91					24	28900									
5	T	11460	3.1	73.5	6.0	1700	91	2.8	6.8	137	1400	24	28320		41							
6	F	11720					91					24	28710									
7	S	11990					91					24	25580									
8	S	13090	3.4	73.1	5.9		91	1.6	6.9	86	1690	24	24310		39							
9	M	11170				1190	92					24	24550									
10	T	11000					92					24	24550									
11	W	12000					92					24	24550									
12	T	11490	3.5	83.4	5.7	720	92	1.6	6.9	69	1700	24	25640									
13	F	12000					92					24	25940									
14	S	11760				740	93					24	28750		39							
15	S	12460	3.8	79.2	5.9		93	1.6	6.8	86	1790	24	31450									
16	M	11820				540	93					24	34150									
17	T	12280					93					24	32550									
18	W	11440					94					24	28400									
19	T	11560	1.3	81.7	6.3	580	94	1.4	6.9	120	1610	24	27900		39							
20	F	12070					94					24	31000									
21	S	11960					94					24	32380									
22	S	12510				850	94					24	34420		32							
23	M	12180	1.9	75.3	—		95	1.3	—	86	1280	24	37810									
24	T	10560					94					24	37430									
25	W	11870					94					24	37560									
26	T	11430	2.9	70.6	—		94	1.4	—	—	—	24	37130									
27	F	11510				1150	94					24	35320									
28	S	11840	2.9	73.2	6.1		94	1.6	6.8	120	1670	24	31150		33							
29	S	12120				650	94					24	29520									
30	M	11700	4.6	77.7	6.2		94	1.5	6.9	120	1400	24	32860									
31																						
MAX.		13090	4.6	83.4	6.3	1700	95	2.8	6.9			24	37820		41							
MIN.		10560	1.3	70.6	5.7	540	91	1.3	6.8			24	24310		32							
AVG.		11871	2.9	76.8	6.0	307/DAY	92	1.6	6.9	92	1554	24	30529		36							

CHAPTER 9

WASTE TREATMENT PONDS

by

A. Hiatt

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Chapter 9. Waste Treatment Ponds

GLOSSARY

Chapter 9. Waste Treatment Ponds

Advanced Waste Treatment: Any process of water renovation that upgrades water quality to meet specific reuse requirements. May include general cleanup of water or removal of specific parts of wastes insufficiently removed by conventional treatment processes.

Bioflocculation (BUY-o-flock-u-LAY-shun): A condition whereby organic materials tend to be transferred from the dispersed form in wastewater to settleable material by mechanical entrapment and assimilation.

Facultative Pond (FACK-ul-tay-tive): The most common type of pond in current use. The upper portion (supernatant) is aerobic, while the bottom layer is anaerobic. Algae supply most of the oxygen to the supernatant.

pH: pH is an expression of the intensity of the alkaline or acidic strength of a water. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion concentration.

$$pH = \text{Log}\,\frac{1}{(H^{+})}$$

The pH may range from 0 to 14, where 0 is most acid, 14 is most alkaline, and 7 is neutral. Natural waters usually have a pH between 6.5 and 8.5.

Photosynthesis (foto-SIN-the-sis): A process in which organisms with the aid of chlorophyll (green plant enzyme) convert carbon dioxide and inorganic substances to oxygen and additional plant material, utilizing sunlight for energy. Land plants grow by the same process.

Population Equivalent: A means of expressing the strength of organic material in wastewater. Domestic wastewater consumes, on an average, approximately 0.2 lb of oxygen per person per day, as measured by the standard BOD test.

Stabilized Waste: A waste that has been treated or decomposed to the extent that if discharged or released, its rate and state of decomposition would be such that the waste would not cause a nuisance or odors.

Tertiary Treatment (TER-she-AIR-ee): See Advanced Waste Treatment.

Toxicity (tocks-IS-it-tee): A condition that may exist in wastes that will inhibit or destroy the growth or function of any organism.

PRE-TEST

Chapter 9. Waste Treatment Ponds

The purpose of the Pre-Test is to indicate to you some of the important material contained in this chapter. It's alright if you don't know many answers. Please write your name and mark the correct answers on the IBM answer sheet.

1. Ponds are used to:

    1. Store wastewater while it is treated
    2. Provide a surface for evaporation
    3. Grow mosquitoes
    4. Ice skate on
    5. Grow tules

2. When starting a pond, wastewater should be added:

    1. When the bottom is covered with grass
    2. When the pond is empty
    3. When the wind is blowing in the right direction
    4. When the mayor returns from his vacation
    5. When the pond bottom is covered with at least one foot of water

3. Scum rafts may be broken up by:

    1. Agitation with garden rakes
    2. Jets of water from pumps
    3. The use of outboard motors on boats
    4. A thrashing machine
    5. Breaking down the bindings

4. Important operation and maintenance aspects of ponds include control of:

    1. Odors
    2. Waste gas burner
    3. Scum
    4. Drying beds
    5. Weeds and insects

5. Pond performance can be indicated by what tests?

   1. pH
   2. Carbon dioxide
   3. Methane
   4. Dissolved oxygen
   5. Hardness

6. Facultative ponds are:

   1. Faulty operating ponds
   2. Completely aerobic
   3. Aerobic on the top and anaerobic on the bottom
   4. Very shallow ponds
   5. The most common type in current use

7. Ponds may not operate properly if:

   1. The influent organic matter content fluctuates considerable every few days
   2. Temperature stays below freezing for a long time
   3. There is no scum blanket
   4. The influent contains a powerful fungicide
   5. The influent has a high sulfur content

8. The influent to the first pond should be discharged at the:

   1. Surface
   2. Mid-depth
   3. Bottom of the pond

9. The effluent should leave the final pond:

   1. At the surface
   2. Just below the surface with a scum baffle around the outlet
   3. At the bottom of the pond

10. The pond outfall should be:

    1. Free
    2. Submerged

11. Minimum pond depth should be:

    1. 3 feet
    2. 4 feet
    3. 5 feet

12. Pond loadings may be expressed in:

    1. Acres per day of BOD
    2. Acres of people per day
    3. Pounds of BOD per acre per day
    4. Persons per acre
    5. Pounds BOD/day/acre

13. Pond performance is a function of:

    1. Type and quantity of algae
    2. pH
    3. Type of soil
    4. Short circuiting
    5. Surface area

14. Dissolved oxygen in a pond is increased by:

    1. Surface aerators
    2. Photosynthesis
    3. Wind action
    4. Algae liberating oxygen from the water molecule
    5. Sludge gases from bottom deposits floating to the surface

15. Advantages of ponds for smaller installations include:

    1. No maintenance
    2. Low cost to build and operate
    3. No insect problems
    4. Capability to handle fluctuating loads
    5. Satisfactory treatment of wastes

16. Estimate the population served if the inflow to a plant is 1.2 MGD.

    1. 1200
    2. 6000
    3. 12,000
    4. 120,000
    5. None of these

17. Two ponds serve a summer resort and are operated in series. They cover an area of 150 ft by 250 ft (average width and length of both ponds combined). The average depth is four feet, and the average inflow is 25,000 gpd. The detention time is approximately:

    1. 40 days
    2. 45 days
    3. 50 days
    4. 55 days
    5. 60 days

18. and when the influent BOD is 200 mg/1, the organic loading is approximately:

    1. 40 lb BOD/day/ac
    2. 42 lb BOD/day/ac
    3. 45 lb BOD/day/ac
    4. 48 lb BOD/day/ac
    5. 50 lb BOD/day/ac

19. Ponds are __________ simple to operate. (Select best answer.)

1. Very
2. Deceptively
3. Not
4. Quite
5. Sort of

CHAPTER 9. WASTE TREATMENT PONDS

USED FOR TREATMENT OF WASTEWATER AND OTHER WASTES

(Lesson 1 of 3 Lessons)

9.1 INTRODUCTION

Shallow ponds (three to five feet deep) are often used to treat wastewater and other wastes instead of, or in addition to, conventional waste treatment processes. (See Figs. 9.1 and 9.2 for typical plant layouts.) Wastes which are discharged into ponds are treated or stabilized[1] by several natural processes acting at the same time. Heavy solids settle to the bottom where they are decomposed by bacteria. Lighter suspended material is broken down by bacteria in suspension.

Dissolved nutrient materials, such as nitrogen and phosphorous, are utilized by green algae which are actually microscopic plants floating and living in the water. The algae utilize carbon dioxide (CO_2) and bicarbonates to build body protoplasm. In so growing they need nitrogen and phosphorous in their metabolism much as land plants do. Like land plants, they release oxygen and some carbon dioxide as waste products.

In recent years, ponds have become more popular as treatment facilities. Extensive studies of their performance have led to a better understanding of the natural processes by which ponds treat wastes. Information is also available which can help operators to regulate the pond processes for efficient waste treatment.

9.2 HISTORY OF PONDS IN WASTE TREATMENT

The first wastewater collection systems in the ancient Orient and in ancient Europe were discharged into adjacent bodies of water. These systems accomplished their intended purpose until overloading, as in modern systems, made them objectionable.

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[1] Stabilized Wastes. A waste that has been treated or decomposed to the extent that if discharged or released, its rate and state of decomposition would be such that the waste would not cause a nuisance or odors.

In ancient times, ponds and lakes were purposefully fertilized with organic wastes to encourage the growth of algae which, in turn, greatly increased the production of fish due to the food supply provided by the algae. This practice still persists and is a recognized art in Germany.

Evidently, the first ponds constructed in the United States were built for the purpose of excluding waste waters from intrusion into places where they would be objectionable. Once constructed, these ponds performed a treatment process that finally became recognized as such. The tendency over the years has been to equate pond treatment efficiency with the non-emission of odors. Actually, the opposite is true as the greatest organic load destroyed per unit of area (high treatment efficiency) may be accompanied by objectionable odors.

Armed with the current scientific knowledge of ponding and utilizing the experience of both successes and failures, engineers have designed and constructed a great number of ponds performing a variety of functions since 1958. Ponds that have been designed with adequate engineering, backed by the research of a qualified biological consultant, and operated in a purposeful manner have produced successful results.

Ponding of wastewater as a complete process offers the following advantages for smaller installations, provided land is not costly and the location is isolated from residential, commercial, and recreational areas:

1. Does not require expensive equipment.

2. Does not require highly trained operating personnel.

3. Is economical to construct.

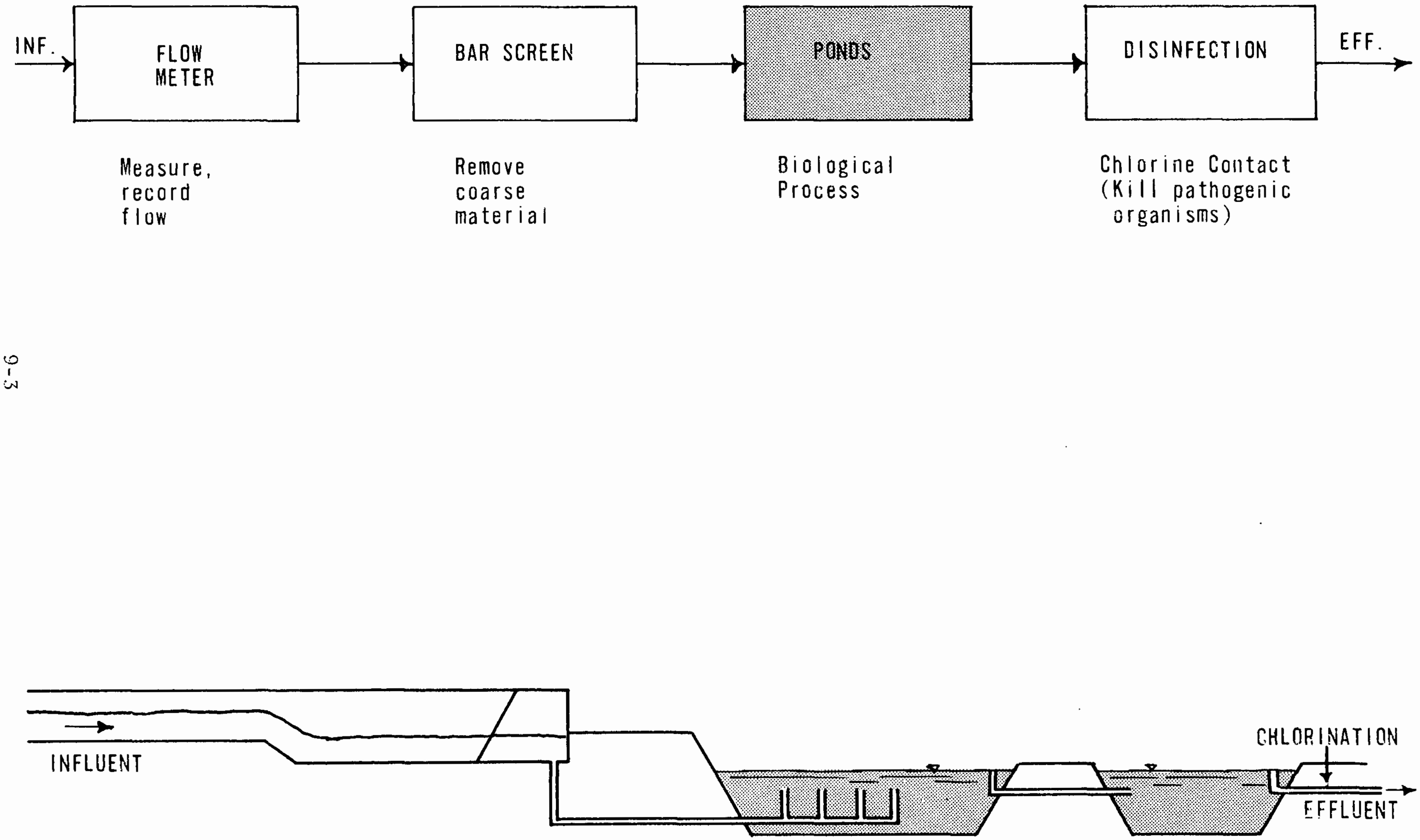

Fig. 9.1 Typical plant; ponds only

4. Provides treatment that is equal to or superior to some conventional processes.

5. Makes a satisfactory short-term method of treating wastewater on a temporary basis until a permanent plant can be constructed.

6. Is adaptable to fluctuating loads.

7. Is probably the most trouble-free of any treatment process when utilized correctly, provided a consistently high quality effluent is not required.

QUESTIONS

9.2A If a pond is giving off objectionable odors, are the wastes being effectively treated? Explain your answer.

9.2B Discuss the advantages of ponds.

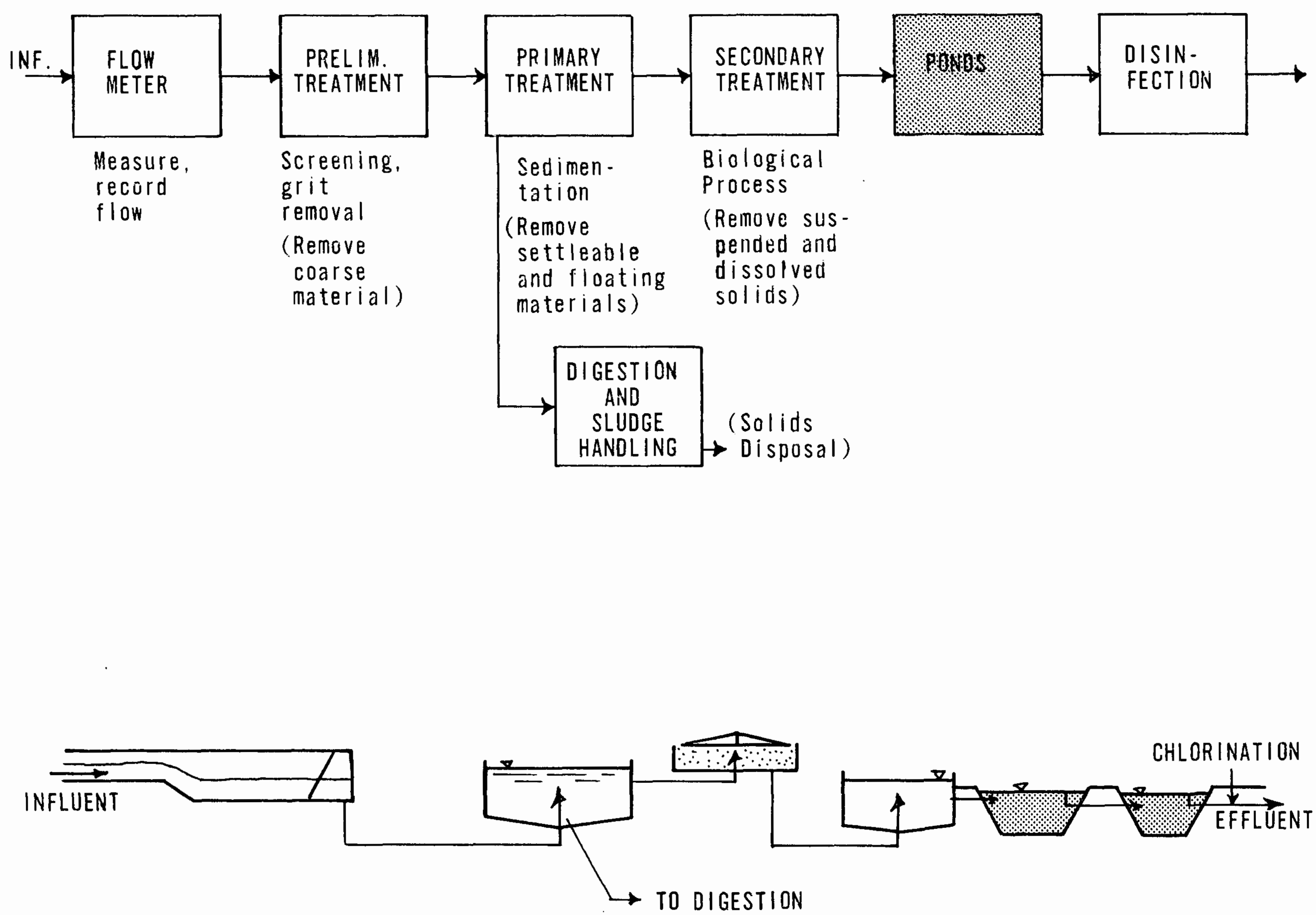

Fig. 9.2 Typical plant; ponds after secondary treatment

9.3 POND CLASSIFICATIONS AND USES

Ponding of raw wastewater, as a complete treatment process, is used to treat the wastes of single families as well as large cities up to the size of the city of Melbourne, Australia, which handles 78 million gallons of wastewater per day. Ponds designed to receive wastes with no prior treatment are often referred to as raw wastewater (sewage) lagoons or stabilization ponds. This requires sizable areas of land.

Ponds are quite commonly used in series (one pond following another) after a primary wastewater treatment plant to provide additional clarification, BOD removal, and disinfection. These ponds are sometimes called oxidation ponds.

Ponds are sometimes used in series after a trickling filter plant, thus giving a form of "tertiary"[2] treatment. These are sometimes called polishing ponds.

Ponds placed in series with each other can provide a high quality effluent which is acceptable for discharge into most watercourses, if stringent disinfection standards are not required.

It is possible to have a great many different variations in ponds due to depth, operating conditions, loading, etc., and a bold line of distinction is often impossible. Current literature generally uses three broad pond classifications: aerobic, anaerobic, and facultative.

Aerobic ponds are characterized by having dissolved oxygen distributed throughout their contents practically all of the time. They usually require an additional source of oxygen other than the rather minimal amount that can be diffused from the atmosphere at the water surface. The additional source of oxygen may be supplied by algae, by mechanical agitation of the surface, or by bubbling air through the pond.

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[2] Tertiary (TER-she-AIR-ee). Tertiary refers to the third treatment process or the process following a secondary treatment process, such as a trickling filter. Some refer to tertiary treatment as advanced waste treatment, meaning processes that remove wastes not normally removed by conventional (secondary) treatment processes.

Anaerobic ponds, as the name implies, are usually without any dissolved oxygen throughout their entire depth. Treatment depends on fermentation of the sludge at the pond bottom. This process, under certain conditions, can be quite odorous, but it is highly efficient in destroying organic wastes. Anaerobic ponds are mainly used for industrial processing wastes, although some domestic waste ponds find their way into this category when they become badly overloaded.

Facultative (FACK-ul-tay-tive) ponds are the most common type in current use. The upper portion (supernatant) of these ponds is aerobic, while the bottom layer is anaerobic. Algae supply most of the oxygen to the supernatant. Facultative ponds are most common because it is almost impossible to maintain completely aerobic or anaerobic conditions all the time at all depths of the pond.

Pond uses may be classified according to detention time. A pond with a detention time of less than three days will perform in ways similar to a sedimentation or settling tank. Some algal growth will occur in the pond, but it will not have a major effect on the treatment of the wastewater.

Prolific algal growth will be observed in ponds with detention periods from three to around 20 days, but large amounts of algae will be found in the pond effluent. In some effluents, the stored organic material may be greater than the amount in the influent. Detention times in this range merely allow the organic material to change form and delay problems until the algae settle out in the receiving waters. Effluent BODs may show considerable reductions from influent BOD concentrations, but this is because BOD is a rate estimate (oxygen used during a 5-day period). The rate of oxygen used is temporarily slowed down, but will increase when anaerobic decomposition of settled dead algal cells starts.

Longer detention periods in ponds provide time for algal sedimentation, hopefully in ponds with anaerobic conditions on the bottom and aerobic conditions on the surface. Combined aerobic-anaerobic treatment provided by long detention periods produces definite stabilization of the influent.

QUESTIONS

9.3A What is the difference between raw wastewater (sewage) lagoons, oxidation ponds, and polishing ponds?

9.3B What is the difference between the terms aerobic, anaerobic, and facultative?

9.3C Describe three possible uses of ponds.

9.4 EXPLANATION OF TREATMENT PROCESS

Waste disposal ponds are classified according to their dissolved oxygen content. Oxygen in an aerobic pond is distributed throughout the entire depth practically all the time. An anaerobic pond is predominantly devoid of oxygen most of the time because oxygen requirements are much greater than the oxygen supply. In a facultative pond, the upper portion is aerobic most of the time, whereas the bottom layer is predominantly anaerobic.

In aerobic ponds, organic matter contained in the wastewater is first converted to carbon dioxide and ammonia, and finally, in the presence of sunlight, to algae. Algae are simple one-cell microscopic plants which are essential to the successful operation of both aerobic and facultative ponds.

By utilizing sunlight through photosynthesis,[3] the one-celled plant uses the oxygen in the water molecule to produce free oxygen, making it available to the aerobic bacteria that inhabit the pond. Each pound of algae in a healthy pond is capable of producing 1.6 pounds of oxygen on a normal summer day. Algae subsist on carbon dioxide and other nutrients in the wastewater. Algae occur in a pond without seeding and multiplying greatly under favorable conditions.

In anaerobic ponds, the organic matter is first converted by a group of organisms called the "acid producers" to carbon dioxide, nitrogen, and organic acids. In an established pond, at the same time, a group called the "methane fermenters" breaks down the acids and other products of the first group to form methane gas and alkalinity. Water is another end product of organic reduction.

In a successful facultative pond, the processes characteristic of aerobic ponds occur in the surface layers, while those similar to anaerobic ponds occur in its bottom layers.

During certain periods sludge decomposition in the anaerobic zone is interrupted and it begins to accumulate. If sludge accumulation

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[3] Photosynthesis. A process in which organisms with the aid of chlorophyll (green plant enzyme) convert carbon dioxide and inorganic substances to oxygen and additional plant material, utilizing sunlight for energy. Land plants grow by the same process.

occurs and decomposition does not set in, it is probably due to lack of suitable bacteriological population, low pH,[4] presence of inhibiting substances, or a low temperature. Under these circumstances the acid production will continue at a slower rate, but the rate of gas (methane) production slows down considerably.

Sludge storage in ponds is continuous with small amounts stored during warm weather and larger amounts when it is cold. During low temperatures the bacteriological population cannot multiply fast enough to handle the waste. When warm weather comes, the "acid producers" start in decomposing the accumulated sludge deposits built up during the winter. If the organic acid production is too great, a lowered pH will occur with the possibilities of an upset pond and resulting hydrogen sulfide odors.

Hydrogen sulfide is ordinarily not a problem in properly designed and operated ponds because it dissociates (divides) into hydrogen and hydrosulfide ions at high pH and may form insoluble metallic sulfides or sulfates. It is because of this high degree of dissociation and the formation of insoluble metallic sulfides that ponds having a pH above 8.5 do not emit odors, even when hydrogen sulfide is present in relatively large amounts.

All of the organic matter that finds its way to the bottom of a stabilization pond through the various processes of sludge decomposition is subject to methane fermentation, provided that proper conditions exist or become established.

In order for methane fermentation to exist, an abundance of organic matter must be deposited and continually converted to organic acids. An abundant population of methane bacteria must be present. They require a pH level within the sludge of from 6.5 to 7.5, alkalinity of several hundred mg/l to buffer (neutralize) the organic acids (volatile acid/alkalinity relationship), and suitable temperatures.

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[4] pH. pH is an expression of the intensity of the alkaline or acid strength of water. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion concentration.

$$\mathrm{pH} = \mathrm{Log}\,\frac{1}{(H^{+})}$$

The pH may range from 0 to 14, where 0 is the most acid, 14 the most alkaline, and 7 is neutral. Most natural waters usually have a pH between 6.5 and 8.5.

Once methane fermentation is established, it accounts for a considerable amount of the organic load removal.

QUESTIONS

9.4A How is oxygen produced by algae?

9.4B Where does the algae found in a pond come from?

9.4C What happens to unstable organic matter in a pond?

9.5 POND PERFORMANCE

The treatment efficiencies that can be expected by ponds vary more than most other treatment devices. Some of the many variables are:

1. Physical Factors

    a. type of soil
    b. surface area
    c. depth
    d. wind action
    e. sunlight
    f. temperature
    g. short circuiting
    h. inflow variations

2. Chemical Factors

    a. organic material
    b. pH
    c. solids
    d. concentration and nature of waste

3. Biological Factors

    a. type of bacteria
    b. type and quantity of algae
    c. activity of organisms
    d. nutrient deficiencies
    e. toxic concentrations

The performance expected from a pond depends upon its design. The design, of course, is determined by the waste discharge requirements or the water quality standards to be met in the receiving waters. Overall treatment efficiency may be about the same as primary treatment (only settling of solids), or it may be equivalent to the best secondary biological treatment plants. Some ponds, usually those located in hot, arid areas, have been designed to take advantage of percolation and high evaporation rates so that there is no discharge.

Depending on design, ponds can be expected to provide BOD removals of from 50 to 90%. Facultative ponds, under normal design loads with 50 to 60 days detention time, will usually remove approximately 90 to 95% of the coliform bacteria and 70 to 80% of the BOD load approximately 80% of the time.

Physical sedimentation by itself has been found to remove approximately 90% of the suspended solids in three days, and about 80% of the dissolved organic solids in ten days. However, in a pond with a healthy algae and bacteria population, a phenomenon known as bioflocculation[5] can occur which will remove approximately 85% of both suspended and dissolved solids within hours. Bioflocculation is accelerated by increased temperature, wave action, and high dissolved oxygen content.

Pond detention times are sometimes specified by regulatory agencies to assure adequate treatment and removal of bacteria. Many agencies specify effluent or receiving water quality standards in terms of median and maximum MPN values that should not be exceeded. In critical water use areas chlorination or other means of disinfection can be used to further reduce the coliform level.

A pond is generally regarded as not fulfilling its function when it creates a visual or odor nuisance, or leaves a high BOD, solids, grease, or coliform group bacteria concentration in the discharge.

QUESTIONS

9.5A What is bioflocculation?

9.5B What biological factors influence the treatment efficiency of a pond?

9.5C What factors indicate that a pond is not fulfilling its function (operating properly)?

END OF LESSON 1 OF 3 LESSONS

on

WASTE TREATMENT PONDS

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[5] Bioflocculation. A condition whereby organic materials tend to be transferred from the dispersed form in wastewater to settleable material by mechanical entrainment and assimilation.

DISCUSSION AND REVIEW QUESTIONS

Chapter 9. Waste Treatment Ponds

(Lesson 1 of 3 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in this lesson.

Write the answers to these questions in your notebook before continuing.

1. When wastewater flows through different treatment processes in a plant, where might ponds be located?
2. Why are most ponds facultative ponds?
3. Where does the oxygen in a pond come from that is produced by algae?
4. What is photosynthesis?
5. What are the three types of factors that may influence pond performance?

9.6 STARTING THE POND

One of the most critical periods of a pond's life is the time that it is first placed in operation. If at all possible, at least one foot of water should be in the pond before wastes are introduced. The water should be turned into the pond in advance to prevent odors developing from waste solids exposed to the atmosphere. Thus a source of water should be available when starting a pond.

It is a good practice to start ponds during the warmer part of the year because a shallow starting depth allows the contents of the pond to cool too rapidly if nights are cold. Generally speaking, the warmer the pond contents, the more efficient the treatment processes.

Algal blooms will normally appear from seven to twelve days after wastes are introduced into a pond, but it generally takes at least 60 days to establish a thriving biological community. A definite green color is evidence that a flourishing algae population has been established. After this length of time has elapsed, bacterial decomposition of bottom solids will usually become established. This is generally evidenced by bubbles coming to the surface near the pond inlet where most of the sludge deposits occur. Although the bottom is anaerobic, travel of the gas through the aerobic surface layers generally prevents odor release.

Wastes should be discharged to the pond intermittently during the first few weeks with constant monitoring of the pH. The pH in the pond should be kept above 7.5 if possible. Initially the pH of the bottom sludge will be below 7 due to the digestion of the sludge by acid-producing bacteria. If the pH starts to drop, discharge to the pond should be diverted to another pond or diluted with make-up water if another pond is not available until the pH recovers. A high pH is essential to encourage a balanced anaerobic fermentation (bacterial decomposition) of bottom sludge. It also is indicative of high algal activity since removal of the carbonates from the water in algal metabolism tends to keep the pH high. A continuing low pH indicates acid production which will cause odors.

QUESTIONS

9.6A Why should at least one foot of fresh water cover the pond bottom before wastes are introduced?

9.6B Why should ponds be started during the warmer part of the year if at all possible?

9.6C What does a definite green color in a pond indicate?

9.6D When bubbles are observed coming to the pond surface near the inlet, what is happening in the pond?

9.7 DAILY OPERATION AND MAINTENANCE

Because ponds are deceptively simple, they are probably neglected more than any other type of wastewater treatment process. Many of the complaints that arise from ponds are the result of neglect or poor housekeeping. Following are listed the day-to-day operational and maintenance duties that will help to insure peak treatment efficiency and to present your plant to its neighbors as a well-run waste treatment facility.

9.70 Scum Control

Scum accumulation is a common characteristic of ponds and is usually the greatest in the spring of the year when the water warms and vigorous biological activity resumes. Ordinarily, wind action will dissipate scum accumulations and cause them to settle; however, in the absence of wind or in sheltered areas, other means must be used. If scum is not broken up, it will dry on top and become crusted. It is not only more difficult to break up then, but a species of blue-green algae is apt to become established on the scum which can give rise to disagreeable odors. If scum is allowed to accumulate, it can reach proportions where it cuts off a significant amount of sunlight from the pond.

Rafts of scum cause a very unsightly appearance in ponds and can quite likely become a source of botulism that will have a devastating effect on waterfowl and shore birds which may be attracted to the facility.

Many methods of breaking up scum have been used, including agitation with garden rakes from the shore, jets of water from pumps or tank trucks, and the use of outboard motors on boats in large ponds. Scum is broken up most easily if it is attended to promptly.

9.71 Odor Control

It is probably inevitable that, at some time, odors will come from a wastewater treatment plant no matter what kind of process is used. Most odors are caused by overloading (see Section 9.117 to determine pond loading) or poor housekeeping practices and can be remedied by taking corrective measures. However, there are times, such as when unexpected shutdowns occur, that plant processes may be upset and cause odors. For these unexpected occurrences it is strongly advised that a careful plan for emergency odor control be available. Odors usually occur during the spring warmup in colder climates because biological activity is reduced during cold weather.

For ponds, recirculation from aerobic units, the use of floating aerators, and heavy chlorination should be considered as means to reduce odors. Recirculation from an aerobic pond to the inlet of an anaerobic pond (1 part recycle flow to 6 parts influent flow) will reduce or eliminate odors. Usually floating aeration and chlorination equipment are too expensive to have setting idle waiting for an odor problem to develop. Odor masking chemicals also have been promoted for this purpose and have some uses for concentrated specific odor sources. However, in almost all cases, process procedures of the type mentioned previously are preferable. In any event, waiting until the emergency arises before planning for odor control is poor procedure. Often several days are needed to receive delivery of materials or chemicals if they are required. Try to have possible alternate methods of control ready to go if they are needed.

In some areas, sodium nitrate has been added to ponds as a source of oxygen to prevent odors. To be effective, sodium nitrate must be dispersed throughout the water in the pond. Once mixed in the pond it acts very quickly because many common organisms (facultative groups) may use the oxygen in nitrates instead of dissolved oxygen. Liquid sodium hydrochloride or chlorine solution is a faster acting solution, but not necessarily the best chemical because it will interfere with biological stabilization of the wastes.

9.72 Weed Control

Weed control is an essential part of good housekeeping and is not a formidable task with modern herbicides and soil sterilants. Weeds around the edge are most objectionable because they allow a sheltered area for mosquito breeding and scum accumulation. In most average ponds there has been little need for mosquito control when edges are kept free of weed growth. Aquatic weeds, such as tules, will grow in depths shallower than three feet, so an operating pond level of at least this depth is necessary. Tules may emerge singly or well scattered but should be removed promptly by hand as they will quickly multiply from the root system. Weeds also can hinder pond circulation.

9.73 Insect Control

Mosquitoes will breed in sheltered areas of standing water where there is vegetation or scum to which the egg rafts of the female mosquito can become attached. These egg rafts are fragile and will not withstand the action of distrubed water surfaces such as caused by wind action or normal currents. Keeping the water edge clear of vegetation and keeping any scum broken up will normally give adequate control. Shallow, isolated pools left by a receding pond level should be drained or sprayed with a larvacide.

Any of several minute shrimp-like animals may infest the pond from time to time during the warmer months of the year (March-November). These predators live on algae and at times will appear in such numbers as to almost clear the pond of algae. During the more severe infestations there will be a sharp drop in the dissolved oxygen of the pond, accompanied by a lowered pH. This is a temporary condition because the predators will outrun the algae supply, and there will be a mass die-off of insects which will be followed by a rapid greening up of the pond again.

Ordinarily there should be no great concern about these infestations because they soon balance themselves; however, in the case of a heavily loaded pond, a sustained low dissolved oxygen content may give rise to noxious odors. In that event any of several commercial sprays can be used with excellent control. Dibrom-8 has been used with good results.

Chironomid midges are often produced in wastewater ponds in sufficient numbers to be serious nuisances to nearby residential areas, farm workers, recreation sites, and industrial plants. When emerging in large numbers they may also create traffic hazards. At present the only satisfactory control is through the use of insecticides such as parathion, Abate, Sursban, and Fenthion. Control measures are time consuming and may be difficult, particularly if there is a discharge to a receiving stream. If possible, lower the level in the ponds enough to contain a day's inflow before applying an insecticide. Holding the insecticide for at least one day will kill more insects and reduce the effect of the insecticide on receiving waters. For better results, insecticides should be applied on a calm day and any recirculation pumps should be stopped.

9.74 Levee Maintenance

Levee slope erosion caused by wave action is probably the most serious maintenance problem. If allowed to continue, it will result in a narrowing of the levee crown which will make accessibility with maintenance equipment most difficult.

If the levee slope is composed of easily erodable material, the only long-range solution is the use of bank protection such as stone riprap or broken concrete rubble.

Levee tops should be crowned so that rain water will drain over the side in a sheet flow rather than flowing a considerable distance along the levee crown and gathering enough flow to cause erosion when it finally spills over the side and down the slope.

If the levees are to be used as roadways during wet weather, they should be paved or well graveled.

9.75 Headworks and Screening

It is important to clean the bar screen as frequently as possible. The screen should be visited at least once or twice a day with more frequent visits during storm periods. Screenings should be disposed of daily in a sanitary manner, such as by burial, to avoid odors and fly breeding.

Many pond installations have grit chambers at the headworks to protect raw wastewater lift pumps or prevent plugging of the influent lines. There are many types of grit removal equipment. Grit removed by the various types of mechanical equipment or by manual means will usually contain small amounts of organic matter and should therefore be disposed of in a sanitary manner. Disposal by burial is the most common method.

9.76 Some Operating Hints

1. Anaerobic ponds should be covered and isolated for odor control and followed by aerobic ponds. Floating polystyrene planks can be used to cover anaerobic ponds and can be painted for protection from the sun. These will help to confine odors and heat and tend to make the anaerobic ponds more efficient.

2. Placing ponds in series tends to cause the first pond to become overloaded and may never allow it to recover; the overload may be carried to the next pond in series. Feeding ponds in parallel allows you to distribute the incoming load evenly between units. Whether ponds are operated in series or in parallel[6] should depend on the loading situation.

   When operating ponds in series, the accumulation of solids in the first pond may become a serious problem after a long period of use. Periodically the flow should be routed around the first pond. This pond should then be drained and the solids removed and buried.

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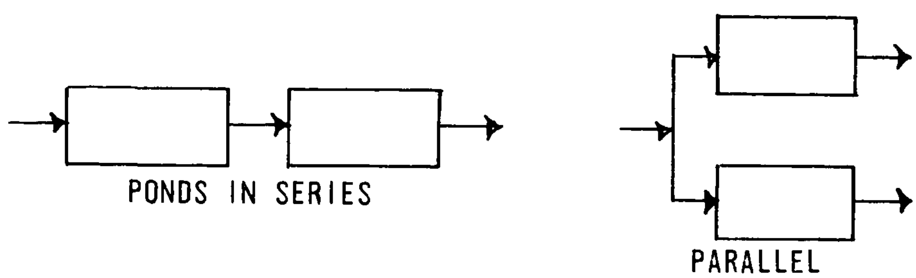


3. It can be helpful to provide for a large amount of recirculation, say 25 to 100%. This allows the algae and other aerobic organisms to become thoroughly mixed with incoming raw wastewater. At the same time, good oxygen transfer can be attained by passing the incoming water over a deck or other type of aerator. This procedure can cause heat loss, however.

4. Heavy chlorination at the recirculation point can assist in odor control, but will probably interefere with treatment.

5. As with any treatment process, it is necessary to measure the important parameters (DO fluctuations during a 24-hour period and solids) at frequent, regular intervals and plot them so that you have some idea of the direction the process is taking in time to take corrective action when necessary.

6. When solids start floating to the surface of a pond during the spring or fall overturn, the pond should be taken out of service and cleaned. Measurement of the sludge depth on the bottom of a pond also will indicate when a pond should be cleaned.

7. Before applying insecticides or herbicides, be sure to check with appropriate authorities regarding the long term effects of the pesticide you plan to use. Do not apply pesticides that may be toxic to organisms in the receiving waters.

QUESTIONS

9.7A Why should scum not be allowed to accumulate on the surface of a pond?

9.7B How can scum accumulations be broken up?

9.7C What are the causes of odors from a pond?

9.7D What precaution would you take to be prepared for an odor problem which might develop?

9.7E Why are weeds objectionable in and around ponds?

9.7F How can weeds be controlled and removed in and around ponds?

9.7G Why should insects be controlled?

9.7H Why should a pond be lowered before an insecticide is applied?

9.7I Why are the contents of ponds recirculated?

9.8 SURFACE AERATORS (Fig. 9.3)

Surface aerators have been used in two types of applications:

1. To provide additional air for ponds during the night or during cold weather, or for overloaded ponds.

2. To provide a mechanical aeration device for ponds operated as an aerated lagoon. Aerated lagoons operate similar to an activated sludge aeration tank without returning any settled activated sludge.

In both cases the aerators are operated by time clocks with established on-off cycles. Laboratory tests on the dissolved oxygen in a pond indicate the time period for on and off cycles to maintain aerobic conditions in the surface layers of the pond. Adjustments in the on-off cycles are necessary when changes occur in the quantity and quality of the influent and seasonal weather conditions. Some experienced operators have correlated their lab test results to pond appearance and regulate the on-off cycles using the following rule: If the pond has foam on the surface, reduce the operating time of the aerator; and if there is no evidence of foam on the pond surface, increase the operating time of the aerator.

Maintenance of surface aerators should be conducted in accordance with manufacturer's recommendations.

9.9 SAMPLING AND ANALYSIS

9.90 General

Probably the most important sampling that can be accomplished easily by any operator is routine pH and dissolved oxygen analysis. It is very desirable to make pH, temperature, and dissolved oxygen tests several times a week, and occasionally during the night, throughout operation of the pond. These values should be recorded because they will serve as a valuable record of performance. The time of day should be varied occasionally for the tests so that the operator becomes familiar with the pond's characteristics at various times of the day. Usually the pH and dissolved oxygen will be lowest just at sunrise. Both will get progressively higher as the day goes on, reaching their highest point in late afternoon.

Fig. 9.3 Surface aerator

Courtesy of EIMCO

It is especially important to remember to avoid getting any atmospheric oxygen into the sample taken to measure dissolved oxygen. This is most necessary when samples are taken in the early morning or if the dissolved oxygen in the pond is low from overloading. If possible, measure the dissolved oxygen with an electric probe, being careful not to allow the membrane on the end of the probe to be exposed to the atmosphere.

Ponds often have clearly developed individuality, each being a biological community that is unique unto itself. Identical adjacent ponds receiving the same influent in the same amount often have a different pH and a different dissolved oxygen content at any given time. One pond may generate considerable scum while its neighbor is devoid of scum. For this reason, each pond should be given routine testing as regards to pH and dissolved oxygen. Such testing may indicate an unequal loading because of the internal clogging of influent or distribution lines that might not be apparent from visual inspection. Tests also may indicate differences or problems that are being created by a build-up of solids or solids recycle.

As an operator becomes familiar with operating a pond, he can soon learn to correlate the results of some of the chemical tests with visual observations. A deep green sparkling color generally indicates a high pH and a satisfactory dissolved oxygen content. A dull green color or lack of color generally indicates a declining pH and a lowered dissolved oxygen content. A grey color indicates the pond is being overloaded.

9.91 Frequency and Location of Lab Samples

The frequency of testing and expected ranges of test results vary considerably from pond to pond, but you should establish those ranges within which your pond functions properly. Test results will also vary during the hours of the day. Table 9-1 summarizes the typical tests, locations, and frequency of sampling.

Tests of pH, DO, and temperature are important indicators of the condition of the pond, whereas BOD, coliform, and solids tests measure the efficiency of the pond in treating wastes. BOD is also used to calculate the loading on the pond.

In order to estimate the organic loading on the pond, the operator must have some knowledge of the biochemical oxygen demand (BOD) of the waste and the approximate average daily flow. Influent BOD and solids will vary with time of day, day of week, and season, but a pond is a good equalizer if not overloaded. Recirculation will help an overloaded pond.

TABLE 9-1

FREQUENCY AND LOCATION OF LAB SAMPLES

Test	Frequency	Location	Common Range
pH*	Daily	Pond	7.5+
Dissolved Oxygen (DO)*	Daily	Pond Effluent	
Temperature	Daily	Pond	
BOD	Weekly	Influent Effluent	
Coliform Group Bacteria	Weekly	Effluent	
Chlorine Residual	Daily	Effluent	0.5-2.0 mg/l
Suspended Solids	Weekly	Influent Effluent	
Dissolved Solids	Weekly	Influent Effluent	

*pH values above 9.0 and DO levels over 15 mg/l are not uncommon.

BODs should be measured on a weekly basis. Samples should be taken during the day at low flow, medium flow, and high flow. The average of these three tests will give a reasonable indication of the organic load of the wastewater being treated. If it is suspected that the BOD varies sharply during the day or from day to day, or if unusual circumstances exist, the sampling frequency should be increased to obtain a clear definition of the variations. If the pond DO level is supersaturated (Chapter 14, DO), the sample must be aerated to remove the excess oxygen before the BOD test is performed. A typical data sheet for a plant consisting mainly of ponds is provided in the Appendix at the end of this chapter.

9.92 Expected Treatment Efficiencies[7]

Table 9-2 is provided as a guide to indicate probable removal efficiencies of typical ponds.

TABLE 9-2

EXPECTED RANGES OF REMOVAL BY PONDS

Item	Detention Time	Expected Removal
BOD		50 to 90%
BOD (facultative pond)[8]	50 to 60 days	70 to 80%[9]
Coliform Bacteria (facultative pond)	50 to 60 days	90 to 95%
Suspended Solids	After 3 days	90%
Dissolved Solids	After 10 days	80%

[7] Waste Removal, % $= \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$

[8] Facultative Pond (FACK-ul-tay-tive). The most common type of pond in current use. The upper portion (supernatant) is aerobic while the bottom layer is anaerobic. Algae supply most of the oxygen to the supernatant.

[9] Expected removal approximately 80% of the time with poorer removals during the remainder of the time.

Example:

The influent BOD to a series of ponds is 300 mg/l, and the effluent BOD is 60 mg/l. What is the efficiency of BOD removal?

$$\text{BOD Removal, \%} = \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

$$= \frac{(300 \text{ mg/l} - 60 \text{ mg/l})}{300 \text{ mg/l}} \times 100\%$$

$$= \frac{240 \text{ mg/l}}{300 \text{ mg/l}} \times 100\%$$

$$= 0.80 \times 100\%$$

$$= 80\%$$

9.93 Response to Poor Pond Performance

See Section 9.7, Daily Operation and Maintenance, especially 9.76, Some Operating Hints.

QUESTIONS

9.9A If the color of a pond is dull green or colorless, what is happening in the pond?

9.9B Why should the pH, temperature, and dissolved oxygen be measured in a pond?

9.9C If the pH and dissolved oxygen are dropping dangerously low in a pond, how can this situation be corrected?

9.9D Influent BOD to a series of ponds is 200 mg/l. If the BOD in the effluent of the last pond is 40 mg/l, what is the BOD removal efficiency?

9.10 SAFETY

Because a pond has little mechanical equipment does not mean that it is devoid of hazards. Catwalks should have guard rails and non-skid walking surfaces. Headworks and any enclosed appurtenances should be well ventilated to prevent dangerous gas accumulations.

WARNING

AN OPERATOR SHOULD **ALWAYS** BE ACCOMPANIED BY A HELPER WHEN PERFORMING ANY TASK THAT IS **DANGEROUS** SINCE POND LOCATIONS ARE USUALLY QUITE ISOLATED.

Tetanus and typhoid are ever-present dangers when working around wastewater. Adequate precautions should be observed.

Fences should surround ponds to keep unauthorized persons and animals out of the pond area. They should be located in such a manner that they will not interfere with mechanical or hand maintenance of levee slopes.

QUESTIONS

9.10A What safety devices should be provided on walkways over ponds?

9.10B Why should an operator be accompanied by a helper when performing any dangerous task?

END OF LESSON 2 OF 3 LESSONS

on

WASTE TREATMENT PONDS

DISCUSSION AND REVIEW QUESTIONS

Chapter 9. Waste Treatment Ponds

(Lesson 2 of 3 Lessons)

Write the answers to these questions before continuing with Lesson 3. The problem numbering continues from Lesson 1.

6. Why should water be introduced into a new pond before any wastewater?

7. Why is good housekeeping an important factor in operating a properly functioning pond?

8. What precautions should be taken when applying an insecticide?

9. Why may chlorine compounds or chlorine solution not be the best method of odor control in a pond?

10. What lab tests measure the condition of a pond?

11. Estimate the BOD removal efficiency of a series of ponds if the influent BOD is 250 mg/l and the effluent BOD is 50 mg/l.

12. Why should fences be placed around ponds?

CHAPTER 9. WASTE TREATMENT PONDS

(Lesson 3 of 3 Lessons)

9.11 DESIGN CRITERIA

A review of some common design criteria will give an insight to the theory and operation of a pond.

9.110 Location

The general considerations for the location of other types of wastewater treatment plants also apply to the location of ponds. Isolation should be as great as can be economically provided. Attention to the direction of prevailing winds with due regard for present and projected downwind residential, commercial, and recreational development is of utmost importance.

9.111 Chemistry of Waste

Before the design of any pond is undertaken, it should be determined whether there are any possible toxic effects (interfere with algal or bacterial growth) from the waste. Some natural water supplies may have a high sulfur content or other chemicals that limit the possibility of desired sludge decomposition.

Certain wastes, such as dairy products and wine products, are difficult to treat because of their low pH. Any processing waste should be carefully investigated before one can be certain that it can be successfully treated by ponding. Some process wastes contain powerful fungicides and disinfectants that may have a great inhibitive effect on the biological activity in a pond.

9.112 Headworks and Screening

A headworks with a bar screen is desirable to remove rags, bones, and other large objects that might lodge in pipes or control structures.

A trash shredder is a luxury that may not be warranted. Any material that gets past an adequate bar screen will in all probability not harm the influent pump. Any fecal matter will be pulverized in going through the pump.

9.113 Flow Measuring Devices

It is highly desirable that an influent measuring device be installed to give a direct reading on the daily volume of wastes that are introduced into the ponds. This information, along with a BOD measurement of the influent, is required to estimate the organic loading on the pond. Comparison of influent and effluent flow rates is necessary for estimating percolation and evaporation losses.

A measuring device provides basic data for prediction of future plant expansion needs or for detecting unauthorized or abnormal flows. Reliable, well-kept records on flow volume help justify budgets and greatly assist an engineer's design of a plant expansion or new installation.

9.114 Inlet and Outlet Structures

Inlet structures should be simple and foolproof and should be standard manufactured articles so that replacement parts are readily available. Telescoping friction fit tubes (see Fig. 9.4) for regulating spill or discharge height should be avoided because a biological growth may become attached and prevent the tubes from telescoping if they are not cleaned regularly.

A submerged inlet will minimize the occurrence of floating material and will help conserve the heat of the pond by introducing the warmer wastewater into the depths of the pond. Warm wastewater introduced at the bottom of a cold water mass will channel to the surface and spread unless it is promptly and vigorously mixed with cold water. Warm wastewater spilled onto the surface of the pond will spread out in a thin layer on the surface and not contribute to the warmth of the lower regions of the pond where heat is needed for bacterial decomposition. Inlet and outlet structures should be so located in relation to each other to minimize possible short circuiting.

Valves that have stems extending into the stream flow should be avoided. Stringy material and rags will collect and form an obstruction and may render the valve inoperative.

Free overfalls (Fig. 9.5) at the outlet should be avoided to minimize release of odors, foaming, and gas entrapment which may hamper pipe flows. Free overfalls should be converted to submerged outfalls if they are causing nuisances and other problems.

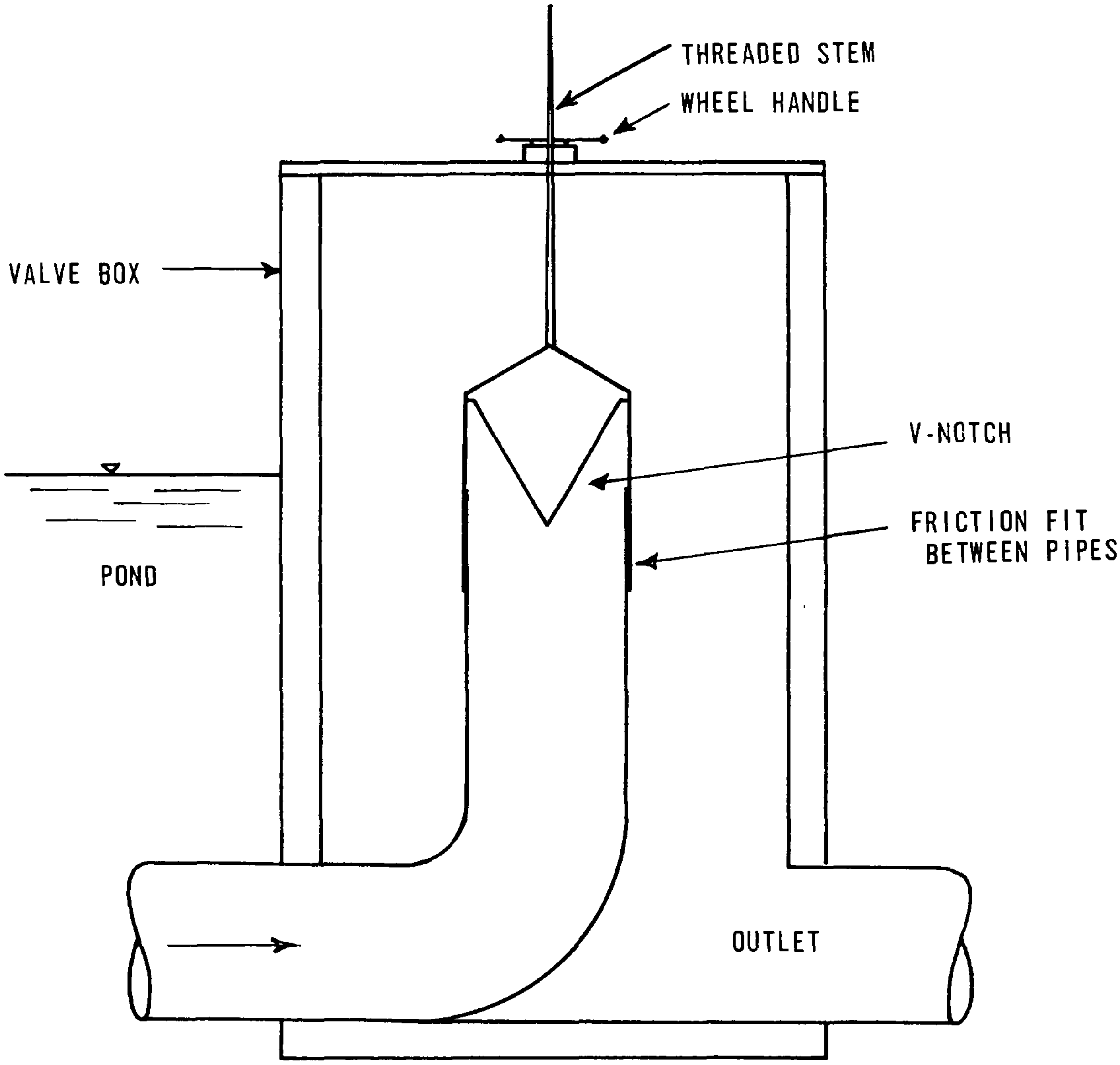
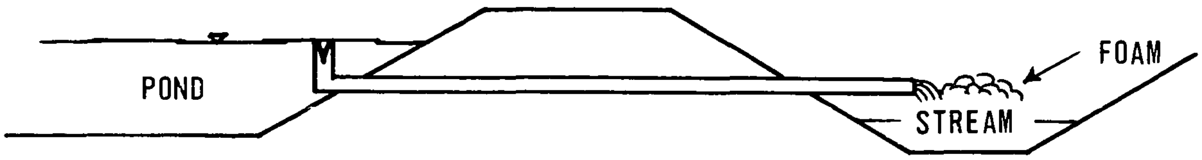
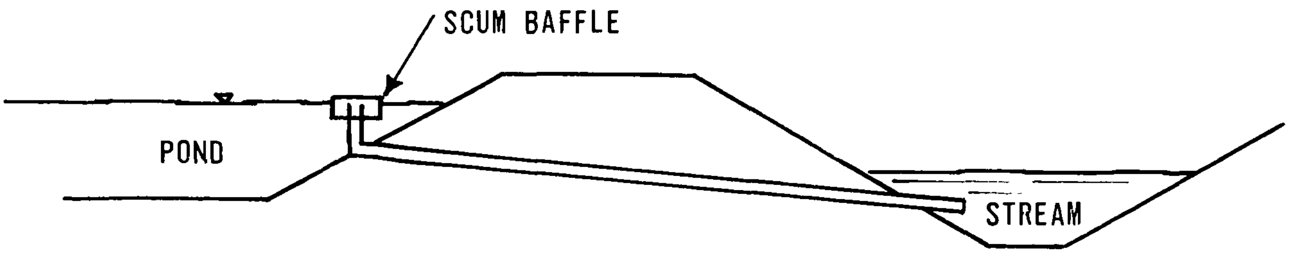


Fig. 9.4 Telescoping friction fit tubes for regulating discharge



FREE OVERFALL--UNDESIRABLE



SUBMERGED OUTLET--NO FOAMING PROBLEMS

Fig. 9.5 Free overflow and submerged outlet

If a pond has a surface outlet, floating material can be kept out of the effluent by building a simple baffle around the outlet. The baffle can be constructed of wood or other suitable material. It should be securely supported or anchored.

9.115 Levee Slopes

The selection of the steepness of the levee slope must depend on several variables. A steep slope erodes quicker from wave wash unless the levee material is of a rocky nature or else protected by riprap. However, a steep slope minimizes waterline weed growth. It is more difficult to operate equipment and to perform routine maintenance on steep slopes. A gentle slope will erode the least from wave wash, is easier to operate equipment on, and is easier to perform routine maintenance on. However, waterline weed growth will have a much greater opportunity to flourish.

9.116 Pond Depths

The operational depth of ponds deserves considerable attention. Depending upon conditions, ponds of less than three feet of depth may be completely aerobic if there are no solids on the bottom (unlikely) because of the depth of sunlight penetration. This means that the treatment of wastes is accomplished essentially by converting the wastes to algae cell material. Ponds of this shallow depth are apt to be irregular in performance because algae blooms will increase to such proportions that a mass die-off will occur with the result of all algae precipitating to the bottom and thereby adding to the organic load. Such conditions could lead to the creation of an anaerobic pond. The bottoms of shallow ponds will become anaerobic when solids collect on the bottom and after sunset.

Discharges from shallow, aerobic ponds contain large amounts of algae. To operate efficiently these ponds should have some means of removing the algae grown in the pond before the effluent is discharged to the receiving waters. If the algae are not removed from the effluent, the organic matter in the wastewater is not removed or treated and the problem is merely transferred to some downstream pool.

An observed phenomenon of lightly loaded, shallow secondary ponds and tertiary ponds is that they are apt to become infested with filamentous algae and mosses that not only limit the penetration of sunlight into the pond but hamper circulation of the pond's contents and clog up inlet and outlet structures. When the loading is increased, this condition improves.

Pond depths of four feet or more allow a greater conservation of heat from the incoming wastes to foster biological activity as the ratio between pond volume and pond area is more favorable. In facultative ponds, depths over four feet provide a physical storage for dissolved oxygen accumulated during the day to carry over through the night when no oxygen is released by the algae, unless floating algae and poor circulation keep all the oxygen near the surface. This physical storage of DO is very important during the colder months when nights are long.

A pond operating depth of at least three feet is recommended to prevent tule and cattail growth. Ponds less than three feet deep

should be lined to prevent troublesome weed growth. Weeds that emerge along the shore line can be effectively controlled by spraying with any of several products available.

QUESTIONS

9.11A Why are some wastes not easily treated by ponds?

9.11B What is the minimum recommended pond operating depth?

9.11C Why should the inlet to a pond be submerged?

9.11D Why should the outlet be submerged?

9.11E How could problems created by a surface outlet be reduced or corrected?

9.11F Why should free overfalls be avoided?

9.11G Why are shallow ponds apt to be irregular in performance?

9.11H Why should the influent to a pond be metered?

9.117 Pond Loading

The waste loading on a pond is generally spoken of in relation to its area, and may be stated in several different ways:

1. lbs of BOD per day per acre = lbs BOD/day/acre (This is called organic loading.)

2. inches (or feet) of depth added per day (This is called hydraulic loading or overflow rate.)

or 3. persons (or population served) per acre (This is called population loading.)

Detention time is related directly to pond hydraulic loading, which is actually the rate of inflow of wastewater. It may be expressed as million gallons per day (MGD), or as the number of acre-inches per day or acre-feet per day (one acre-foot covers one acre to a depth of one foot or twelve inches and is equal to 43,560 cu ft). We must know the pond volume in order to determine detention time; this is most easily computed on an acre-foot basis.

A. Detention Time

$$\text{Detention (in days)} = \frac{\text{Pond Volume (ac-ft)}}{\text{Influent Rate (ac-ft/day)}}$$

This equation does not take into consideration water which may be lost through evaporation or percolation. Detention time may vary from 30 to 120 days, depending on the treatment requirements to be met.

B. Population Loading

Loading calculated on a population-served basis is expressed simply as:

$$\text{No. of Persons per Acre} = \frac{\text{Population Served, persons}}{\text{Area of Pond, ac}}$$

The population loading may vary from 50 to 500 persons per acre, depending on many local factors.

C. Hydraulic Loading

The hydraulic loading or overflow rate is expressed as:

$$\text{Inches per day} = \frac{\text{Inflow (ac-in per day)}}{\text{Pond Area, ac}}$$

The hydraulic loading may vary from half an inch to several inches per day, depending on the organic load of the influent.

NOTE: If the wastewater inflow rate is known in million gallons per day (MGD), it can be converted to an equivalent number of acre-inches per day as follows:

Inflow, acre-inches per day = (Inflow, MGD) x 36.8 [10]

If the pond detention time is known, the hydraulic loading can also be calculated, as follows:

$$\text{Inches per day} = \frac{\text{Depth of Pond, in}}{\text{Detention Time, days}}$$

D. Organic Loading

The organic loading is expressed as:

$$\text{Organic Load (lbs BOD per day per acre)} = \frac{\text{(BOD, mg/l)(Flow, MGD)(8.34 lbs/gal)}}{\text{Pond area, ac}}$$ [11]

Typical organic loadings may range from 10 to 50 lbs BOD per day per acre.

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[10] $$1 \text{ MGD} = \frac{1{,}000{,}000 \text{ gal}}{\text{day}} \times \frac{1 \text{ cu ft}}{7.48 \text{ gal}} \times \frac{1 \text{ ac}}{43{,}560 \text{ sq ft}} \times \frac{12 \text{ in}}{1 \text{ ft}} = 36.8 \frac{\text{ac-in}}{\text{day}}$$

[11] Recall lbs/day = (Conc. mg/M mg)(M gal/day)(8.34 lbs/gal)

EXAMPLE CALCULATIONS

NOTE TO OPERATOR: If you have difficulty following the work shown in Example 1 below, you should refer to the Pond Attachment at the end of this chapter (Section 9.14) for further details. If you have no trouble, continue with the lesson.

EXAMPLE NO. 1:

Use of the pond loading formulas can be illustrated by examining a typical situation. The following data should be obtained so that all the calculations can be performed:

Essential Data

1. Depth of Pond = 4 feet

2. Width of Pond

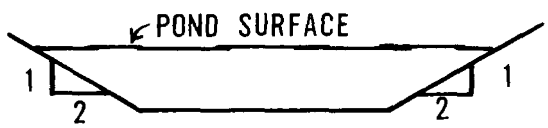
   Bottom = 412 feet
   Water Surface = 428 feet
   Average Width = 420 feet

3. Length of Pond

   Bottom = 667 feet
   Water Surface = 683 feet
   Average Length = 675 feet

4. Side Slopes

   (2 ft horizontal to 1 ft vertical) = 2:1



5. Influent = 0.2 million gallons per day
   = 0.2 MGD
   = 200,000 gallons per day

6. BOD = 200 mg/l
   = 200 lbs BOD per million lbs of wastewater

7. Population = 2000 persons

To calculate the loading parameters, first determine the pond area and volume.

I. POND AREA, ACRES

$$\text{Pond Area, ac} = \frac{(\text{Average Width, ft})(\text{Average Length, ft})}{43{,}560 \text{ sq ft/ac}}$$

$$= \frac{(420 \text{ ft})(675 \text{ ft})}{43{,}560 \text{ sq ft/ac}}$$

$$= 6.51 \text{ ac}$$

II. POND VOLUME, ACRE-FEET

$$\text{Volume, ac-ft} = (\text{Area, ac})(\text{Depth, ft})$$

$$= (6.51 \text{ ac})(4 \text{ ft})$$

$$= 26.04 \text{ ac-ft (say 26 ac-ft)}$$

Convert flow rate from gallons per day to ac-ft/day.

$$\text{Flow Rate, ac-ft/day} = \frac{200{,}000 \text{ gal}}{\text{day}} \times \frac{\text{cu ft}}{7.48 \text{ gal}} \times \frac{\text{ac}}{43{,}560 \text{ sq ft}}$$

$$= 0.61 \text{ ac-ft/day}$$

III. LOADING PARAMETERS

NOTE TO OPERATORS: Details for calculations in the remainder of Example 1 have not been given. If you have trouble, go to the end of this lesson and study Section 9.14, Pond Attachment, for details, and try to apply them to this section.

1. Detention Time

$$\text{Detention Time, days} = \frac{\text{Pond Volume, ac-ft}}{\text{Flow Rate, ac-ft/day}}$$

$$= \frac{26 \text{ ac-ft}}{0.61 \text{ ac-ft/day}}$$

$$= 42.6 \text{ days}$$

2. Population Loading

$$\text{Number of Persons per acre} = \frac{\text{Population Served by Sewer System, persons}}{\text{Pond Area, ac}}$$

$$= \frac{2000 \text{ Persons}}{6.51 \text{ ac}}$$

$$= 307 \text{ persons/ac}$$

NOTE: If there is a significant waste flow from industry mixed in with the domestic waste, an adjustment must be made to take the industrial waste into consideration. This is usually done by analyzing the industrial waste and converting it to a "population equivalent".[12]

3. Hydraulic Loading (Overflow Rate)

$$\text{Inches per day} = \frac{\text{Depth of Pond, in}}{\text{Detention Time, days}}$$

$$= \frac{(\text{Depth, 4 ft})\ (12 \text{ in/ft})}{42.6 \text{ days}}$$

$$= 1.13 \text{ in/day}$$

4. Organic Loading

$$\text{Organic Load, lb BOD/day/ac} = \frac{(\text{BOD Conc., mg/l})\ (\text{Flow, MGD})\ (8.34 \text{ lb/gal})}{\text{Area, ac}}$$

$$= \frac{200 \text{ lb}}{\text{M lb}} \times \frac{0.2 \text{ M gal}}{\text{day}} \times \frac{8.34 \text{ lb}}{\text{gal}} \times \frac{1}{6.5 \text{ ac}}$$

$$= 51 \text{ lbs BOD/day/ac}$$

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[12] Population Equivalent. A means of expressing the strength of organic material in wastewater. Domestic wastewater consumes, on an average, approximately 0.2 lb of oxygen per person per day, as measured by the standard BOD test.

EXAMPLE NO. 2:

NOTE TO OPERATORS: Details for calculations in Example 2 have not been given. If you have trouble, go back and study the procedures for Example 1 and try to apply them to Example 2.

Suppose that a small wastewater treatment plant must be completely shut down for major repairs that will require several months of work. Enough vacant land is near the plant to enable 16 acres of temporary ponds to be constructed as raw wastewater (sewage) lagoons. Determine if this is feasible, given the following data:

Influent Rate	=	1 MGD
BOD	=	150 mg/1
	=	150 lbs BOD per million lbs of wastewater
Pond Area	=	16 acres
Average Operating Depth	=	42 inches $= \frac{42 \text{ in}}{12 \text{ in/ft}} = 3.5$ ft

Assume that at least a 60-day detention period (average time the wastewater must take to flow through the pond for disinfection) is desired for bacterial die-off.

Assume that the organic loading (BOD) should not exceed 50 lbs per day per acre.

Calculate what the waste detention time would be in the pond:

One acre-foot = 325,829 gallons

Pond Volume, ac-ft = Pond Area, ac x Pond Depth, ft

= 16 ac x 3.5 ft

= 56 ac-ft

Influent Flow Rate = 1,000,000 gals per day

$$= \frac{1{,}000{,}000 \text{ gpd}}{325{,}829 \text{ gal/ac-ft}}$$

= 3.07 ac-ft per day

$$\text{Detention Time} = \frac{56 \text{ ac-ft}}{3.07 \text{ ac-ft per day}}$$

= 18.2 days

Thus the detention time would not be sufficient to satisfy requirements. Increasing the depth to 5 feet would help.

Calculate the organic loading:

$$\text{Organic Loading, lbs BOD/day} = (\text{BOD Conc., mg/l})(\text{Flow, MGD})(8.34\ \text{lbs/gal})$$

$$= (150\ \text{mg/l})(1\ \text{MGD})(8.34\ \text{lbs/gal})$$

$$= 1250\ \text{lbs BOD per day}$$

The organic loading per acre of pond would be:

$$\text{Organic Loading, lbs BOD/day/ac} = \frac{\text{Loading, lbs BOD/day}}{\text{Area, ac}}$$

$$= \frac{1250\ \text{lbs BOD per day}}{16\ \text{ac}}$$

$$= 78.1\ \text{lbs BOD/day/ac}$$

Therefore, the organic loading would exceed the desired maximum of 50 lbs BOD/day/acre.

QUESTION

9.11I Given a pond receiving a flow of 2.0 MGD from 20,000 people. Influent BOD is 180 mg/l. Pond area is 24 acres, and the average operating depth is four feet. Determine the detention time, organic loading, population loading, and hydraulic loading.

9.12 ACKNOWLEDGMENT

Liberal use has been made of the many papers presented by Professor W. J. Oswald of the University of California at Berkeley on the subject of the treatment of wastes by ponding.

9.13 ADDITIONAL READING

a. New York Manual, page 71

b. Texas Manual, pages 283-302

c. <u>Raw Sewage Lagoons in California</u>, by California State Department of Public Health, Bureau of Sanitary Engineering, Berkeley, California, May 1969.

d. Waste Stabilization Lagoons - Design, Construction, and Operation Practices Among Missouri Basin States, Missouri Basin Engineering Health Council, 1960. Reproduced by U.S. Public Health Service, Region VI, Kansas City, Missouri.

END OF LESSON 3 OF 3 LESSONS

on

WASTE TREATMENT PONDS

DISCUSSION AND REVIEW QUESTIONS

Chapter 9. Waste Treatment Ponds

(Lesson 3 of 3 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 2.

13. Why is it desirable for a pond to be isolated?

14. How can scum be controlled from leaving a pond?

15. How can erosion of levee slopes be controlled?

A pond receives an inflow of 0.01 MGD from 100 people. The pond is 150 feet long, 150 feet wide, and 4 feet deep. Influent BOD is 200 mg/l. Determine the following loading parameters.

16. Detention Time in days

17. Population loading in persons per acre

18. Hydraulic loading in inches per day

19. Organic loading in pounds of BOD applied per day per acre

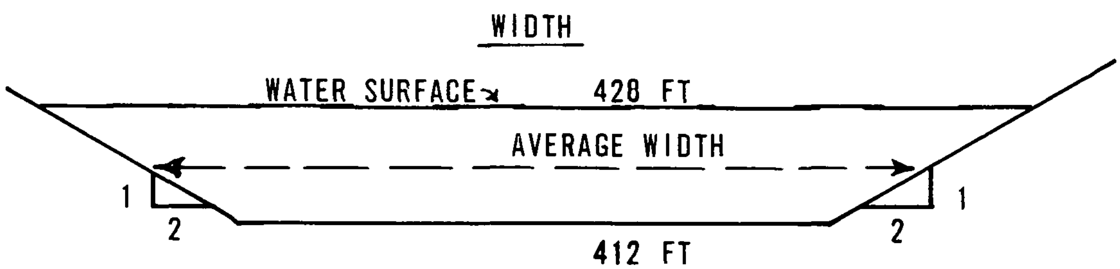
9.14 POND ATTACHMENT (Details of Example Calculations)

References: New York Manual, pages 215-219
Chapter 15, Basic Mathematics

Solution: Example 1

I. Pond Area, sq ft = (Average Width, ft)(Average Length, ft)

A. Calculate average width.



$$\text{Average Width, ft} = \frac{\text{Water Surface Width, ft} + \text{Bottom Width, ft}}{2}$$

$$= \frac{428 \text{ ft} + 412 \text{ ft}}{2}$$

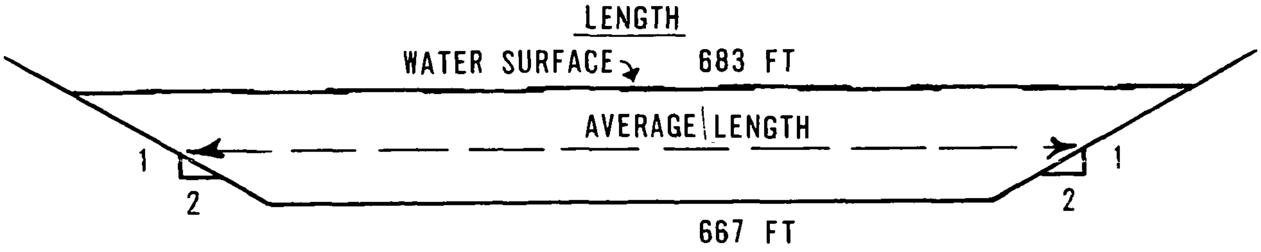
$$\begin{array}{r} 428 \\ \underline{412} \\ 840 \end{array}$$

$$= \frac{840 \text{ ft}}{2}$$

$$= 420 \text{ ft}$$

$$\begin{array}{r} 420 \\ 2 \overline{)840} \\ \underline{8} \\ 04 \\ \underline{4} \\ 00 \end{array}$$

B. Calculate average length.



$$\text{Average Length, ft} = \frac{\text{Water Surface Length, ft} + \text{Bottom Length, ft}}{2}$$

$$= \frac{683 \text{ ft} + 667 \text{ ft}}{2}$$

$$= \frac{1350 \text{ ft}}{2}$$

$$= 675 \text{ ft}$$

$$\begin{array}{r} 683 \\ \underline{667} \\ 1350 \end{array}$$

$$\begin{array}{r} 675 \\ 2\overline{)1350} \\ \underline{12} \\ 15 \\ \underline{14} \\ 10 \\ \underline{10} \\ 0 \end{array}$$

C. Calculate pond area.

$$\text{Area, sq ft} = (\text{Average Width, ft})(\text{Average Length, ft})$$

$$= (420 \text{ ft})(675 \text{ ft})$$

$$= 283{,}500 \text{ sq ft}$$

$$\begin{array}{r} 675 \\ \underline{420} \\ 000 \\ 1350 \\ \underline{2700} \\ 283{,}500 \end{array}$$

Units: When we multiply ft by ft we obtain square feet or ft^2.

$$\text{Area, acres} = \frac{\text{Area, sq ft}}{43{,}560 \text{ sq ft/ac}}$$

$$= \frac{283{,}500 \text{ sq ft}}{43{,}560 \text{ sq ft/ac}}$$

$$= 6.5 \text{ ac}$$

```
              6.508
43560 / 283500.
        261360
         22140 0
         21780 0
           360 00
           000 00
           360 000
           348 480
            11 520
```

Units: The sq ft on top (numerator) and bottom (denominator) cancel out, and the /acre on the bottom shifts to the top (numerator).

Our result is 6.508 acres, but we will round our answer off to the nearest tenth (0.1), or 6.5. This is sufficient accuracy.

II. Calculate pond volume.

$$\text{Pond Volume, ac-ft} = (\text{Area, ac})(\text{Depth, ft})$$

$$= (6.51 \text{ ac})(4 \text{ ft})$$

$$= 26.04 \text{ ac-ft}$$

```
  6.51
   x 4
 26.04
```

SUGGESTED ANSWERS

Chapter 9. Waste Treatment Ponds

9.2A Objectionable odors coming from a pond could be caused by development of anaerobic conditions locally or throughout most of the pond, such as in an overloaded pond or one not functioning properly.

9.2B Advantages of ponds include low initial and operating costs, ease of expansion, and adaptability to fluctuating loads, provided land is cheap.

9.3A The difference between raw wastewater (sewage) lagoons, oxidation ponds, and polishing ponds is the amount of treatment wastewater receives before reaching the pond. Wastewater receiving no treatment flows directly into a raw wastewater (sewage) lagoon. A pond located after a primary clarifier or sedimentation tank is called an oxidation pond, and a polishing pond is placed after a trickling filter or activated sludge plant.

9.3B Aerobic ponds have DO distributed throughout the pond; anaerobic ponds do not contain any DO. Most ponds are facultative and have aerobic (have DO) conditions on the surface and are anaerobic (no DO) on the bottom.

9.3C The use of a pond will depend on the detention period. Ponds with detention times less than three days will act like sedimentation tanks. In ponds with a detention period from three to 20 days the organic material in the influent will be converted to algae, and high concentrations of algae will be found in the effluent. Ponds with longer detention periods provide time for algal sedimentation and a better effluent.

9.4A Algae produce oxygen from the water (H_2O) molecule.

9.4B Algae simply appear in a pond on their own without seeding. They are found in soil, water, and air and multiply under favorable conditions.

9.4C Organic matter in a pond is converted to carbon dioxide and ammonia and, finally, in the presence of sunlight, to algae. The organic matter in anaerobic bottom sections is first converted by a group of organisms called "acid producers" to carbon dioxide, nitrogen, and organic acids. Next, a group called the "methane fermenters" breaks down the acids and other products of the first group to form methane gas. Another end product of organic reduction is water.

9.5A Bioflocculation is a condition whereby organic materials tend to be transferred from the dispersed form in wastewater to settleable material by mechanical entrapment and assimilation.

9.5B Biological factors influencing the treatment efficiency of a pond include the type of bacteria, type and quantity of algae, activity of organisms, and nutrient deficiencies.

9.5C A pond is not functioning properly when it creates a visual or odor nuisance, or leaves a high BOD, solids, grease, or coliform group bacteria concentration in the effluent unless it was designed to be anaerobic in the first stages and aerobic in later ponds for final treatment.

9.6A At least one foot of water should cover the pond bottom before wastes are introduced to prevent decomposing solids from being exposed and causing odor problems.

9.6B Ponds should be started during the warmer months because higher temperatures are associated with efficient treatment processes.

9.6C A definite green color in a pond indicates a flourishing algae population and is a good sign.

9.6D When bubbles are observed coming to the pond surface near the inlet, this indicates that the solids which settled to the bottom are being decomposed anaerobically by bacterial action.

9.7A Scum should not be allowed to accumulate on the surface of a pond because it is unsightly, may prevent sunlight from reaching the algae, and an odor-producing species of algae may develop on the scum.

9.7B Scum accumulations may be broken up with rakes, jets of water, or by use of outboard motors.

9.7C Odors are caused in ponds by overloading or poor housekeeping.

9.7D An odor control chemical should be available before an odor problem develops. Sodium nitrate or a floating aerator will help control odors and improve treatment of the wastewater.

9.7E Weeds are objectionable in and around ponds because they provide a shelter for the breeding of mosquitoes and scum accumulation and also hinder pond circulation.

9.7F Weeds may be controlled by herbicides and soil sterilants.

9.7G Insects should be controlled because they may, in sufficient numbers, be a serious nuisance to nearby residential areas, farm workers, recreation sites, industrial plants, and drivers on highways.

9.7H A pond should be lowered before the application of an insecticide to improve the mortality of insects and reduce the effect of the insecticide on the receiving waters by holding the wastewater at least one day. Lowering of the pond also will dry-up weeds and insects.

9.7I The contents of ponds are recirculated to allow algae and other aerobic organisms to become thoroughly mixed with incoming raw wastewater.

9.9A When a pond turns dull green, grey, or colorless, generally the pH and dissolved oxygen have dropped too low. This condition may be caused by overloading or lack of circulation.

9.9B pH, temperature, and dissolved oxygen should be measured to provide a record of pond performance and to indicate the status (health) of the pond and whether corrective action is or may be necessary. DO may be expected to be low in the morning and increase with sunlight hours.

9.9C When the pH and dissolved oxygen drop dangerously low, the loading should be reduced or stopped. Recirculating water from a healthy pond to the problem pond should help the situation. Recirculation from outlet to inlet areas is beneficial for seeding, DO, and mixing.

9.9D BOD Removal, %

$$= \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

$$= \frac{(200\ \text{mg/l} - 40\ \text{mg/l})}{200\ \text{mg/l}} \times 100\%$$

$$= \frac{160\ \text{mg/l}}{200\ \text{mg/l}} \times 100\%$$

$$= 0.80 \times 100\%$$

$$= 80\%$$

9.10A Walkways over ponds should have handrails and non-skid walking surfaces.

9.10B An operator should be accompanied by a helper when performing any dangerous task because immediate aid might prevent serious injury or loss of life.

9.11A Some wastes are not easily treated by ponds because they contain substances with interfering concentrations which hinder algal or bacterial growth.

9.11B The minimum recommended pond operating depth is three feet. At shallower depths aquatic weeds become a nuisance.

9.11C The inlet to a pond should be submerged to distribute the heat of the influent as much as possible and to minimize the occurrence of floating material.

9.11D The outlet of a pond should be submerged to prevent the discharge of floating material.

9.11E The discharge of floating material over a surface outlet may be corrected by constructing a baffle around the outlet.

9.11F Free overfalls should be avoided to minimize odors, foaming, and gas entrapment which may hamper the flow of water in pipes. They are generally controlled with pipes at the outfall.

9.11G Any pond is apt to be irregular in performance because the algae grow, die, and settle to the bottom, thus creating a new organic load. Algae <u>produce</u> and <u>store</u> organic matter that must be stabilized later. Objectionable "burps" of unstable material are common in pond effluents.

9.11H The influent to a pond should be metered to justify budgets, indicate unexpected fluctuations in flows which may cause upsets, and provide data for future expansion when necessary.

9.11I Given:

Flow	=	2.0 MGD
Population	=	20,000 people
Influent BOD	=	180 mg/l
Pond Area	=	24 acres
Average Depth	=	4 feet

Reqd.: Detention Time

Organic Loading

Population Loading

Hydraulic Loading

Determine pond volume in acre-feet.

$$\text{Volume, ac-ft} = (\text{Area, ac})(\text{Depth, ft})$$

$$= (24\ \text{ac})(4\ \text{ft})$$

$$= 96\ \text{ac-ft}$$

Convert flow rate from MGD to ac-ft per day.

$$\text{Flow, ac-ft/day} = \frac{2{,}000{,}000\ \text{gal}}{\text{day}} \times \frac{\text{cu ft}}{7.48\ \text{gal}} \times \frac{\text{acre}}{43{,}560\ \text{sq ft}}$$

$$= 6.1\ \text{ac-ft/day}$$

Determine detention time in days.

$$\text{Detention Time, days} = \frac{\text{Pond Volume, ac-ft}}{\text{Flow Rate, ac-ft/day}}$$

$$= \frac{96\ \text{ac-ft}}{6.1\ \text{ac-ft/day}}$$

$$= 15.7\ \text{days}$$

$$\begin{array}{r}
15.7 \\
6.1 \overline{)\,96.0} \\
\underline{61} \\
350 \\
\underline{305} \\
450 \\
427
\end{array}$$

Calculate organic loading in pounds of BOD per day per acre.

$$\text{Organic Load, lb BOD/day/ac} = \frac{(\text{BOD, mg/l})(\text{Flow, MGD})(8.34\ \text{lbs/gal})}{\text{Area, ac}}$$

$$= \frac{180\ \text{lb}}{\text{M lb}} \times \frac{2.0\ \text{MG}}{\text{day}} \times \frac{8.34\ \text{lbs}}{\text{gal}} \times \frac{1}{24\ \text{ac}}$$

$$= 125\ \text{lb BOD/day/ac}$$

Estimate the population loading in persons per acre.

$$\text{Population Loading, persons/ac} = \frac{\text{Population, persons}}{\text{Area, ac}}$$

$$= \frac{20{,}000 \text{ persons}}{24 \text{ ac}}$$

$$= 833 \text{ persons/ac}$$

Calculate the hydraulic loading in inches per day.

$$\text{Hydraulic Loading, in/day} = \frac{\text{Pond Depth, in}}{\text{Detention Time, days}}$$

$$= \frac{(4 \text{ ft})(12 \text{ in/ft})}{15.7 \text{ days}}$$

$$= \frac{48}{15.7}$$

$$= 3.06 \text{ in/day}$$

$$\begin{array}{r} 3.057 \\ 15.7 \overline{)\,48.0} \\ \underline{47.1} \\ 900 \\ \underline{785} \\ 1150 \\ 1099 \end{array}$$

OBJECTIVE TEST

Chapter 9. Waste Treatment Ponds

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1.

1. Ponds are used to:

   1. Store wastewater while it is treated
   2. Provide a surface for evaporation
   3. Grow mosquitoes
   4. Ice skate on
   5. Grow tules

2. When starting a pond, wastewater should be added:

   1. When the bottom is covered with grass
   2. When the pond is empty
   3. When the wind is blowing in the right direction
   4. When the mayor returns from his vacation
   5. When the pond bottom is covered with at least one foot of water.

3. Scum rafts may be broken up by:

   1. Agitation with garden rakes
   2. Jets of water from pumps
   3. The use of outboard motors on boats
   4. A thrashing machine
   5. Breaking down the bindings

4. Important operation and maintenance aspects of ponds include control of:

   1. Odors
   2. Waste gas burner
   3. Scum
   4. Drying beds
   5. Weeds and insects

5. Pond performance can be indicated by what tests?

   1. pH
   2. Carbon dioxide
   3. Methane
   4. Dissolved oxygen
   5. Hardness

6. Facultative ponds are:

   1. Faulty operating ponds
   2. Completely aerobic
   3. Aerobic on the top and anaerobic on the bottom
   4. Very shallow ponds
   5. The most common type in current use

7. Ponds may not operate properly if:

   1. The influent organic matter content fluctuates considerably every few days.
   2. Temperature stays below freezing for a long time
   3. There is no scum blanket
   4. The influent contains a powerful fungicide
   5. The influent has a high sulfur content

8. The influent to the first pond should be discharged at the:

   1. Surface
   2. Mid-depth
   3. Bottom of the pond

9. The effluent should leave the final pond:

   1. At the surface
   2. Just below the surface with a scum baffle around the outlet
   3. At the bottom of the pond

10. The pond outfall should be:

    1. Free
    2. Submerged

11. Minimum pond depth should be:

    1. 3 feet
    2. 4 feet
    3. 5 feet

12. Pond loadings may be expressed in:

    1. Acres per day of BOD
    2. Acres of people per day
    3. Pounds of BOD per acre per day
    4. Persons per acre
    5. Pounds BOD/day/acre

13. Pond performance is a function of:

    1. Type and quantity of algae
    2. pH
    3. Type of soil
    4. Short circuiting
    5. Surface area

14. Dissolved oxygen in a pond is increased by:

    1. Surface aerators
    2. Photosynthesis
    3. Wind action
    4. Algae liberating oxygen from the water molecule
    5. Sludge gases from bottom deposits floating to the surface

15. Advantages of ponds for smaller installations include:

    1. No maintenance
    2. Low cost to build and operate
    3. No insect problems
    4. Capability to handle fluctuating loads
    5. Satisfactory treatment of wastes

16. Estimate the population served if the inflow to a plant is 1.2 MGD.

    1. 1200
    2. 6000
    3. 12,000
    4. 120,000
    5. None of these

17. Two ponds serve a summer resort and are operated in series. They cover an area of 150 ft by 250 ft (average width and length of both ponds combined). The average depth is four feet, and the average inflow is 25,000 gpd. The detention time is approximately:

    1. 40 days
    2. 45 days
    3. 50 days
    4. 55 days
    5. 60 days

18. and when the influent BOD is 200 mg/l, the organic loading is approximately:

    1. 40 lb BOD/day/ac
    2. 42 lb BOD/day/ac
    3. 45 lb BOD/day/ac
    4. 48 lb BOD/day/ac
    5. 50 lb BOD/day/ac

19. Ponds are __________ simple to operate. (Select best answer.)

  1. Very
  2. Deceptively
  3. Not
  4. Quite
  5. Sort of

Review Question:

20. Estimate the velocity in a grit chamber if a stick travels 30 feet in 40 seconds.

  1. 0.50 ft/sec
  2. 0.75 ft/sec
  3. 1.00 ft/sec
  4. 1.25 ft/sec
  5. 1.33 ft/sec

Please write on your IBM answer sheet the total time required to work all three lessons and this objective test.

APPENDIX

(Monthly Data Sheet)

CLEANWATER, U.S.A.
WATER POLLUTION CONTROL PLANT

MONTHLY RECORD __________ 19___ OPERATOR: ______________

DATE	DAY	WEATHER	TIME OF VISIT	FLOW (MGD) EFFLUENT	TEMP. °F NO. 1 POND	TEMP. °F NO. 2 POND	pH NO. 1 POND	pH NO. 2 POND	D.O. NO. 1 POND	D.O. NO. 2 POND	B.O.D. INFLUENT	B.O.D. EFFLUENT	CL2 FEED RATE LB./DAY	CL2 RESIDUAL Mg./L.	E-COLI. M.P.N./100	MIXING HRS. NO. 1 POND	MIXING HRS. NO. 2 POND	REMARKS
1	T												35					
2	W	OVER CAST	9:30 A.M.	0.025	68	70	7.6	7.9	0.8	1.4	183	32	35	3.2	62	-0-	-0-	
3	T	CLEAR	2:00 P.M.	0.038	76	79	7.7	8.4	1.3	8.7			35	1.4				
4	F												"					
5	S												"					
6	S												"					
7	M	CLEAR	10:00 A.M.	0.026	70	74	7.6	8.1	1.2	7.6			"					
8	T												"					
9	W	CLEAR	10:30 A.M.	0.027	69	73	7.6	8.1	1.1	7.8	158	29	35	0.8	2400	-0-	-0-	
10	T												"					
11	F	CLEAR HOT	3:15 P.M.	0.039	77	80	7.6	8.3	1.5	11.2			"					
12	S												"					
13	S												"					
14	M	CLEAR	9:30 A.M.	0.023	70	75	7.8	8.5	1.9	7.6			"					
15	T												40					INCREASED Cl_2 FEED RATE TO 40#/DAY
16	W	CLEAR	1:30 P.M.	0.031	75	79	7.8	8.4	1.7	10.6	162	33	40	4.2	700	-0-	-0-	
17	T												40					
18	F	CLEAR	3:30 P.M.	0.037	79	85	7.8	8.6	2.1	14.5			40	2.5	23			
19	S												"					
20	S												40	2.8				
21	M												"					DECLARED HOLIDAY - NO PLANT CHECK
22	T	CLEAR	9:00 A.M.	0.020	71	76	7.6	8.4	1.0	7.8			40	5.6				
23	W	CLEAR	10:30 A.M.	0.028	72	78	7.7	8.4	1.0	8.1	178	30	40	5.0	6	-0-	-0-	
24	T												"					
25	F	CLEAR	2:15 P.M.	0.035	80	87	7.8	8.5	1.3	11.4			40	3.8				
26	S												"					
27	S												"					
28	M	CLEAR	10:00 A.M.	0.026	73	79	7.7	8.5	1.1	8.6			40	4.7				Cl_2 FEED RATE BACK TO 35#/DAY
29	T												35					
30	W	CLEAR	4:15 P.M.	0.038	81	88	7.8	8.5	1.8	15.3	168	35	35	1.1	6	-0-	-0-	
31																		
MAX.				0.039	81	88	7.8	8.6	2.1	15.3	183	35	40	5.6	2400	-0-	-0-	
MIN.				0.020	68	70	7.6	7.9	0.8	7.6	162	29	35	0.8	6	-0-	-0-	
AVG.		CLEAR		0.030	73	78	7.7	8.3	1.3	9.2	169	31	37.2	2.7	62	-0-	-0-	

SUMMARY DATA

% REMOVAL B.O.D.	81.6 %
LBS. B.O.D. / ACRE / DAY	52.8
DETENTION TIME — DAYS	86.7

PONDS OPERATED IN SERIES ALL MONTH.

MIXERS NOT OPERATED DURING MONTH.

COST DATA

MAN DAYS 4 x 2.5 HRS. PER VISIT PAYROLL	122.76
POWER PURCHASED	34.80
OTHER UTILITIES (GAS, H_2O)	NONE
GASOLINE, OIL, GREASE	NONE
CHEMICALS & SUPPLIES	69.30
MAINTENANCE	NONE
VEHICLE COSTS	48.70
OTHER	NONE
TOTAL	$ 275.56
OPERATING COST/CAPITA/MO.	$ 0.92
COST/1000 GAL. TREATED	$ 0.296

FLOW METER:
LAST 232602
1st 231672
TOTAL 0.930 MG.

ELECTRIC METER:
LAST 5978
1st 5817
MULT. 40 X 161 = 6440 KWH

CHAPTER 10

DISINFECTION AND CHLORINATION

by

Leonard W. Hom

(With a special section by J. L. Beals)

TABLE OF CONTENTS

Chapter 10. Disinfection and Chlorination

PRE-TEST

Chapter 10. Disinfection and Chlorination

Name ______________________________ Date ____________

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to each question.

1. Disease producing bacteria are called:

    1. Saprophytes
    2. Facultative
    3. Parasitic
    4. Pathogenic
    5. Coliform

2. Reduction of the number of pathogenic organisms in wastewater may be accomplished by:

    1. Sedimentation
    2. Prechlorination
    3. Postchlorination
    4. Providing chlorine contact time
    5. Adding orthotolidine

3. Chlorine may be applied for H_2S control in the:

    1. Collection lines
    2. Plant headworks
    3. Trickling filter
    4. Aeration tank
    5. Plant effluent

4. An operator should never enter a room containing high concentrations of chlorine gas without:

    1. Help standing by
    2. Notifying proper authorities
    3. A self-contained air or oxygen supply

5. You should never tamper with or apply heat to the fusible plug of a chlorine container.

    1. True
    2. False

6. Chlorine cylinders:

   1. Can easily be lifted by one man
   2. Can be handled safely
   3. Contain a fusible metal safety plug
   4. Should be rolled horizontally
   5. Should be stored at temperatures above 50°F and kept away from steam pipes

7. What should be the approximate chlorine feed rate for a flow of 1.5 MGD and a chlorine dosage of 15 mg/l?

   1. 200 lbs/24 hr
   2. 100 lbs/24 hr
   3. 20 lbs/24 hr
   4. 10 lbs/24 hr
   5. 2 lbs/24 hr

8. Chlorine should be applied continuously to:

   1. Keep the plant equipment from breaking down
   2. Keep the plant effluent disinfected
   3. Keep the chlorine pipes from developing leaks
   4. Keep the chlorine supplier in business
   5. Protect the downstream water users

9. Field chlorination studies have shown that:

   1. Constant vigilance is required to maintain a consistently high degree of disinfection at most wastewater treatment plants.
   2. Thorough mixing of chlorine solution with wastewater is essential to achieve maximum efficiency of coliform kill for a given chlorine dosage.
   3. Chlorine feed rates required to produce a desired disinfection level are constant from day to day.
   4. Actual contact time in most chlorine chambers is the same as the theoretical contact time.
   5. Chlorine residuals can be increased without limit and the coliform densities will always continue to be reduced with each increase in residual.

10. Chlorinators should be located:

   1. Near point of application
   2. Outdoors
   3. In a separate room
   4. In a room that will not allow chlorine to leak into rooms where operators work or where controls and equipment are located.
   5. In an adequately heated room

11. Postchlorination is generally more effective in a well-clarified effluent than in a turbid one.

   1. True
   2. False

12. Teflon tape makes a good:

    1. Joint lubricant
    2. Leak stopper

13. Hydrogen sulfide is found in most collection systems.

    1. True
    2. False

14. To protect the health of downstream water users, treatment plant effluents must be:

    1. Sterilized
    2. Disinfected

15. Hydrogen sulfide:

    1. Is associated with corrosion
    2. Causes odors
    3. Smells like chlorine
    4. Can paralyze your respiratory system
    5. Can form an explosive mixture with air

GLOSSARY

Chapter 10. Disinfection and Chlorination

Amperometric (am-PURR-o-MET-rick): A method of measurement that records electric current flowing or generated, rather than recording voltage. Amperometric titration is an electrometric means of measuring concentrations of substances in water.

Bacteria (back-TEAR-e-ah): Bacteria are living organisms, microscopic in size, which consist of a single cell. Most bacteria utilize organic matter for their food and produce waste products as the result of their life processes.

Biodegradation (BUY-o-de-grah-DAY-shun): The breakdown of organic matter by bacteria to more stable forms which will not create a nuisance or give off foul odors.

Chloramines (KLOR-a-means): Chloramines are compounds formed by the reaction of chlorine with ammonia.

Chlorine Demand: Chlorine demand is the difference between the amount of chlorine added to wastewater and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, nature and amount of the impurities in the water.

Chlorine Requirement: The amount of chlorine which must be added to produce the desired result under stated conditions. The result (the purpose of chlorination) may be based on any number of criteria, such as a stipulated coliform density, a specified residual chlorine concentration, the destruction of a chemical constituent, or others. In each case a definite chlorine dosage will be necessary. This dosage is the chlorine requirement.

Chlororganic (chlor-or-GAN-nick): Chlororganic compounds are organic compounds combined with chlorine. These compounds generally originate from or are associated with living or dead organic materials.

Coliform (COAL-i-form): The coliform group of organisms is a bacterial indicator of contamination. This group has as one of its primary habitats the intestinal tract of human beings. Coliforms also may be found in the intestinal tract of warm-blooded animals, and in plants, soil, air, and the aquatic environment.

Colorimetric: A means of measuring unknown concentrations of water quality in a sample by comparing the sample's color, after the addition of specific reagents, with the color of known concentrations.

Degradation (de-grah-DAY-shun): The conversion of a substance to simpler compounds.

Disinfection (DIS-in-feck-shun): The process by which pathogenic (disease) organisms are killed. There are several ways to disinfect but chlorination is the most frequently used method in water and wastewater treatment.

Enteric: Intestinal.

Enzymes (EN-zimes): Enzymes are substances produced by living organisms that speed up chemical changes.

Hepatitis: Hepatitis is an acute viral infection of the liver (yellow jaundice).

Hypochlorinators: Hypochlorinators are devices that are used to feed calcium, sodium or lithium hypochlorite as the disinfecting agent.

Hypochlorites (hi-po-KLOR-ites): Hypochlorites are compounds containing chlorine that are used for disinfection. They are available as liquid or solids (powder, granules, and pellets), in barrels, drums, and cans.

MPN: MPN is the Most Probable Number of coliform group organisms per unit volume. Expressed as density of organisms per 100 ml.

Motile (MO-till): Motile organisms exhibit or are capable of movement.

Nomogram: A chart or diagram containing three or more scales used to solve problems with three or more variables instead of using mathematical formulas.

Orthotolidine (or-tho-TOL-i-dine): Orthotolidine is a clorimetric indicator of chlorine residual in which a yellow-colored compound is produced.

Parasitic Bacteria (PARA-SIT-tick): Parasitic bacteria are those bacteria which normally live off another living organism, known as the host.

Pathogenic (path-o-JEN-nick) Organisms: Bacteria or viruses which can cause disease (typhoid, cholera, dysentery). There are many types of bacteria which do not cause disease and which are not called pathogenic. Many beneficial bacteria are found in wastewater treatment processes actively cleaning up organic wastes.

Postchlorination: Chlorination of the plant discharge or effluent following plant treatment.

Prechlorination: Chlorination at the headworks of a plant; influent chlorination prior to plant treatment.

Reliquefaction (re-LICK-we-FACK-shun): The return of a gas to a liquid. For example, a condensation of chlorine gas returning to the liquid form.

Residual Chlorine: Residual chlorine is the amount of chlorine remaining after a given contact time and under specified conditions.

Saprophytes (SAP-pro-fights): Organisms living on dead or decaying organic matter; they help natural decomposition of the organic solids in wastewater.

Septicity (sep-TIS-it-tee): Septicity is the condition in which organic matter decomposes to form foul-smelling products associated with the absence of free oxygen.

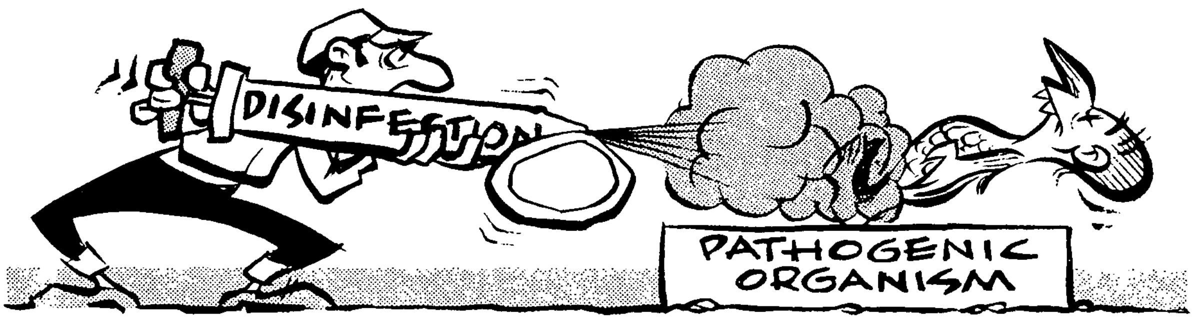
CHAPTER 10. DISINFECTION AND CHLORINATION

(Lesson 1 of 4 Lessons)

10.0 PRINCIPLES OF WASTEWATER DISINFECTION WITH CHLORINE

10.00 Introduction

Wastewater contains organisms from both the healthy and sick people discharging their wastes into the collection system. Disease-producing organisms are potentially present in all wastewaters, and these organisms must be removed or killed before treated wastewater can be discharged to the receiving waters. The purpose of disinfection is to destroy pathogenic organisms[1] and thus prevent the spread of water-borne diseases.



The conventional waste treatment processes described in previous chapters remove pathogens from wastewater in varying degrees. The destruction and removal of pathogens is brought about in several ways:

1. Physical removal through sedimentation and filtration

2. Natural die-away of organisms in an unfavorable environment during storage

3. Destruction by chemicals introduced for treatment purposes

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[1] Pathogenic (path-o-JEN-nick) Organisms. Bacteria or viruses which can cause disease (typhoid, cholera, dysentery). There are many types of bacteria which do not cause disease and which are not called pathogenic. Many beneficial bacteria are found in wastewater treatment processes actively cleaning up organic wastes.

Although the number of microorganisms in polluted waters is reduced by treatment processes and natural purification, the term disinfection is used in practice to describe treatment processes that have as their major objective the killing of pathogenic organisms (Fig. 10.1). Because chlorine and some of its compounds disinfect so well, and because they are available at reasonable cost, they have been used almost to the exclusion of other disinfecting agents. This chapter on disinfection will be concerned primarily with the principles and practice of chlorine disinfection.

10.01 Disinfection

The main use of chlorine in domestic waste treatment is disinfection. Strictly defined, disinfection is the destruction of all pathogenic organisms, while sterilization is the total destruction or removal of all microorganisms. When wastewater effluents are discharged to receiving waters which may be used as a source of public water supply, shellfish growing areas, or for recreational purposes, treatment for the destruction of pathogenic organisms is required to minimize the health hazards of pollution of these receiving waters. Such treatment is known as disinfection.

Chlorination for disinfection purposes requires killing essentially all of the pathogens in the domestic waste effluent. Many other sensitive organisms in contact with chlorine are destroyed too. No attempt is made to sterilize wastewater, which is both unnecessary and impractical. In some instances sterilization would be detrimental where other treatment, dependent upon the activity of the saprophytes,[2] follows chlorination. Chlorine is a nonselective killer. It affects organisms on the basis of sensitivity, growth rate, concentration and exposure time.

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[2] Saprophytes (SAP-pro-fights). Organisms living on dead or decaying organic matter; they help natural decomposition of the organic solids in wastewater.

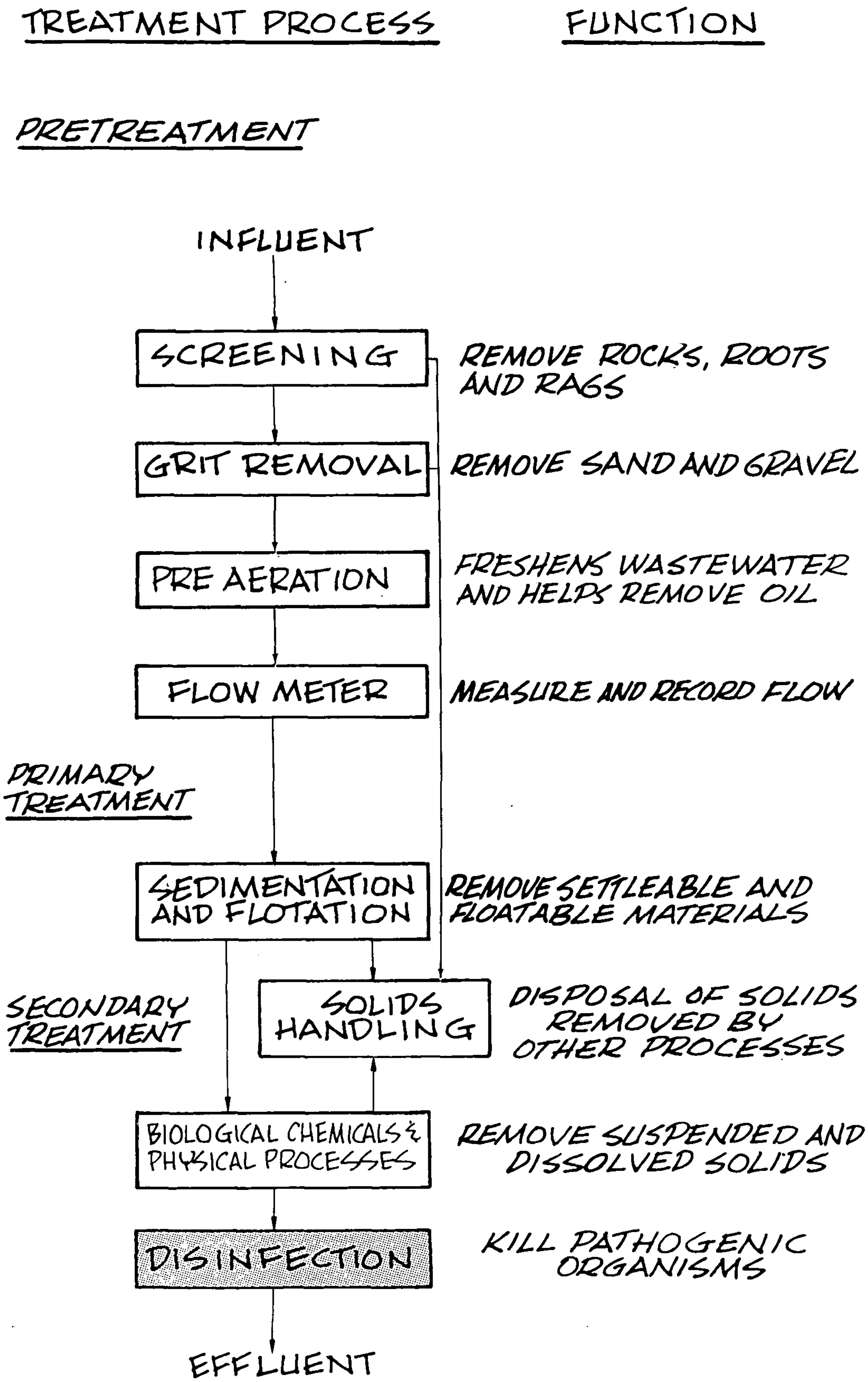

Fig. 10.1 Typical flow diagram of wastewater treatment plant

To accomplish disinfection, sufficient chlorine must be added to satisfy the chlorine demand[3] and leave a residual chlorine[4] that will destroy bacteria. The residual must be maintained for a sufficient "contact time" to insure killing the pathogens. For most wastewater, extending chlorine contact time can be more effective than increasing dosages.

Special laboratory equipment is necessary to measure the effectiveness of chlorination for reducing the number of bacteria. The tests require several days to complete. Thus bacterial examinations are not generally practical for the day-to-day control of the application of chlorine. For many years disinfection requirements often specified an orthotolidine[5] chlorine residual of 0.5 milligrams per liter after a chlorine contact time of thirty minutes. Compliance with this requirement generally resulted in MPNs[6] of about 3000 coliform[7] organisms per 100 ml (California, 1966). However, this resulting MPN may vary considerably (several orders of magnitude) from plant to plant. Considering dilution with water having a low coliform content, this standard appeared suitable when public contact with the waters was limited. Today people are living more intimately with wastewater than ever before. Wastewater effluents are

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[3] Chlorine Demand. Chlorine demand is the difference between the amount of chlorine added to wastewater and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, nature and amount of impurities in water. Chlorine Demand = Chlorine Applied - Chlorine Residual.

[4] Residual Chlorine. Residual Chlorine is the amount of chlorine remaining after a given contact time and under specified conditions.

[5] Orthotolidine (or-tho-TOL-i-dine). Orthotolidine is a colorimetric indicator of chlorine residual in which a yellow-colored compound is produced.

[6] MPN. MPN is the Most Probable Number of coliform group organisms per unit volume expressed as density of organisms per 100 ml.

[7] Coliform (COAL-i-form). The coliform group of organisms is a bacterial indicator of contamination. This group has as one of its primary habitats the intestinal tract of human beings. Coliforms also may be found in the intestinal tract of warm-blooded animals, and in plants, soil, air, and the aquatic environment.

used for irrigating lawns, parks, cemeteries, freeway planting, golf courses, college campuses, athletic fields, and other public areas. Recreational lakes used for boating, swimming, water skiing, fishing, and other water sports are frequently made up partially and, in a few cases, solely of treated effluents. As public contact has increased and diluting waters have decreased or become of poor quality, it has become obvious that more consideration must be given to disinfection practices.

QUESTIONS

10.0A What is the purpose of disinfection? Why is this important?

10.0B How are pathogenic bacteria destroyed or removed from water?

10.0C Why is chlorination used for disinfection?

10.0D Why are wastes not sterilized?

10.02 Reaction of Chlorine in Wastewater

In order to determine where in the treatment process and how much chlorine should be applied to accomplish the purpose desired, it is necessary to know the action of chlorine when added to wastewater.

Chlorine is an extremely active chemical that will react with many compounds to produce may different products. If a small amount of chlorine is added to wastewater, it will react rapidly with such substances as hydrogen sulfide, thiosulfates (industiral wastes), and ferrous iron. Under these conditions, chlorine is converted to chloride and little or no disinfection will result. If enough chlorine is added to react with all of these substances, called reducing compounds, a little more chlorine added will react with ammonia or other nitrogenous compounds present and form chloramines, which have disinfecting action. Again, if enough chlorine is added to react with all the reducing compounds and all the nitrogenous matter, this chlorine will react with organic matter to produce chlororganic compounds[8] or other combined forms of chlorine, which have slight disinfecting action. Finally, if enough chlorine is added to react with all of the above compounds, any additional chlorine will form free available chlorine (HOCl) which has the highest disinfecting action. (Fig. 10.2, Page 10-9)

The exact mechanism of this disinfection action is not fully known. In some theories, chlorine is considered to exert a direct action against the bacterial cell, thus destroying it. A more recent theory is that the toxic character of chlorine inactivates the enzymes[9] upon which the living microorganisms are dependent for utilizing their food supply. As a result, the organisms die of starvation. From the point of view of wastewater treatment, the mechanism of the action of chlorine is much less important than its effects as a disinfecting agent.

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[8] Chlororganic (chlor-or-GAN-nick). Chlororganic compounds are organic compounds combined with chlorine. These compounds generally originate from or are associated with living or dead organic materials

[9] Enzymes (EN-zimes). Enzymes are substances produced by living organisms that speed up chemical changes.

The quantity of reducing substances, both organic and inorganic, in wastewater varies, so the amount of chlorine that has to be added to wastewater for different purposes will vary. The chlorine used by these organic and inorganic reducing substances is defined as the chlorine demand. It is equal to the amount added minus that remaining as combined chlorine after a period of time, which is generally thirty minutes. Thus,

Chlorine Demand = Chlorine Dose - Chlorine Residual

Although significant kill of sensitive organisms occurs while the chlorine demand is being satisfied, disinfection is caused primarily by that amount remaining after the chlorine demand has been satisfied. This quantity of chlorine in excess of the chlorine demand is defined as residual chlorine and is expressed as milligrams per liter (mg/l).

It should be noted that in wastewater treatment chlorination is not normally to the "break point" (Fig. 10.2) so that a free residual would exist. The "break point" for good secondary effluent would be a chlorine dosage of approximately 150 mg/l. Thus we are talking primarily about a combined residual. However, with some of the more advanced treatment processes in which a high degree of nitrification occurs, treatment to free chlorine residuals beyond the break point is possible at a chlorine dose of less than 25 mg/l.

Both chlorine addition and contact time are essential for organism kill. Experimental determination of the best combination of combined residual and contact time is necessary to insure both proper chlorination and minimum use of chlorine. Changes in pH affect the disinfection ability of chlorine and the operator must reexamine the best combination of chlorine addition and contact time when the pH fluctuates.

It must be emphasized that wastewaters are not and need not be carried to a free residual for effective bactericidal action at the present time in most locations. With increasingly stringent receiving water standards requiring higher quality effluents in the future, the need for disinfection to the free chlorine residual is a distinct possibility. Complete disinfection ("kill" of pathogenic bacteria and viruses) is assured mainly by chlorination to a free available chlorine residual.

Calculation of the chlorine dosage and chlorine demand is illustrated in the following problem.

EXAMPLE:

A chlorinator is set to feed 50 pounds of chlorine per 24 hours; the wastewater flow is at a rate of 0.85 MGD, and the chlorine as measured by the OT (orthotolidine) tests after thirty minutes of contact is 0.5 mg/l. Find the chlorine dosage and chlorine demand in mg/l.

$$\text{Chlorine Feed or Dose, mg/l} = \frac{\text{50 lbs chlorine/day}}{\text{0.85 MG/day}}$$

$$\begin{array}{r} 59. \\ 0.85\ \overline{)\ 50.00} \\ \underline{42\ 5} \\ 7\ 50 \\ 7\ 65 \end{array}$$

$$= \text{59 lbs chlorine per MG}$$

$$= \frac{\text{59 lbs chlorine/MG}}{\text{8.34 lbs/gal}}$$

$$= \text{7.1 lbs chlorine/million pounds water}$$

$$= \text{7.1 ppm (parts per million parts)}$$

$$= \text{7.1 mg/l}$$

$$\text{Chlorine Demand, mg/l} = \text{Chlorine Dose, mg/l} - \text{Chlorine Residual, mg/l}$$

$$= \text{7.1 mg/l} - \text{0.5 mg/l}$$

$$= \text{6.6 mg/l}$$

QUESTIONS

10.0E How does chlorine react with wastewater?

10.0F How much chlorine must be added to wastewater to produce disinfecting action?

10.0G How is the chlorine demand determined?

10.0H How is the chlorine dosage determined?

10.0I Calculate the chlorine demand of treated domestic wastewater if:

Flow Rate = 1.2 MGD

Chlorinator = 70 lbs of chlorine per 24 hours

Residual = 0.4 mg/l after thirty minutes

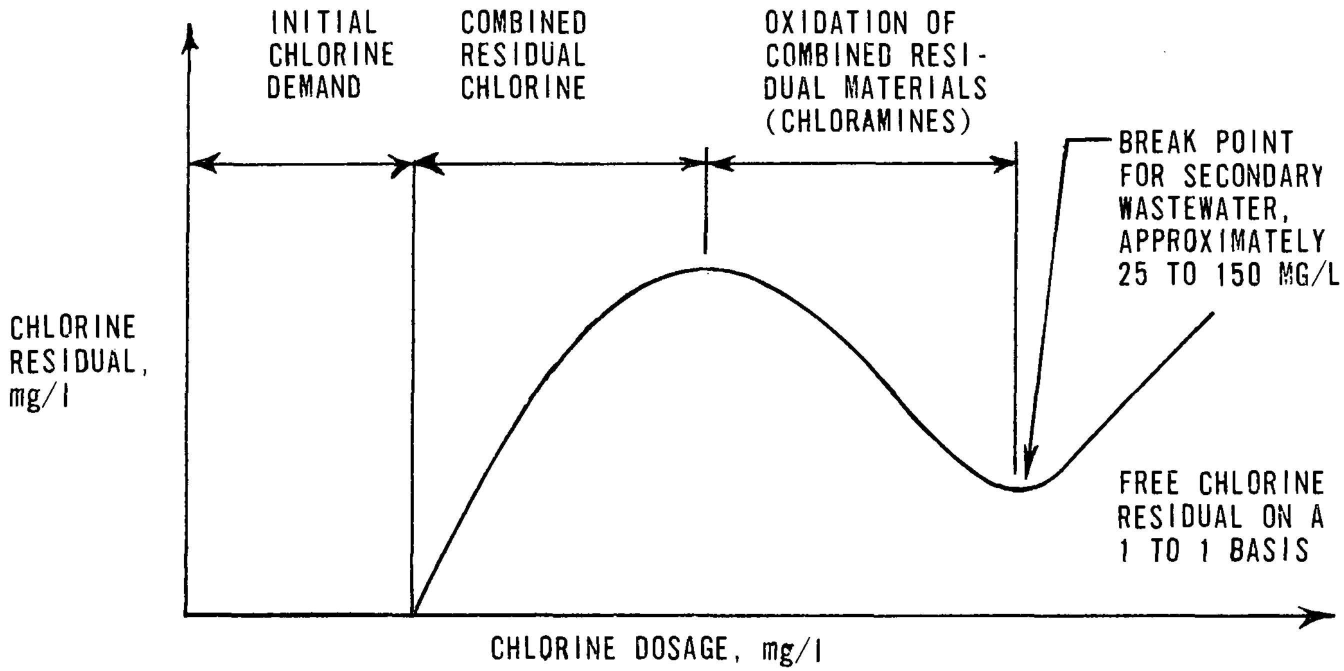

Fig. 10.2 Break-point chlorination curve

10.03 Rules of Disinfection

The State of California presently (1969) specifies the coliform MPN in the effluent as a primary standard for effectiveness of disinfection. It has been established that the bacteria causing enteric[10] diseases are less resistant to the chlorine than the non-pathogenic intestinal bacteria, designated as the coliform group. For this reason the destruction of the coliform group of bacteria generally provides an effective criterion of wastewater disinfection. However, certain viruses, spores, and pathogenic bacteria inside solids may be more resistant than coliform group bacteria to chlorine. When a chlorine residual criterion is also set, it is considered to be a secondary standard and is valid only if, and as long as, bacterial kill meets the MPN standard. One sample is not as meaningful as a series of samples indicating trends.

Studies have shown great variation in MPNs in chlorinated wastewater samples even under apparently similar conditions. These variations occur for numerous reasons, some of which are as follows:

1. MPN does not directly measure the true number of coliform bacteria present, but rather is an expected or probable number based on analysis of samples from a large population (all of the wastewater flowing by the sampling point).

2. Small samples from large amounts of a source are not representative unless the source is uniform, and certainly wastewater is far from uniform.

3. Many variables affect the number of coliform bacteria present in a chlorinated waste: numbers and characteristics of bacteria prior to chlorination, concentration and nature of the specific agent accomplishing the disinfection, accessibility of the disinfectant to the microorganisms, and various environmental factors.

4. The test is not always performed under ideal conditions. For example, culture media dilutions or other factors may be unfavorable for valid coliform counts.

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[10] Enteric: Intestinal

Several different methods including MPNs, membrane filters, and fecal coliforms may be specified for defining adequate disinfection. The format used is geared to fit the specific discharge and the downstream uses of the receiving waters. Check with your state regulatory agency for the requirements applicable to your plant.

Because of limited laboratory facilities available at most wastewater treatment plants, the following statement has been included in disinfection requirements issued in California:

> "Methods other than bacterial testing for the demonstration of effectiveness of disinfection will be accepted after the discharger has provided sufficient laboratory data showing that statistically sound correlation[11] exists at all times between bacterial results and measurements produced by the alternate proposed method."

Many of the smaller dischargers in California have asked the State for assistance in correlating chlorine residual and coliform MPN. The State has conducted studies at several plants. The studies have not been of a research nature, but were conducted for the purpose of determining whether disinfection as being practiced at the specific plants was adequate to protect the public health. Following are some of the findings from these studies:

1. It is difficult to maintain a consistently high degree of disinfection at most wastewater treatment plants. Chlorination is apparently more effective in a well-clarified effluent than one in which significant suspended solids are present. A lump of solids may consume available chlorine before the chlorine penetrates the particle. Organisms imbedded within the particle are thus protected from the chlorine and are not disinfected.

2. Thorough mixing of chlorine solution with the wastewater is essential to achieve maximum efficiency of coliform kill for a given chlorine dosage.

3. Higher chlorine residuals (after a given contact time) are required for primary treated wastes than for secondary treated wastes to effect a comparable coliform quality.

4. Two-stage chlorination (pre- and post-chlorination) provides more consistent production of low coliform density than postchlorination alone.

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[11] Correlation: Relationship

5. Generally speaking, a correlation exists between chlorine residual and coliform density. (Coliform densities decrease with increased chlorine residuals.) The individualities of wastewater treatment plants and their effluent conditions, as well as sampling and analysis techniques, make it difficult to apply a correlation determined from one plant to other plants.

6. Chlorine residuals, and corresponding feed rates, required to afford a desired disinfection level vary from day to day and from morning to afternoon at most treatment plants.

7. Increases in chlorine residuals above a certain point do not appear to reduce coliform densities significantly.

8. Increases in detention time above a certain point do not appear to reduce coliform densities significantly.

9. The actual contact time in most chlorine contact chambers is considerably less than the theoretical contact time.

10. Samples of wastewater chlorinated in a laboratory do not give results comparable to those obtained in chlorine contact chambers.

11. The better the treatment the more effective the disinfection at a given chlorine dosage.

10.04 Chlorine Requirement

The object of disinfection is the destruction of pathogenic bacteria, and the ultimate measure of the effectiveness is the bacteriological result. The measurement of residual chlorine does supply a tool for practical control. If the residual chlorine value commonly effective in most wastewater treatment plants does not yield satisfactory bacteriological kills in a particular plant, the residual chlorine that does must be determined and used as a control in that plant. In other words, the 0.5 mg/l residual chlorine, while generally effective, is not a rigid standard but a guide that may be changed to meet local requirements.

One special case would be the use of chlorine in the effluent from a plant serving a tuberculosis hospital. Studies have shown that a residual of at least 2.0 mg/l should be maintained in the effluent from this type of institution, and that detention time should be at least two hours at the average rate of flow instead of the thirty minutes which is normally used for basis of design. Two-stage chlorination may be particularly effective in this case.

It will generally be found that in a domestic waste the following dosages of chlorine are a reasonable guideline to produce chlorine residual adequate for disinfection. Individual plants may require higher or lower dosages, depending upon type and amount of suspended and dissolved organic compounds in the chlorinated sample.

TYPE OF TREATMENT	DOSAGE (Based on Average Flow)
Primary plant effluent	20 - 25 mg/l
Trickling filter plant effluent	15 mg/l
Activated sludge plant effluent	8 mg/l
Sand filter effluent	6 mg/l

QUESTIONS

10.0J Which is more resistant to chlorination, bacteria causing enteric diseases or non-pathogenic intestinal bacteria, designated as the coliform group?

10.0K Why does one find great variation in MPNs in chlorinated wastewater samples even under apparently similar conditions?

10.0L What are some of the findings of studies attempting to correlate chlorine residual and coliform MPN?

10.0M How is the effectiveness of the chlorine residual for a particular plant determined?

END OF LESSON 1 OF 4 LESSONS

on

DISINFECTION AND CHLORINATION

Please answer the discussion and review questions before continuing with Lesson 2.

<u>DISCUSSION AND REVIEW QUESTIONS</u>

Chapter 10. Disinfection and Chlorination

(Lesson 1 of 4 Lessons)

At the end of each lesson in this chapter you will find discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson.

Write the answers to these questions in your notebook before continuing.

1. Why must wastewaters be disinfected?

2. Why is chlorination used to disinfect wastewater?

3. To improve disinfection, which is more effective--increasing the chlorine dose, or extending the chlorine contact time?

4. What constituents in wastewater are mainly responsible for the chlorine demand?

5. Calculate the chlorinator setting (lbs per 24 hours) to treat a waste with a chlorine demand of 12 mg/l, when a chlorine residual of 2 mg/l is desired, if the flow is 1 MGD.

6. How do suspended and dissolved organic compounds in an effluent affect disinfection?

CHAPTER 10. DISINFECTION AND CHLORINATION

(Lesson 2 of 4 Lessons)

10.1 POINTS OF CHLORINE APPLICATION

10.10 Collection System Chlorination

One of the primary benefits of up-sewer chlorination is to prevent the deterioration of structures. Other benefits include odor and septicity control, and possibly BOD reduction to decrease the load imposed on the wastewater treatment processes. In some instances, the maximum benefit may result from a single application of chlorine at a point on the main intercepting sewer before the junction of all feeder sewer lines. In others, several applications at more than one point on the main intercepting sewer or at the upper ends of the feeder lines may prove most effective. Chlorination should be considered as a temporary or emergency measure in most cases, with emphasis being placed on proper design. Aeration also is effective in controlling septic conditions in collection systems. Although many problems result from improper design or design for future capacity requirements, the need for hydrogen sulfide protection exists under the best of conditions.

10.11 Prechlorination

Prechlorination is defined as the addition of chlorine to wastewater at the entrance to the treatment plant, ahead of settling units and prior to the addition of other chemicals.

In addition to its application for aiding disinfection and odor control at this point, prechlorination is applied to reduce plant BOD load, as an aid to settling, to control foaming in Imhoff units, and to help remove oil. Current trends are away from prechlorination to up-sewer aeration for control of odors.

10.12 Plant Chlorination

Chlorine is added to wastewater during treatment by other processes, and the specific point of application is related to the results desired. The purpose of plant chlorination may be for control and prevention of odors, corrosion, sludge bulking, digester foaming, filter ponding, filter flies, and as an aid in sludge thickening. Here again, chlorination should be an emergency measure.

10.13 Postchlorination

Postchlorination is defined as the addition of chlorine to municipal or industrial wastewater following other treatment processes. This point of application should be before a chlorine contact unit[12] and after the final settling unit in the treatment plant. This is the most effective place for chlorine application after treatment and on a well clarified effluent. Postchlorination is employed primarily for disinfection. As a result of chlorination for disinfection, some reduction in BOD may be observed; however, chlorination is rarely practiced solely for the purpose of BOD reduction.

QUESTIONS

10.1A What is the purpose of up-sewer chlorination?

10.1B Where should chlorine be applied in sewers?

10.1C What are the reasons for prechlorination?

10.1D Why might chlorine be added to wastewater during treatment by other processes?

10.1E What is the objective of postchlorination?

[12] Chlorine Contact Unit. A baffled basin that provides sufficient detention time for disinfection to occur.

10.2 CHLORINATION PROCESS CONTROL

10.20 Chlorinator Control

The control of chlorine flow to points of application is accomplished by six basic methods and a seventh method which combines two of the basic six.

10.200 Manual Control

Feed rate adjustment and starting and stopping of equipment is done by hand.

10.201 Start-Stop Control

Feed rate adjustment by hand, starting and stopping (by interrupting injector water supply) controlled by starting of wastewater pump, flow switch, level switch, etc.

10.202 Step-Rate Control

Chlorinator feed rate is varied according to the number of wastewater pumps in service. As each pump starts, a pre-set quantity of chlorine is added to the flow of chlorine existing at starting time. This system can be applied conveniently with installations employing up to eight pumps.

10.203 Timed Program Control

Chlorine feed rate is varied on a timed step-rate basis regulated to correspond to the times of flow changes or by using a time-pattern transmitter which employs a revolving cam cut to match a flow pattern.

10.204 Flow Proportional Control

Chlorinator feed rate is controlled by a system which converts wastewater flow information into a chlorinator control value. This can be accomplished by a variety of flow metering equipment, including all process control instrumentation presently available and nearly all metering equipment now in use on wastewater systems.

10.205 Chlorine Residual Control

Chlorine feed rate is controlled to a desired chlorine residual (usually combined chlorine) level. After mixing and reaction time (about five minutes maximum), a wastewater sample is titrated by an amperometric[13] analyzer-recorder (or indicator). As the residual chlorine level varies above or below the desired (setpoint) level, the chlorinator is caused to change its feed rate to bring the chlorine residual back to the desired level.

10.206 Compound Loop Control

Any "automatic" control system (step-rate, timed program, flow proportional, or residual) can be employed in two ways: (1) by positioning the feed rate valve, or (2) by varying the vacuum differential across the feed rate valve. Compound loop control employs both controls simultaneously. For instance, a flow proportional (or step-rate, or timed program) control system may position the feed rate valve, and a residual control system may vary the vacuum differential across the feed rate valve. Thus, changes in flow cause changes in feed rate valve position, but changes in chlorine demand may occur without any flow change. When this happens the residual analyzer detects a change in chlorine residual and by varying the vacuum differential across the feed rate valve causes the chlorinator to change rates to meet the desired chlorine residual level.

Various combinations of compound loop control can be employed. Generally speaking, the part of the system requiring the fastest response should be applied to valve positioning (since it responds faster). If flow changes are rapid, flow control should be by valve position. If flow and demand change rates are nearly the same, the magnitude of change may dictate the selection of control.

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[13] Amperometric (am-PURR-o-MET-rick). A method of measurement that records electric current flowing or generated, rather than recording voltage. Amperometric titration is an electrometric means of measuring concentrations of substances in water.

The selection of control methods should be based on treatment costs and treatment results (required or desired). A waste discharger must normally meet a disinfection standard. A small treatment plant might do this with a compound loop control system costing several thousand dollars, but may save less than one hundred dollars a year in chlorine consumed. In this case the expense would not be justified. A manual system might be employed which would meet the maximum requirements and over-chlorinate at a minimum requirement periods. It is not unheard of for a plant to have maximum chlorine residual requirements because of irrigation and/or marine life tolerances. In these cases the uncontrolled or promiscuous application of chlorine cannot be considered, no matter how large the added cost.

A chlorine residual level may be required at some point down-stream from the best residual control sample point. In this case a residual analyzer should be used to monitor and record residuals at this point. It may also be employed to change the control set point of the controlling residual analyzer.

Ultimate control of dosage for disinfection rests on the results desired, that is, the bacterial level or concentration acceptable or permissible at the point of discharge. Determination of chlorine requirements according to the current edition of *Standard Methods for the Examination of Water and Wastewater* is the best method of control. You must remember that the chlorine requirement or chlorine dose will vary with wastewater flow, time of contact, temperature, pH, and major waste constituents such as hydrogen sulfide, ammonia, and amount of dead and living organic matter.

QUESTIONS

10.2A How can chlorine gas feed be controlled?

10.2B Control of chlorine dosage depends on the bacterial ____________________ desired.

10.2C Define amperometric.

10.21 Chlorination Control Nomogram[14]

Determination of chlorine residual after contact gives confirmatory data on previous choice of dosage, and may serve to indicate need for readjustment of dosage. The contact period must be specified as longer contact period increases chlorine uptake.

Since feed rate is expressed in pounds per day, the rate setting of the feeder must be calculated from determination of chlorine required and the flow. The simplest means of making the calculation is by a chlorination control nomogram taken from the WPCF Manual of Practice No. 11, 1968 (Fig. 10.3). To use this nomogram:

1. Lay a straight edge (ruler) on point on Line A, representing flow, and on point on Line B, representing chlorine required,[15] and read point on Line C, which shows setting for chlorine feeder.

2. For any value in excess of maximum indicated on Scales A, B, or C, introduce proper factor of ten or multiple thereof. The application of a factor of ten will be presented later in Example 2.

3. Greatest accuracy will be obtained when the angle of the straight edge approaches a right angle with Line B. Multiplier of ten may be applied to aid in accomplishing this objective.

4. If straight edge does not cross all three scales, introduce necessary factors of ten and move straight edge to points where all three scales will be crossed.

Let's try some examples using Fig. 10.3. Assume the given chlorine dosage was selected on the basis of preliminary tests as capable of producing the desired results.

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[14] Nomogram. A chart or diagram containing three or more scales used to solve problems with three or more variables instead of using mathematical formulas.

[15] Chlorine Requirement. The amount of chlorine which must be added to produce the desired results under stated conditions. The result (the purpose of chlorination) may be based on any number of criteria, such as a stipulated coliform density, a specified residual chlorine concentration, the destruction of a chemical constituent, or others. In each case a definite chlorine dosage will be necessary. This dosage is the chlorine requirement.

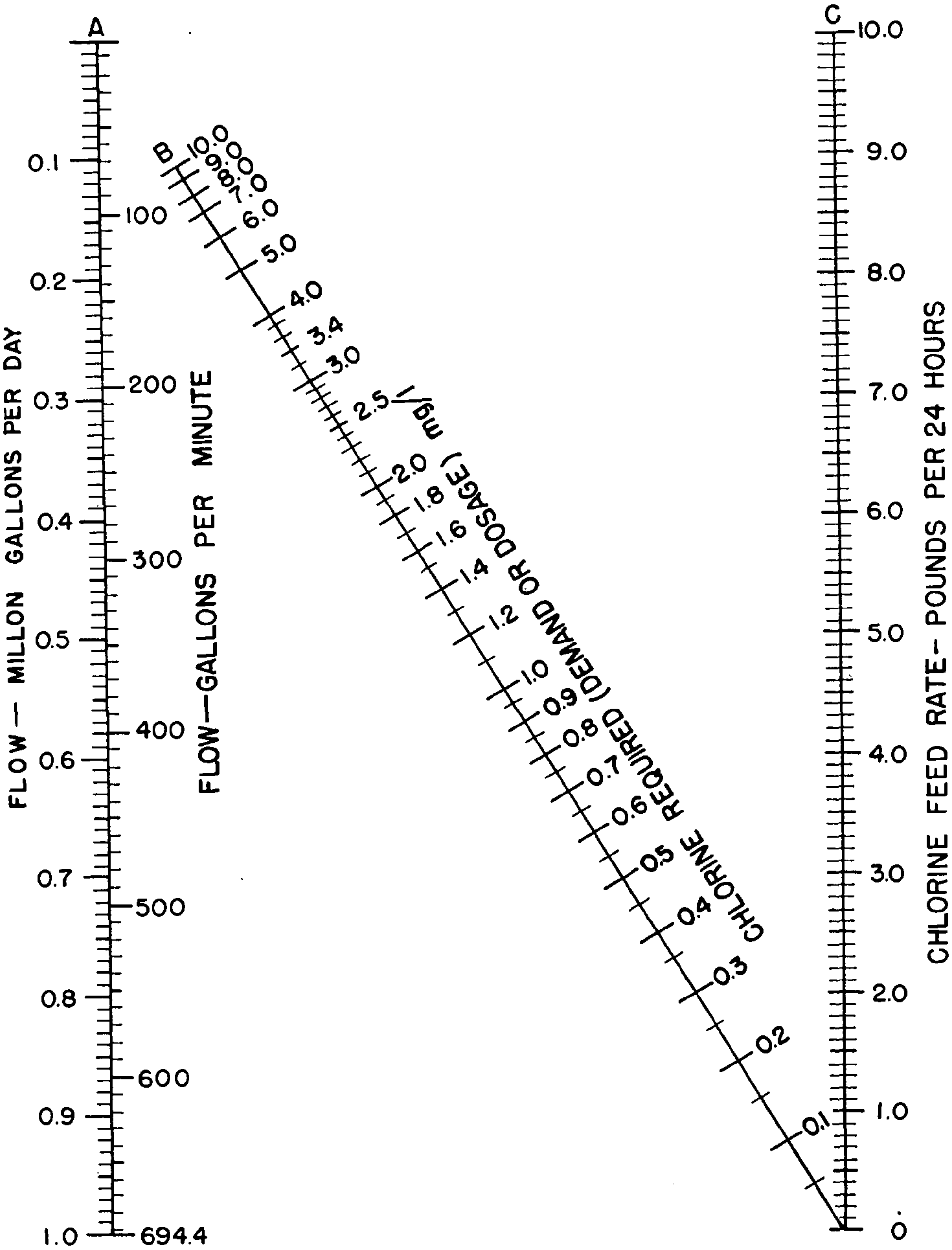

Fig. 10.3 Chlorination control nomogram

(Source: WPCF MOP No. 11, 1968)

EXAMPLE 1

Given: Maximum Flow Rate = 0.5 MGD

Chlorine Dosage = 1.0 mg/l

Procedure: Place one end of straight edge (ruler) on 0.5 MGD (Line A) and draw a line through the point on Line B representing a chlorine dosage of 1.0 mg/l. Extend the line to Line C and read the point indicating the chlorine feed rate.

Answer: Chlorine Feed Rate = 4.2 lbs per 24 hours

Check:

Chlorine Feed Rate = (Max. Flow, MGD) (Dosage, mg/l)(8.34 lbs/gal)

$$= 0.5 \frac{MG}{day} \times 1.0 \frac{mg}{M\ mg}^{16} \times 8.34 \frac{lbs}{gal} \qquad \begin{array}{r} 8.34 \\ \underline{0.5} \\ 4.170 \end{array}$$

= 4.17, say 4.2 lbs per day

EXAMPLE 2

Given: Maximum Flow Rate = 5.0 MGD

Chlorine Dosage = 1.0 mg/l

Procedure: 5.0 MGD is off our scale on Line A. Reduce flow by a factor of ten to 0.5 MGD, or 5.0 MGD/10 = 0.5 MGD. The problem is the same as Example 1, and the chart gives a chlorine feed rate of 4.2 lbs per 24 hrs. The flow rate is actually ten times 0.5 MGD (10 x 0.5 MGD = 5 MGD). Therefore the required chlorine feed rate is 10 x 4.2 lbs per 24 hours (10 x 4.2 = 42) or 42 lbs per 24 hours.

Note: On a cold day, a 150-lb cylinder may not be adequate to provide this feed rate.

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[16] Recall concentrations in mg/l are the same as mg/M mg.

EXAMPLE 3

Given: Maximum Flow Rate = 0.4 MGD

Chlorine Dosage = 5.0 mg/l

Procedure: A line through a flow of 0.4 MGD (Line A) and 5.0 mg/l (Line B) misses Line C. The chlorine dosage should be reduced by a factor of ten to be able to use the nomogram.

$$\text{Chlorine Dosage} = \frac{5.0 \text{ mg/l}}{10} = 0.5 \text{ mg/l}$$

Chlorine Feed Rate = 1.7 lbs per 24 hours (from chart)

Actual Feed Rate = (10)(1.7 lbs per 24 hrs)

= 17 lbs per 24 hrs

The chlorine feed rate must be ten times the rate from the chart because the chlorine required was reduced by a factor of ten to use the chart.

The results from the chart should be checked using the mathematical calculations used in Example 1 to avoid errors. It should be noted that the chlorine requirement should take into consideration the chlorine demand so that a desired residual is obtained after a given contact period. As discussed in Section 10.02, chlorine requirements vary with the wastewater characteristics, concentration, flow, and temperature. Adjustment of chlorine feeder rates to meet all these variations is the ultimate goal of good operation practice. More frequent adjustments are usually required for primary effluent than for secondary effluent.

Suggested schedule for adjusting manual feeder rates:

1. In large plants--at least every hour
2. In medium-sized plants--every two to four hours
3. In small plants--every eight hours

Other methods of chlorinator control have been described in Section 10.20.

10.22 Hypochlorinator[17] Feed Rate

Chlorine for disinfection and other purposes is provided in some plants by the use of hypochlorites.[18] The amount of chlorine delivered depends on the type of hypochlorite. For example, HTH (high test hypochlorite) contains 67 percent, by weight, of chlorine, and chlorinated lime contains 34 percent.

Manufacturers of hypochlorites define available chlorine as the amount of gaseous chlorine required to make the equivalent hypochlorite chlorine. If you prepare a hypochlorite solution for disinfection and immediately measure the chlorine residual, you will find the chlorine residual about half of the expected value based on the manufacturer's amount of available chlorine. When hypochlorites are mixed with water, approximately half of the chlorine forms hydrochloric acid (HCl) and the other half forms hypochlorite (OCl^-), the chlorine residual that you measured.

EXAMPLE:

A wastewater requires a chlorine feed rate of 17 lbs per day. How many pounds of chlorinated lime will be required to provide the needed chlorine?

$$\text{Chlorinated Lime Feed Rate, lbs/day} = \frac{\text{Chlorine Required, lbs/day}}{\text{Portion of Chlorine in lb of Hypochlorite}}$$

$$= \frac{17 \text{ lbs/day}}{0.34}$$

$$= 50 \text{ lbs/day}$$

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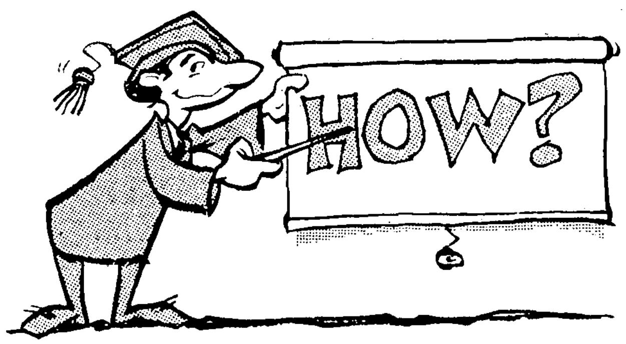
[17] Hypochlorinator. Hypochlorinators are devices that are used to feed calcium, sodium, or lithium hypochlorite as the disinfecting agent.

[18] Hypochlorites. Hypochlorites are compounds containing chlorine that are used for disinfection. They are available as liquid or solids (powder, granules, and pellets), in barrels, drums, and cans.

QUESTIONS



10.2D How is the rate of dosage for a chlorinator determined?

10.2E Determine the chlorine feed rate, pounds per 24 hours, if you are treating:

1. A flow of 0.5 MGD and the chlorine required is 1.0 mg/l.
2. Flow = 0.8 MGD and chlorine required = 4.0 mg/l.
3. Flow = 6 MGD and chlorine required = 25 mg/l.

10.2F How frequently should feeder rates be adjusted with manual controls? Why?

10.2G How many pounds of HTH (high test hypochlorite) should be used per day by a hypochlorinator dosing a flow of 0.55 MGD at 12 mg/l of chlorine?

10.23 Chlorine Solution Discharge Lines, Diffusors, and Mixing

10.230 Solution Discharge Lines

Solution discharge lines are made from a variety of materials depending upon the requirements of service. Two primary requisites are that it must be resistant to the corrosive effects of chlorine solution and of adequate size to carry the required flows. Additional considerations are pressure conditions, flexibility (if required), resistance to external corrosion and stresses when underground or passing through structures, ease and tightness of connections, and the adaptability to field fabrication or alteration.

Development of plastics in the past several years has contributed greatly to chemical solution transmission. Polyvinyl chloride (PVC) pipe and black polyethylene flexible tubing have all but eliminated the use of rubber hose. Both are generally less expensive and both outlast rubber in normal service. The use of hose is almost exclusively limited to applications where flexibility is required or where extremely high back pressures exist.

PVC and polyethylene can be field fabricated and altered. PVC should be Schedule 80 to limit its tendency to cold flow and partially collapse under vacuum conditions, or for higher pressure ratings if required. Schedule 80 PVC may be threaded and assembled with ordinary pipe tools or may be installed using solvent welded fittings.

Rubber lined steel pipe has been used for many years where resistance to external stresses is required. It cannot be field fabricated or altered and is thus somewhat restricted in application. PVC lining of steel pipe has not yet become economically competitive, but other plastics have been developed which can readily compete with rubber lining and are adaptable to field fabrication and alteration.

Never use neoprene hose to carry chlorine solutions because it will become hard and brittle in a short time.

10.231 Chlorine Solution Diffusors

These diffusors are normally constructed of the same materials used for solution lines. Their design is an extremely important part of a chlorination program. This importance is almost completely related to the mixing of the chlorine solution with the wastewater being treated; however, strength, flexibility, etc., also must be given consideration. In most circular, filled conduits flowing at 0.25 ft/sec (or greater) a solution injected at the center of the pipeline will mix with the entire flow in ten pipe diameters. Mixing in open channels can be accomplished by the use of a hydraulic jump (Fig. 10.4) or by sizing diffusor orifices so that a high velocity (about 16 ft/sec) is attained at the diffusor discharge. This accomplishes two things: (1) introducing a pressure drop to get equal discharge from each orifice, and (2) imparting sufficient energy to the surrounding wastewater to complete the mixing. Generally speaking, a diffusor should be supplied for each two to three feet of channel depth.

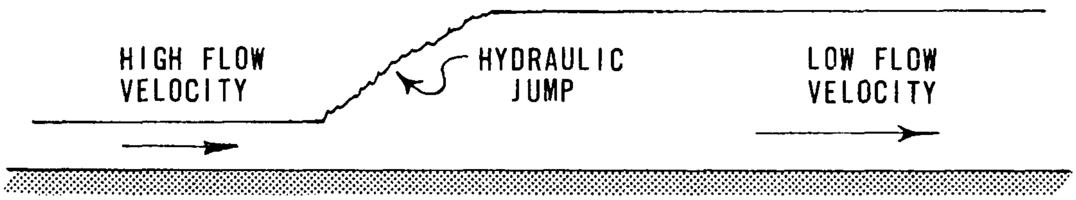


Fig. 10.4 Hydraulic jump

10.232 Mixing

Mixing is extremely important ahead of a chlorine contact tank or a residual sampling point. Since a contact tank is usually designed for low velocity, little mixing occurs after wastewater enters it. It is therefore necessary to achieve mixing before the contact tank is entered. The same is true for a chlorine residual sampling point; otherwise erratic results will be obtained by the residual analyzing system.

QUESTIONS

10.2H Why does little mixing of the chlorine solution with wastewater occur in chlorine contact basins?

10.2I Chlorine solution discharge lines may be made of ____________ or ____________

10.24 Measurement of Chlorine Residual

Refer to Chapter 14, Laboratory Procedures and Chemistry, for procedures to measure chlorine residual. Amperometric titration provides the most convenient, fastest, and most repeatable results; however, apparatus costs are high (approximately $500). The orthotolidine test should be run shortly after the chlorine has been applied. The iodometric method will produce satisfactory results in samples containing wastewater, such as plant effluents and receiving waters.

END OF LESSON 2 OF 4 LESSONS

on

DISINFECTION AND CHLORINATION

Please answer the discussion and review questions before continuing with Lesson 3.

DISCUSSION AND REVIEW QUESTIONS

Chapter 10. Disinfection and Chlorination

(Lesson 2 of 4 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 1.

7. Where might chlorine be applied in the treatment of wastewater?

8. Where is chlorine usually applied for disinfection purposes?

9. What is the ultimate control of chlorine dosage for disinfection?

10. Determine the chlorine feed rate for a flow of 0.75 MGD and a chlorine dosage of 18 mg/l.

11. Why must the chlorine solution be well mixed with the wastewater?

10.3 SAFETY AND FIRST AID

All persons handling chlorine should be thoroughly aware of its hazardous properties. Personnel should know the location and use of the various pieces of protective equipment and be instructed in safety procedures. For additional information on this topic, see the Water Pollution Control Federation's Manual of Practice No. 1, *Safety in Wastewater Works*, and the Chlorine Institute's *Chlorine Manual*, 4th edition.[19]

10.30 Chlorine Hazards

Chlorine is a gas, heavier than air, extremely toxic and corrosive in moist atmospheres. Dry chlorine gas can be safely handled in steel containers and piping, but with moisture must be handled in corrosion-resisting materials such as silver, glass, teflon, and certain other plastics. Chlorine gas at container pressure should never be piped in silver, glass, teflon, or any other plastic material. The gas is very irritating to the mucous membranes of the nose, to the throat, and to the lungs; a very small percentage in the air causes severe coughing. Heavy exposure can be fatal. (See Table 10-1.)

WARNING

WHEN ENTERING A ROOM THAT MAY CONTAIN CHLORINE GAS, OPEN THE DOOR SLIGHTLY AND CHECK FOR THE SMELL OF CHLORINE. **NEVER** GO INTO A ROOM CONTAINING CHLORINE GAS WITH HARMFUL CONCENTRATIONS IN THE AIR WITHOUT A SELF-CONTAINED AIR SUPPLY, PROTECTIVE CLOTHING AND HELP STANDING BY. HELP MAY BE OBTAINED FROM YOUR CHLORINE SUPPLIER AND YOUR LOCAL FIRE DEPARTMENT.

[19] Write to: Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016; price to WPCF members, \$0.75; others, \$1.50. The Chlorine Institute, Inc., 342 Madison Avenue, New York, New York 10017; price \$0.75.

TABLE 10-1

PHYSIOLOGICAL RESPONSE TO CONCENTRATIONS OF CHLORINE GAS[20]

Effect	Parts of Chlorine Gas Per Million Parts of Air By Volume (ppm)
Slight symptoms after several hours' exposure	1
Detectable odor	3
60-minute inhalation without serious effects	4
Noxiousness	5
Throat irritation	15
Coughing	30
Effects dangerous to one-half to one hour	40
Death after a few deep breaths	1000

[20] Adapted from data in U.S. Bureau of Mines Technical Paper 248 (1955).

10.31 Why Chlorine Must Be Handled With Care

You must always remember that chlorine is a hazardous chemical and must be handled with respect. Concentrations of chlorine gas in excess of 1000 ppm may be fatal after a few breaths.

Because the characteristic sharp odor of chlorine is noticeable even when the amount in the air is small, it is usually possible to get out of the gas area before serious harm is suffered. This feature makes chlorine less hazardous than gases such as carbon monoxide, which is odorless, and hydrogen sulfide, which impairs your sense of smell in a short time.

Inhaling chlorine causes general restlessness, panic, severe irritation of the throat, sneezing, and production of much saliva. These symptoms are followed by coughing, retching and vomiting, and difficulty in breathing. Chlorine is particularly irritating to persons suffering from asthma and certain types of chronic bronchitis. Liquid chlorine causes severe irritation and blistering on contact with the skin.

10.32 Protect Yourself From Chlorine

Every person working with chlorine should know the proper ways to handle it, should be trained in the use of self-contained breathing apparatus, and should know what to do in case of emergencies.

WARNING

CANNISTER TYPE 'GAS MASKS' ARE USUALLY **INADEQUATE AND INEFFECTIVE** IN SITUATIONS WHERE CHLORINE LEAKS OCCUR AND ARE THEREFORE NOT RECOMMENDED FOR USE UNDER ANY CIRCUMSTANCES. **SELF-CONTAINED AIR OR OXYGEN SUPPLY TYPE BREATHING APPARATUS ARE RECOMMENDED.**

Here are some items you should always remember in order to protect yourself and others from possible injury:

a. In an emergency, only authorized persons with adequate safety equipment should be in the danger area. Have your fire department examine your chlorine handling facilities and safety equipment so they will be aware of what you have and the possible dangers. They are well trained in the use of breathing apparatus and may be able to help you in an emergency, especially if they are familiar with chlorine hazards.

b. In any chlorine atmosphere, short shallow breathing is safer than deep breathing. Recovery from exposure depends on the amount of chlorine inhaled, so it is important to keep that amount as small as possible.

c. Clothing contaminated with liquid or gaseous chlorine continues to give off chlorine gas and irritate the body even after leaving a contaminated area. Therefore, contaminated clothing should be removed immediately and the exposed parts of the body washed with a large amount of cool water.

The use of a breathing apparatus is advisable during these operations. All caution should be taken to prevent any liquid from coming in contact with clothing not designed for protection, because the liquid can penetrate the cloth and cause skin problems.

d. Learn the correct way of using the breathing apparatus, practice using it regularly, and take safety drills seriously. What you learn may save your life. The fire department is well trained in the use of breathing apparatus and can be very helpful in training.

e. If you have found a chlorine leak and left the area before the leak was stopped, you should use an apparatus with a separate air supply when you return and repair the leak. Never rely on a cannister type mask for protection in repairing chlorine leaks. Cannister masks are not recommended because they do not supply oxygen. They only remove chlorine, if they are effective. Some agencies allow the use of cannister type masks; however, most operators who have had experience repairing chlorine leaks do not use cannister masks because of their short shelf life (approximately three to four months) and inability to provide adequate protection against high concentrations of chlorine. Extensive ventilation is recommended.

f. Cooperate in taking care of all safety equipment, handling it carefully, and returning it to its proper storage place after use. Defective equipment, or equipment which you can't find when you need it, will not protect you.

g. Always be sure that you know the location of first aid cabinets, breathing apparatus, showers, and other safety equipment. Review emergency instructions regularly to be sure you know them.

h. Notify your police department that you need help if it becomes necessary to stop traffic on roads and to evacuate persons in the vicinity of a chlorine leak.

10.33 First Aid Measures

a. Be sure you know the location of breathing apparatus, first aid kits, and other safety equipment at all times.

b. Remove clothing contaminated with liquid chlorine at once. Carry patient away from gas area--if possible to a room with a temperature of 70°F. Keep patient warm, with blankets if necessary. Keep him quiet.

c. Place patient on his back with his head higher than the rest of his body.

d. Call a doctor and fire department immediately. Immediately begin appropriate treatment.

e. Eyes. If even small quantities of chlorine have entered the eyes, hold the eyelids apart and flush copiously with lukewarm running water. Continue flushing for about fifteen minutes. Do not attempt any medication except under specific instructions from a physician.

f. Skin. Get patient under a shower immediately, clothes and all. Remove clothing while the shower is running. Wash the skin with large quantities of soap and water. Do not attempt to neutralize chlorine with chemicals. Do not apply salves or ointments except as directed by a physician.

g. Inhalation. If the patient is breathing, place him in a comfortable position; keep him warm and at rest until a physician arrives.

   If breathing seems to have stopped, begin artificial respiration immediately. Mouth-to-mouth resuscitation or any of the approved methods may be used. Oxygen should be administered if equipment and trained personnel are available.

   Automatic artificial respiration is considered preferable to manual, but only when administered by an experienced operator.

   Rest is recommended after severe chlorine exposure.

h. Throat Irritation. Drinking milk will relieve the discomforts of throat irritation from chlorine exposure. Chewing gum or drinking spirits of peppermint also will help reduce throat irritation. Follow emergency rules given by your physician. In the absence of such rules, the first aid steps above are suggested.

Taken in part from Chlorine Safe Handling Pamphlet, published by The Chemical Division of PPG Industries, Inc.

QUESTIONS

10.3A What are the hazards of chlorine gas?

10.3B What type of breathing apparatus is recommended when repairing a chlorine leak?

10.3C What first aid measures should be taken if a person comes in contact with chlorine?

10.4 CHLORINE HANDLING

10.40 Chlorine Containers

10.400 Cylinders

Cylinders containing 100 to 150 pounds of chlorine are convenient for the average small consumer. These cylinders are usually of seamless steel construction (Fig. 10.5).

A fusible plug is placed in the valve, below the valve seat (Fig. 10.6). This plug is a safety device. The fusible metal softens or melts at 158° to 165°F, to prevent building up of excessive pressures and the possibility of rupture due to a fire or high surrounding temperatures.

Cylinders will not explode and can be handled safely.

The following are procedures for handling chlorine cylinders.

1. Move cylinders with a properly balanced hand truck with clamp supports that fasten at least two-thirds of the way up the cylinder.

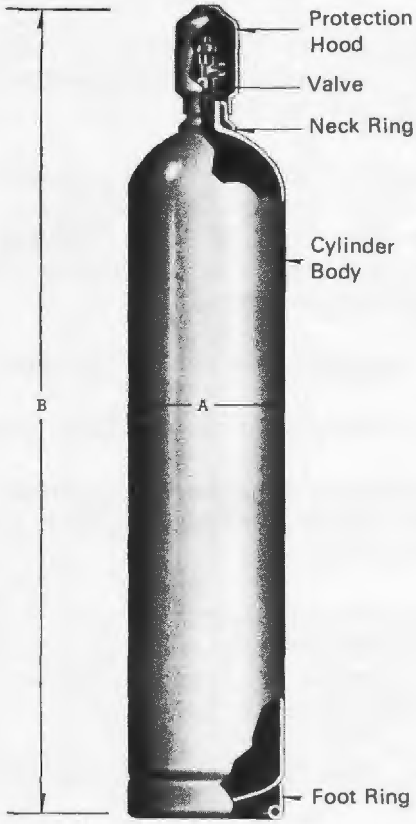
2. 100- and 150-pound cylinders can be rolled in a vertical position. Lifting of these cylinders should be avoided except with approved equipment. Never lift with chains, rope slings, or magnetic hoists.

3. Protective cap should always be replaced when moving a cylinder.

4. Cylinders should be kept away from direct heat (steam pipes, radiators, etc.).

5. Cylinders should be stored in an upright position.

Chlorine Cylinder



Net Cylinder Contents	Approx. Tare, Lbs.*	Dimensions, Inches	
		A	B
100 Lbs.	73	8 1/4	54 1/2
150 Lbs.	92	10 1/4	54 1/2

*Stamped tare weight on cylinder shoulder does not include valve protection hood.

Fig. 10.5 Chlorine cylinder

(Courtesy of PPG Industries, Inc., Chemical Division)

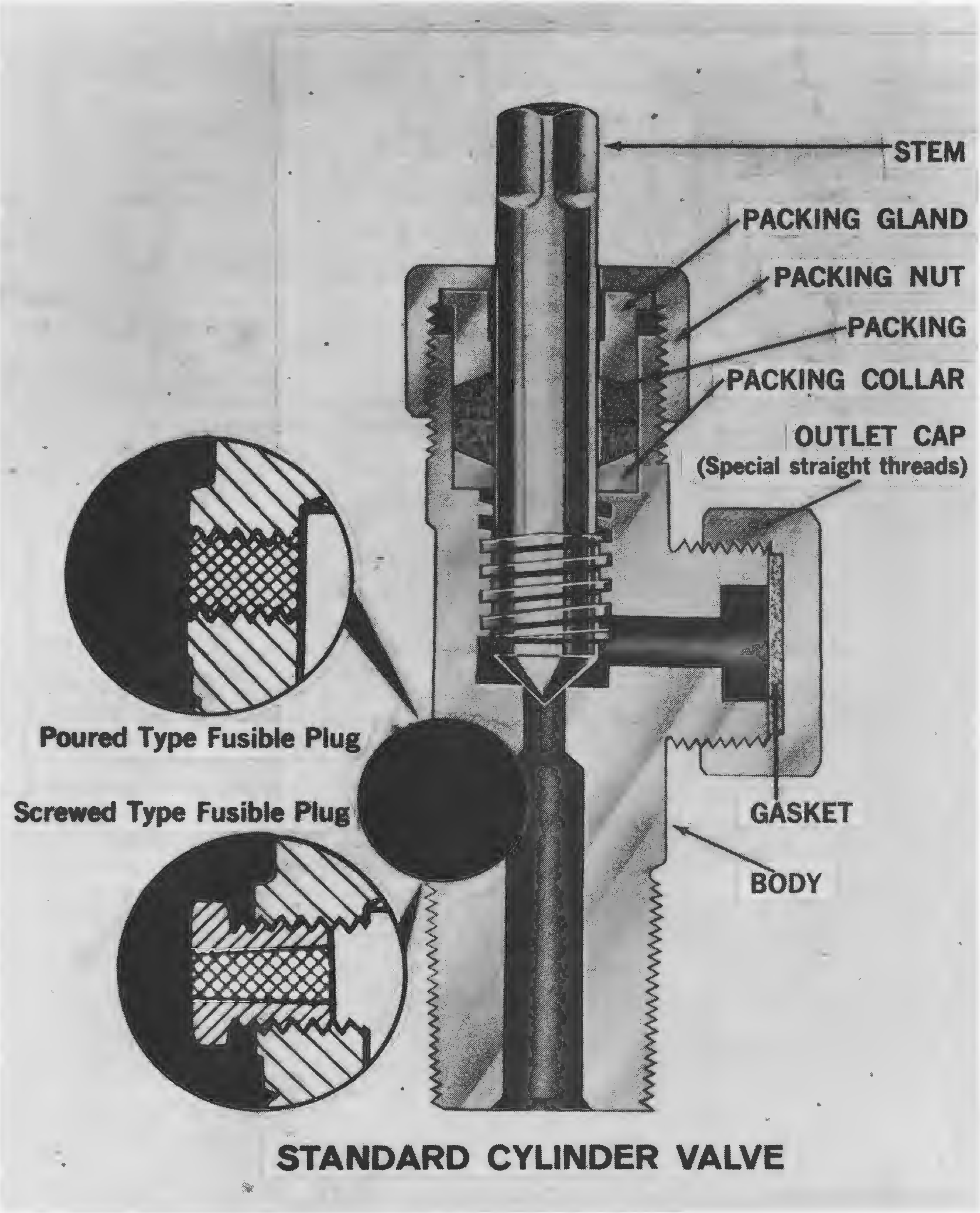


Fig. 10.6 Standard cylinder valve

Reproduced with permission (1959, 1966)
The Dow Chemical Company

10.401 Ton Tanks

Ton tanks are of welded construction and have a loaded weight of as much as 3700 pounds. They are about 80 inches in length and 30 inches in outside diameter. The ends of the tanks are crimped inward to provide a substantial grip for lifting clamps (Fig. 10.7).

The following are some characteristics of and procedures for handling ton tanks.

Most ton tanks have eight openings for fusible plugs and valves (Figs. 10.7 and 10.8). Generally, two operating valves are located on one end near the center and six or eight fusible metal safety plugs, three or four on each end. These are designed to melt within the same temperature range as the safety plug in the cylinder valve.

WARNING

IT IS **VERY IMPORTANT** THAT FUSIBLE PLUGS SHOULD NOT BE TAMPERED WITH **UNDER ANY CIRCUMSTANCES** AND THAT THE TANK SHOULD NOT BE HEATED. ONCE THIS PLUG OPENS, ALL OF THE CHLORINE IN THE TANK WILL BE RELEASED.

Ton tanks are shipped by rail in multi-unit tank cars. Single units may be transported by truck or semi-trailer.

Ton tanks should be handled with a suitable lift clamp in conjunction with a hoist or crane of at least two-ton capacity (Fig. 10.7).

Ton tanks should be stored and used on their sides, above the floor or ground, on steel or concrete supports. They should not be stacked more than one high.

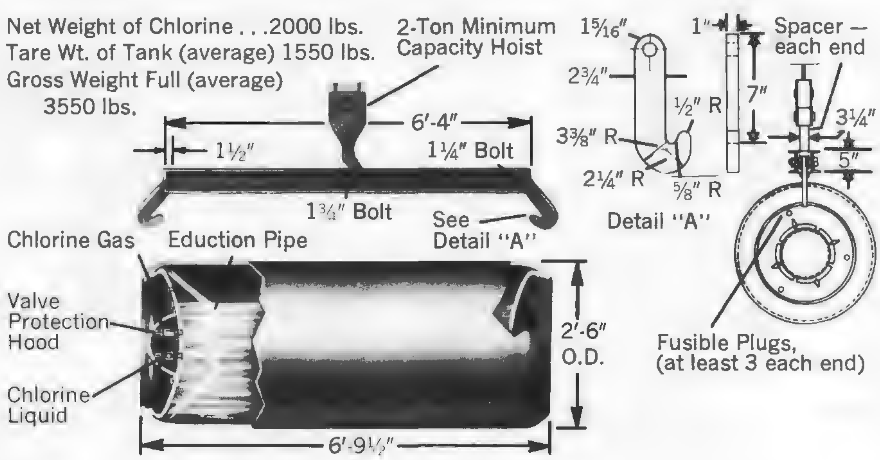


Fig. 10.7 Ton tank lifting beam

(Courtesy of PPG Industries, Inc., Chemical Division)

Ton Tank Valve   100 and 150 lb. Cylinder Valve

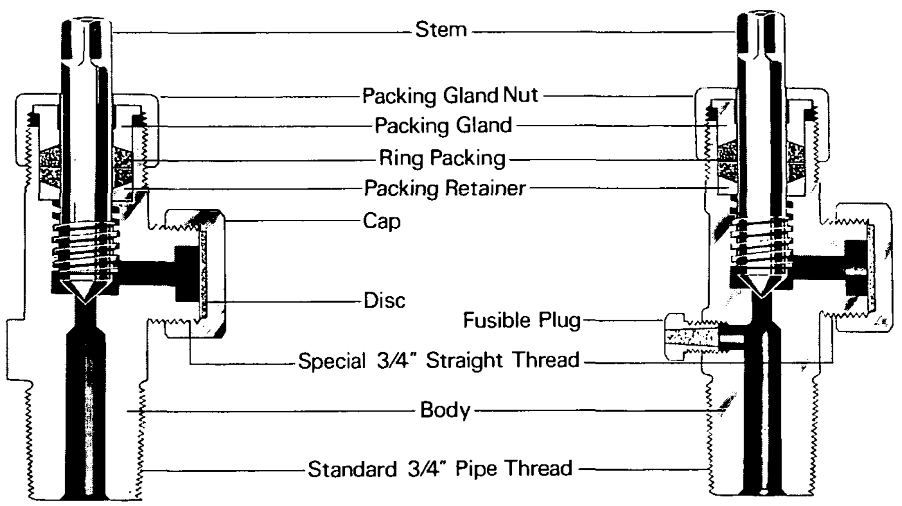


Fig. 10.8 Comparison of ton tank valve with cylinder valve

(Courtesy of PPG Industries, Inc., Chemical Division)

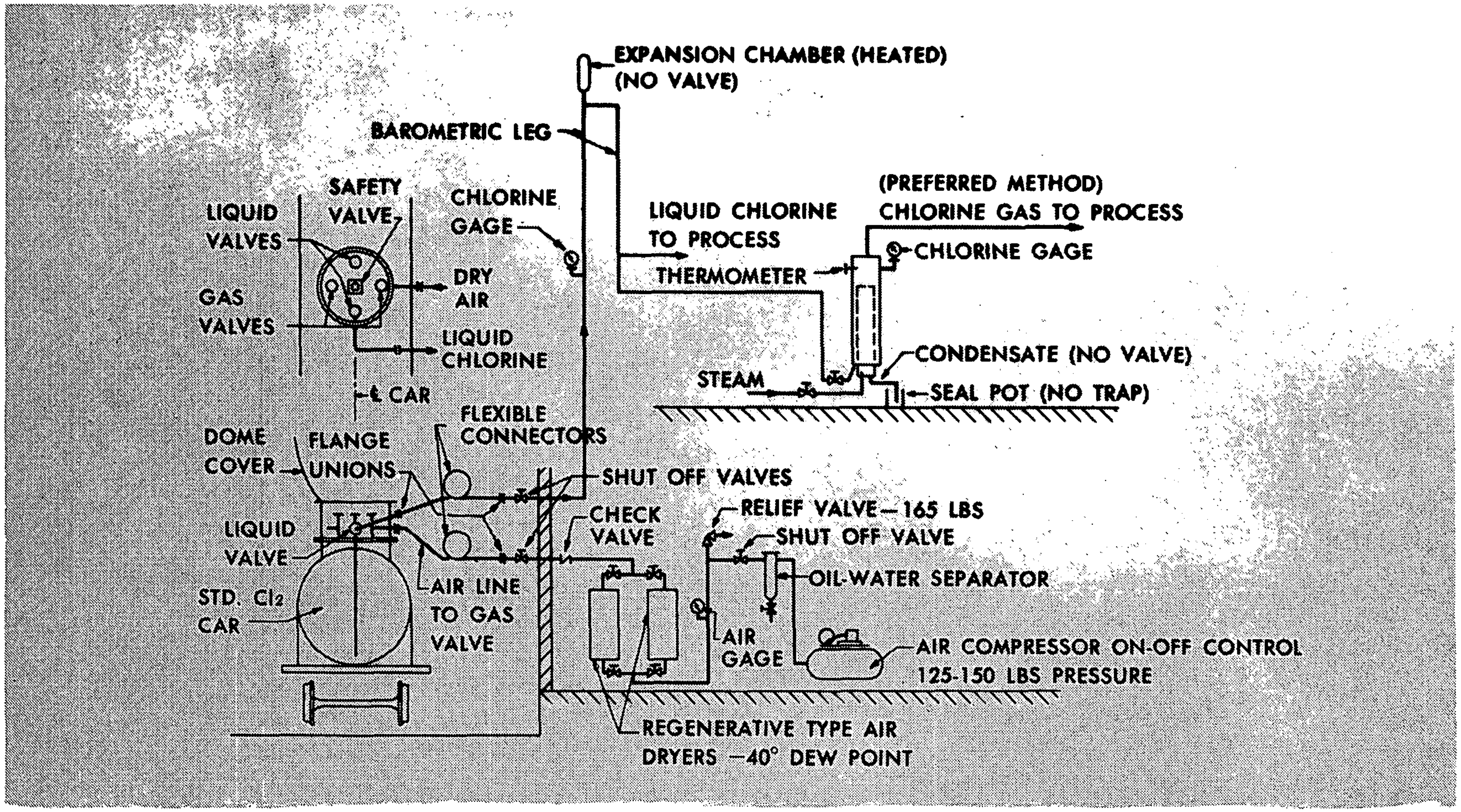


Fig. 10.9 Typical chlorine tank car unloading arrangement

Reproduced with permission (1959, 1966) The Dow Chemical Company

Ton tanks should be placed on trunnions which are equipped with rollers so that the withdrawal valves may be positioned, one above the other. The upper valve will discharge chlorine gas, and the lower valve will discharge liquid chlorine (see Fig. 10.7). Trunnion rollers should not exceed 3-1/2 inches in diameter so that the containers will not rotate too easily and be turned out of position. Roller shafts should be equipped with a zerk type lubrication fitting and slotted for even lubrication. Roller bearings are not advised because of the ease with which they rotate. Locking devices are not required when these rules are observed.

10.402 Chlorine Tank Cars

Chlorine tank cars are of 16-, 30-, 55-, 85-, or 90-ton capacity. All have four-inch cork board insulation protected by a steel jacket. The dome of the standard car contains four angle valves plus a safety valve. The two angle valves located on the axis line of the tank are equipped for discharging liquid chlorine. The two angle valves at right angles to the axis of the tank deliver liquid chlorine (Fig. 10.9).

The following are some procedures for unloading chlorine tank cars.

Unloading of tank cars should be performed by trained personnel in accordance with Interstate Commerce Commission (ICC) regulations.

In most situations chlorine is withdrawn from tank cars as a liquid and then passed through chlorine evaporators. Sometimes dry air is passed into the tank car through one of the gas valves to assist in liquid withdrawal. This practice is referred to as "air padding".

QUESTIONS

10.4A How may chlorine be delivered to a plant?

10.4B What is the purpose of the fusible plug?

10.41 Removing Chlorine From Containers

10.410 Connections

Outlet threads on container valves are not tapered pipe threads. Use fittings and gaskets for connections furnished by your chlorine supplier or chlorinator equipment manufacturer. Do not try to use regular pipe thread fittings. New gaskets should be used for each new connection where required.

Flexible 3/8-inch 2000-pound (psi) annealed copper tubing is recommended for connections between chlorine containers and stationary piping. Care should be taken to prevent sharp bends in the tubing because this will weaken it and eventually the tubing will start leaking. Many operators recommend use of a sling to hold the tubing when disconnecting it from an empty cylinder to prevent the tubing from flopping around and getting kinked or getting dirt inside it.

A shut-off valve is needed after the container valve or at beginning of stationary piping, to simplify changing of containers.

10.411 Valves

Do not use wrenches longer than six inches, pipe wrenches, or wrenches with an extension on container valves. To unseat, strike end of wrench with heel of hand to rotate the valve stem in a counterclockwise direction. Then open slowly.

One complete turn permits maximum discharge. Do not force valve beyond this point.

If valve is too tight to open, loosen the packing gland nut slightly to free the stem.

10.412 Ton Tanks

One-ton tanks (Fig. 10.7) must be placed on their side with the valves in a vertical position. Connect the flexible tubing to the top valve to remove chlorine gas from the tank. The bottom valve is used to remove liquid chlorine and is used only with a chlorine evaporator. The valves are similar to those on the smaller chlorine cylinders (fusible plugs are not located at valves on ton containers) and must be handled with the same care.

10.42 Chlorine Leaks

Chlorine leaks must be taken care of immediately or they will become worse.

Corrective measures should be undertaken only by trained men wearing proper safety equipment. All operators should be trained to safely repair chlorine leaks.

All other persons should leave the danger area until conditions are safe again.

If the leak is large, all persons in the adjacent areas should be warned and evacuated. Obtain police help. You must always consider your neighbors...PEOPLE, animals, and plants.

1. Before any new system is put into service, it should be cleaned, dried, and tested for leaks. Pipelines may be cleaned and dried by flushing and steaming from the high end to allow condensate and foreign materials to drain out. After the empty line is heated thoroughly, dry air may be blown through the line until it is dry. After drying, the system may be tested for tightness with 150 psi dry air. Leaks may be detected by application of soapy water to the outside of joints. Small quantities of chlorine gas may now be introduced into the line, the test pressure built up with air, and the system tested for leaks. Whenever a new system is tested for leaks, at least one chlorinator should be on the line to withdraw chlorine from the system in case of a leak. The same is true in case of an emergency leak at any installation. If a chlorinator is not running, at least one or more should be started. Preferably, all available chlorinators should be put on the line.

2. To find a chlorine leak, tie a rag on a stick, dip the rag[21] in a strong ammonia solution, and swab it over the suspected points. Waving the rag around the room also may help locate the source of a leak. White fumes will indicate the exact location of the leak. Location of leaks by this method may not be possible for large leaks which diffuse the gas over large areas.

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[21] A one-inch paint brush may be used instead of a rag.

3. If the leak is in the equipment in which chlorine is being used, close the valves on the chlorine container at once. Repairs should not be attempted while the equipment is in service. All chlorine piping and equipment that is to be repaired by welding should be flushed with water or steam. Before returning equipment to use, it must be cleaned, dried, and tested as previously described.

4. If the leak is in a chlorine cylinder or container, use the emergency repair kit supplied by most chlorine suppliers. These kits can be used to stop most leaks in a chlorine cylinder or container and can usually be delivered to a plant within a few hours if one is not already at the site of the leak. It is advisable to have emergency repair kits available at your plant at all times and to train personnel in their use. Location of such kits should be posted outside chlorine storage areas.

   If chlorine is escaping as a liquid from a cylinder or a ton tank, turn the container so that the leaking side is on top. In this position, the chlorine will escape only as a gas, and the amount which escapes will be only 1/15 as much as if the liquid chlorine were leaking. Keeping the chlorinators running also will reduce the amount of chlorine gas leaking out of a container. Increase the feed rate to cool the supply tanks as much as possible.

5. For situations where a prolonged or unstoppable leak is encountered, emergency disposal of chlorine should be provided. Chlorine may be absorbed in solutions of caustic soda, soda ash, or agitated hydrated lime slurries (Table 10-2). Chlorine should be passed into the solution through an iron pipe or a properly weighted rubber hose to keep it immersed in the absorption solution. The container should not be immersed because the leaks will be aggravated due to the corrosive effect, and the container may float when partially empty. In some cases it may be advisable to move the container to an isolated area. Discuss the details of such precautions with your chlorine supplier.

6. Never put water on a chlorine leak. A mixture of water and chlorine will increase the rate of corrosion of the container and make the leak larger. Besides, water may warm the chlorine, thus increasing the pressure and forcing the chlorine to escape faster.

TABLE 10-2

CHLORINE ABSORPTION SOLUTIONS*

Absorption Solution		Alkali (lb)	Water (gal)
Caustic Soda (100%)	a	125	40
	b	188	60
	c	2500	800
Soda Ash	a	300	100
	b	450	150
	c	6000	2000
Hydrated Lime**	a	125	125
	b	188	188
	c	2500	2500

Chlorine Container Size (lb net):
a = 100, b = 150, c = 2000

* Source: The Chlorine Institute.

** Hydrated lime solution must be continuously and vigorously agitated while chlorine is to be absorbed.

7. Leaks around valve stems can often be stopped by closing the valve or tightening the packing gland nut. Tighten the nut or stem clockwise.

8. Leaks at the valve discharge outlet can often be stopped by replacing the gasket or adapter connection.

9. Leaks at fusible plugs and cylinder valves usually require special handling and emergency equipment. Call your chlorine supplier immediately and obtain an emergency repair kit for this purpose if you do not have a kit readily available.

10. Pin hole leaks in the walls of cylinder and ton tanks can be stopped by using a clamping pressure saddle with a turnbuckle available in repair kits. This is only a temporary measure, and the container must be emptied as soon as possible.

    If a repair kit is not available, use your ingenuity. One operator stopped a pin hole leak temporarily until a repair kit arrived by placing several folded layers of neoprene packing over a leak, a piece of scrap steel plate over the packing, wrapping a chain around the cylinder and steel plate, and applying leverage pressure with a crowbar.

11. A leaking container must not be shipped. If the container leaks or if the valves do not work properly, keep the container until you receive instructions from your chlorine supplier for returning it. If a chlorine leak develops in transit, keep the vehicle moving until it reaches an open area.

12. Do not accept delivery of containers showing evidence of leaking, stripped threads, or abuse of any kind.

QUESTION

10.4C How would you look for a chlorine leak?

END OF LESSON 3 OF 4 LESSONS

on

DISINFECTION AND CHLORINATION

Please answer the discussion and review questions before continuing with Lesson 4.

DISCUSSION AND REVIEW QUESTIONS

Chapter 10. Disinfection and Chlorination

(Lesson 3 of 4 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 2.

12. What type of breathing apparatus should be worn when entering an area in which chlorine gas is present?

13. Why should clothing be removed from a person who has been in an area contaminated with liquid or gaseous chlorine?

14. How could your police department assist you in the event of a serious chlorine leak?

15. Why should chlorine containers and cylinders be stored where they won't be heated?

16. Why are slings used to hold chlorine tubing when changing chlorine cylinders?

17. Why should water never be poured on a chlorine leak?

18. How would you attempt to repair a pin hole leak in a chlorine cylinder?

CHAPTER 10. DISINFECTION AND CHLORINATION

(Lesson 4 of 4 Lessons)

10.5 CHLORINATION EQUIPMENT AND MAINTENANCE (by J. L. Beals)

10.50 Chlorinators

Chlorine may be delivered from a feeder by one of two methods:

1. Solution feed, commonly practiced, in which the chlorine gas is controlled, metered, introduced into a stream of injector water, and then conducted as a solution to the point of application.

2. Direct feed, sometimes called dry feed, in which the gas is introduced directly through a suitable diffuser at the point of application. This method is used only when a source of injector water at adequate pressure, or power for an injector pump, is not available. Operating difficulties experienced in metering dry chlorine gas directly to the point of application make this type of equipment a "last resort".

Following are the common types of feeders used in wastewater treatment plants.

10.500 Vacuum-Solution Feed Chlorinators

This type of equipment (Fig. 10.10) comprises in excess of 90% of all gas chlorination equipment in service today in water and wastewater treatment operations. The primary advantage of vacuum operation is safety. If a failure or breakage occurs in the vacuum system, the chlorinator either stops the flow of chlorine into the equipment or allows air to enter the vacuum system rather than allowing chlorine to escape into the surrounding atmosphere. In case the chlorine inlet shut-off fails, a vent valve discharges the incoming gas to the outside of the chlorinator building.

The operating vacuum is provided by a hydraulic injector. The injector operating water absorbs the chlorine gas, and the resultant chlorine solution is conveyed to a chlorine diffusor through corrosion resistant conduit.

A vacuum chlorinator also includes a vacuum regulating valve to dampen fluctuations and give smooth operation. A vacuum relief prevents excessive vacuum within the equipment.

A typical vacuum control chlorinator is shown in Fig. 10.10. Chlorine gas flows from a chlorine container to the gas inlet (located above the circled Y in the middle right of the figure). After entering the chlorinator the gas passes through a spring loaded pressure regulating valve which maintains the proper operating pressure. A rotameter is used to indicate the rate of gas flow. The rate is controlled by a V-notch variable orifice. The gas then moves to the injector where it is dissolved in water and leaves the chlorinator as a chlorine solution (HOCl) ready for application.

10.501 Partial Vacuum, Pressure Type, and Pulsating Type Chlorinators

Aside from the pressure type which has been described previously, these types of equipment are limited in application and few remain in service. Pulsating and partial vacuum chlorinators are primarily designed for extremely low feed rates. Vacuum-solution feed equipment can feed less than 0.25 lbs/day. The reduced cost of hypochlorination has almost eliminated their use.

10.51 Hypochlorinators

Hypochlorinators are devices that are used to feed chlorine in the form of calcium, sodium, or lithium hypochlorite. Hypochlorites are available as liquids or various forms of solids (powder, pellets), and in a variety of containers or in bulk.

QUESTION

10.5A How is chlorine delivered (fed) to the point of application?

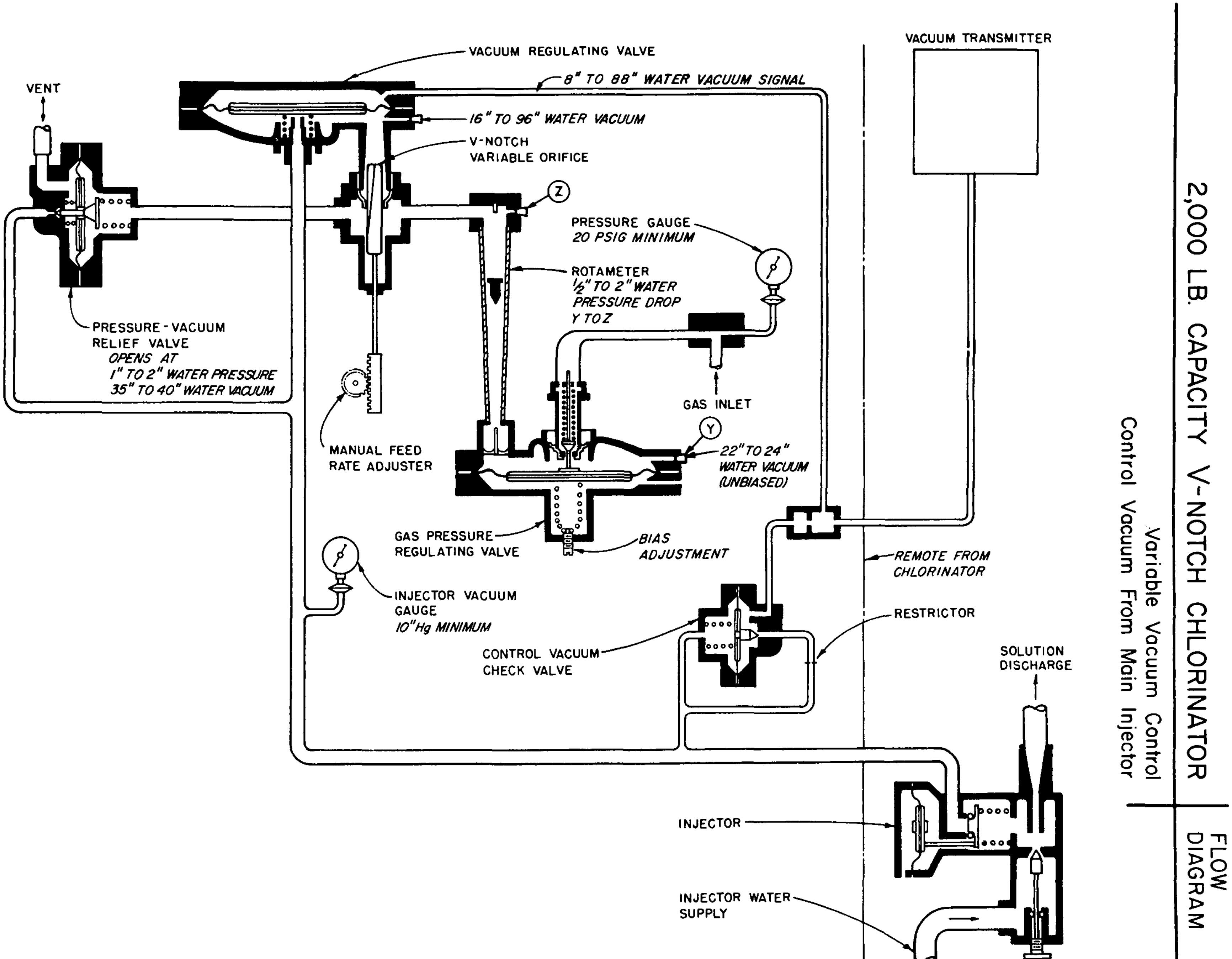

Fig. 10.10 Vacuum solution feed chlorinator

(Courtesy Wallace & Tiernan)

10.52 Installation, Operation, and Maintenance

The following are some features of importance when working with chlorine facilities.

1. Chlorinators should be located near point of application.

2. If possible, there should be a separate room for chlorinators and chlorine container storage (above ground) to prevent chlorine gas leaks from damaging equipment and harming personnel. There should be no access to this room from a room containing equipment or where personnel work.

3. Ample working space around the equipment and storage space for spare parts should be provided.

4. There should be an ample supply of water to operate chlorinator at required capacity under maximum pressure conditions at the chlorinator injector discharge.

5. The building should be adequately heated. The temperature of chlorine cylinder and chlorinator should be above 50°F. Line heaters may be used to keep chlorine piping and chlorinator at higher temperatures to prevent condensing of gas into liquid in the pipelines and chlorinator. The maximum temperature at which a chlorine cylinder is stored should not exceed 110°F.

6. It is not advisable to draw more than 40 pounds of chlorine from any one 100- to 150-pound cylinder in a 24-hour period because of the danger of freezing and slowing up the chlorine flow. With ton containers, the limit of chlorine gas is about 450 pounds per day. When evaporators are provided, these limitations do not apply.

7. There should be adequate light.

8. There should be adequate ventilation. Continuous ventilation is desirable. Forced ventilation must be provided to remove gas if a large leak develops. The outlet of a forced ventilation system must be near the floor because chlorine is 2.5 times heavier than air. Use a pressurized fan (keep room under slight positive pressure). Do not suck air from the room through the fan, because chlorine gas can damage the fan motor. Louvers on vents should swing out and always be open, or open automatically. It should be impossible to lock the louvers shut.

9. Adequate measuring and controlling of chlorine dosage is required. Scales and recorders indicating loss in weight are desirable as a continuous check and as a record of the continuity of chlorination. Record weights daily.

10. There should be continuity of chlorination. When chlorination is practiced for disinfection, it is needed continuously for the protection of downstream water users. Therefore, arrange that chlorination will function for 1440 minutes per day. To secure continuous chlorination, the chlorine gas lines from cylinders should feed to a manifold so that the cylinders can be removed without interrupting feed of gas. Duplicate units or an emergency hypochlorinator should be provided.

11. For additional information on chlorinator maintenance, refer to Chapter 11, Maintenance.

QUESTIONS

10.5B Why should chlorinators be in a separate room?

10.5C Why is room temperature important for proper chlorinator operation?

10.5D Why should not more than 40 pounds of chlorine per day be drawn from any one cylinder?

10.5E Why is adequate ventilation important in a chlorinator room?

10.5F How can chlorinator rooms be ventilated?

10.5G How can chlorination rates be checked against the chlorinator setting?

10.5H Why should chlorination be continuous?

10.5I How can continuous chlorination be achieved?

10.53 Installation Requirements

(Section A from Wallace & Tiernan
Catalog Sheet Nos. 5.110 and 5.111)

10.530 Piping, Valves, and Manifolds

After you have determined (a) the availability of various types of chlorine containers and selected the type most suited to particular needs, (b) the inventory required and the space needed, (c) the method of handling the containers, and (d) the type of weighing scales to be used, the final step in regard to chlorine supply is to plan the required piping.

CONNECTIONS AT CONTAINERS: It is standard practice to connect an auxiliary tank valve (either union or yoke type) to the container valve to facilitate changing containers, to minimize the release of gas when containers are changed, and to serve as a shut-off valve in the event the container valve is defective. From this auxiliary valve a flexible connection is used to connect to the manifold, or, in the case of small installations, directly to the chlorinator.

CONNECTIONS AT CHLORINATOR: In general, small chlorinators are equipped to receive a flexible connection directly from the chlorine container and no other piping is necessary. Larger chlorinators may use a flexible connection from a manifold, if located close to the container, or may employ piping from the manifold to the chlorinator where the distance is greater.

CONNECTIONS AT EVAPORATOR: Where evaporators are used, the piping from the manifold to the evaporator carries liquid chlorine, and the piping from the evaporator to the chlorinator carries chlorine gas. Evaporators normally are furnished with all necessary immediate valves and fittings.

PIPING--MATERIALS AND JOINTS: Best practice calls for the use of extra heavy, black, genuine wrought iron, or seamless carbon steel (Schedule 80) pipe for conducting chlorine gas or liquid and fittings that are forged or cast carbon steel, 300 lb USA flanged. Except in unusual cases, the size will be 3/4" or 1". In most installations, it will be found practical to use threaded joints. These joints should be put together using teflon tape as a joint lubricant. Unions of the flanged, ammonia type, two-bolt oval are recommended. For pipe sizes larger than one inch in diameter, a four-bolt oval should be used. From the standpoint of maintenance, line valves should be kept to a minimum. Insulation is required only in those unusual cases where it is necessary to prevent chlorine gas lines from becoming chilled or liquid lines from becoming overheated.

PIPING--CHLORINE GAS: It is important to observe the correct temperature conditions in conducting chlorine gas from the location of the containers to the point of use. To avoid difficulty with reliquefaction[22] of chlorine, piping and control equipment should be at a higher temperature than that of the chlorine containers. In general, a difference of 5 or 10°F is recommended. It is preferable to run chlorine gas lines overhead through relatively warm areas rather than along the floor or through basement areas where lower temperatures may be encountered.

Where it is not possible to secure suitable temperature conditions, the use of an external chlorine pressure reducing valve near the containers is recommended.

The use of a chlorine pressure reducing valve is also recommended in those localities where severe temperature changes are likely to be encountered during a 24-hour period.

PIPING--LIQUID CHLORINE: In the case of liquid chlorine, it is important to avoid conditions that will encourage vaporization. Thus it is important to keep liquid chlorine lines as cool as, or cooler than, the containers. Avoid running liquid chlorine lines through overheated areas where gasification is likely to take place.

Valves in liquid chlorine lines should be kept to a minimum, and it is particularly important to avoid situations where it is easy to close two valves in a line thus trapping liquid which, upon an increase in temperature, may develop dangerous pressures.

The use of an expansion chamber is recommended where traps occur in the line or where it is necessary to run lines a considerable distance. An expansion chamber is generally a 100-pound or 150-pound empty chlorine cylinder installed in an inverted position directly above the liquid line by means of a tee. As the name implies, the cylinder provides an area of expansion in the event that valves at both ends of the line are closed.

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[22] Reliquefaction (re-LICK-we-FACK-shun). The return of a gas to a liquid. For example, a condensation of chlorine gas returning to liquid form.

VALVES AND MANIFOLDS: Chlorine valves consist of the following: (a) auxiliary tank valves for use at the container, (b) header valves for use on or in conjunction with manifolds, (c) line valves for insertion in liquid and gas lines for shut-off purposes, and (d) pressure reducing valves to reduce the pressure in gas lines where necessary. Manifolds are assemblies to receive the flexible connections from the container, generally provide a shut-off valve, and include the means of connecting to the chlorinator piping. They are available in types and sizes to accommodate any required number of containers and may be mounted in any convenient manner.

10.531 Chlorinator Injector Water Supply

The injector operating water supply serves to produce the vacuum under which vacuum chlorinators function and to dissolve the chlorine and discharge it as a solution at the point of application. The quantity of water required and the minimum pressure at which it is supplied depend upon:

1. maximum chlorinator feed rate, and

2. back pressure at injector discharge (pressure at point of chlorine application, plus friction loss in solution line, and plus or minus elevation differences between injector and point of application).

Water quantity and pressure can vary from one to two gpm at 15 psi (for 10 lbs/day at 0 back pressure) up to 360 gpm at 60 psi (8000 lbs/day at 20 psi back pressure). In some extremely high back pressure situations, injector water may be required up to 300 psi. These conditions do not occur often in wastewater treatment installations, and back pressures exceeding 20 psi (except in force main applications) are uncommon.

Plant effluent is used frequently as injector operating water. When this is the case, a pump is usually required to provide the required quantity and pressure. If a pump is used exclusively for injector operation, it should be designed for 25 to 50% over capacity to allow for wear. Injector water is often supplied from a service water system also providing water for other purposes. If a potable water supply is the only source of injector water, precautions must be taken to insure against direct cross-connections between wastewater and potable water. (Consult your local public health authority.)

Injector water requirements vary so widely depending upon make, model, capacity, back pressure, etc., that it is advisable to consult the chlorinator manufacturer if a new system is to be installed or if an existing system must be altered and any of these operating conditions are to be changed.

QUESTIONS

10.5J What is the best piping material for conducting chlorine gas or liquid?

10.5K Plant ____________ is used frequently as the chlorinator injector water supply.

10.6 OTHER USES OF CHLORINE

10.60 Odor Control

Chlorination of wastewater for odor control is used to inhibit the growth of odor-producing bacteria and to destroy hydrogen sulfide (H_2S), the most common odor nuisance, which has the smell of rotten eggs. Hydrogen sulfide, in addition to creating an odor nuisance, can be an explosion hazard when mixed with air in certain concentrations. Breathing H_2S can impair your ability to smell, and too much will paralyze your respiratory center, causing death in severe cases. It also can cause corrosion of metals and concrete, being particularly damaging to electrical equipment even in low concentrations.

The presence of hydrogen sulfide may be detected in significant quantities in any collection and treatment system where sufficient time is allowed for its development. It may be expected to be present most often in new systems where flows are extremely low in comparison with design capacity, and particularly in lift stations where pump operating cycles may be at a low frequency. Collection systems which serve large areas often allow time for H_2S development even when operating at design capacity.

The purpose of this section is not to discuss the reasons for odor production, but rather their elimination or control by chlorination; however, the correction of an odor problem will usually require a decision being made between system modification and treatment. Sometimes both may be required. Choices of this type often hinge on the costs involved, and it will frequently be found that modifications to major system components are far more costly than treatment. When this is the case, chlorination is usually the most economical solution. Other solutions include the use of air or ozone.

Sulfides develop whenever given time to do so. The rate of sulfide production increases with temperature (about 7% on the average with each 1°C increase in wastewater temperature).

The odors which are controllable with chlorine are specifically hydrogen sulfide which can be inactivated by chlorination at levels well below the chlorine demand point. This is commonly referred to as "sub-residual chlorination". The reason that this is true is based on the fact that the $Cl_2 + H_2S$ reaction precedes most other chlorine-consuming reactions. Since it is known that bacterial kills occur at sub-residual levels, it is logical that odor-producing bacteria can be reduced in numbers without satisfying the chlorine demand. This can be accomplished without significantly interfering with organisms beneficial to the treatment processes.

The quantities of chlorine required to accomplish control of odors vary widely from plant to plant and at any given plant fluctuate over a broad range. Hydrogen sulfide is generally found in higher concentrations when flows are low. For this reason it is usually not economical to chlorinate for odor control in direct proportion to flow. Tests should be run over periods which include all the various conditions which could possibly affect odor production in order that a basis for treatment may be established.

When the requirements are known, the primary concern is to apply chlorine at the proper location. The best locations are generally up-sewer ahead of the plant influent structures, and up-sewer ahead of lift stations. This is done to allow mixing and reaction time before the waste reaches a point of agitation.

Sometimes force mains empty into the gravity sections of a collection system several hours after pumping. If odor problems result, a treatment point should be placed upstream at a point where the sewer is still under pressure and flowing full; thus treatment can be completed before odors are released to the atmosphere.

Hydrogen sulfide should not be considered merely an odor nuisance. It must always be kept in mind that it can create an explosion hazard, it can paralyze your respiratory center, and it should always be considered a source of corrosion. For these reasons, odor masking agents should not be used except possibly as additional treatment for odors not eliminated by chlorination. Excessive use of masking agents could prevent detection of a serious problem condition.

10.61 Protection of Structures

The destruction of hydrogen sulfide in wastewater also reduces the production of sulfuric acid that is highly corrosive to sewer systems and structures. This is particularly significant where temperatures are high and time of travel in the sewer system is unusually long. The treatment is similar to that for odor control: chlorination sufficient to prevent hydrogen sulfide formation or to destroy hydrogen sulfide that has been produced (about 2 mg/l chlorine per mg/l of hydrogen sulfide). Sulfide problems also may be corrected by oxygenation in sewers. The choice between oxygenation and chlorination will usually depend on the costs involved.

10.62 Aid to Treatment

Among its many uses, chlorine improves treatment efficiency in the following ways.

10.620 Sedimentation

Prechlorination at the influent of a settling tank improves clarification by improving settling rate, reducing septicity[23] of raw wastewater, and increasing grease removal. Maximum grease removal is achieved when chlorination is combined with aeration ("aero-chlorination"). It is an expensive procedure, and some studies have indicated that benefits are minimal. Generally grease removal in this manner is considered a beneficial side effect or "bonus" reaction to chlorine which is essentially applied for other reasons. Excess chlorination ahead of secondary processes can inhibit the bacterial action critical to the process and decrease sedimentation efficiency.

10.621 Trickling Filters

Continuous chlorination at the filter influent controls slime growths and destroys filter fly larvae (Psychoda). Generally the chlorine is applied to produce a residual of 0.5 mg/l (continuous) at the orifices or nozzles. Caution should be used because some filter growth may be severely damaged by excessive chlorination. Suspended solids will increase in a trickling filter effluent after chlorination for filter fly control. Also, it will be difficult to evaluate filter performance on the basis of BOD removals because chlorine can interfere with the BOD test. As a general statement, it would be well to look closely at

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[23] Septicity (sep-TIS-it-tee) is the condition in which organic matter decomposes to form foul-smelling products associated with the absence of free oxygen.

loadings, operation, and general adequacy of the process when filter fly chlorination is continuously necessary, because continuous chlorination may be an expensive alternative for adequate design and operation.

10.622 Activated Sludge

Chlorination of return sludge reduces bulking of activated sludge that is caused by overloading. The point of application should be where the return sludge will be in contact with the chlorine solution for about one minute before the sludge is mixed with the incoming settled wastewater. Chlorine is also commonly used to control filamentous organisms. Again, chlorine used in this manner is an expensive alternative for adequate design and operation. The main effort should be directed toward process improvement, considering chlorination mainly as an emergency solution. Never forget that chlorine is toxic to organisms that are needed to treat the incoming wastes.

10.623 Reduction of BOD

Chlorination of raw wastewater to produce residual of 0.5 mg/l after 15 minutes of contact may cause a reduction of 15 to 30% in the BOD of the wastewater (Baity, 1929). Generally a reduction of at least 2 mg/l of BOD is obtained for each mg/l of chlorine absorbed up to the point at which the residual is produced. Snow (1952) has shown that the BOD reduction also depends on the condition of the wastewater. He reported a 10% reduction in fresh wastewater and a 25 to 40% reduction in stale wastewater. Both real and apparent effects of chlorination are evident in the wastewater and in the test bottle.

QUESTIONS

10.6A How can odors be controlled? Why?

10.6B How can sulfuric acid damage to structures be minimized or eliminated? Why?

10.7 ACKNOWLEDGMENTS

Portions of the information contained in this chapter were taken in part from Chapter 17, Disinfection and Chlorination, Water Pollution Control Federation Manual of Practice No. 11; and from Chapter 7, Chlorination of Sewage, Manual of Instruction for Sewage Treatment Plant Operators (New York Manual). Both publications are excellent references for additional study. Mr. J. L. Beals provided many helpful comments.

10.8 REFERENCES

Baity, H.G., "Reduction of BOD in Sewage by Chlorination", Sewage Works J., 1, 279 (1929).

California State Department of Public Health, "Laws and Regulations Relating to Ocean Water-Contact Sports Areas" (1958).

California State Department of Public Health, "Statewide Standards for the Safe Direct Use of Reclaimed Waste Water for Irrigation and Recreational Impoundments" (1968).

California State Department of Public Health, "Laws and Regulations Relating to Swimming Pools" (1966).

California State Department of Public Health, "Some Experience with Disinfection of Waste Water in California", G.E. Browning and F.R. McLaren (1966).

Chlorine Institute, "Chlorine Manual" (1969).

Dow Chemical, "Dow Chlorine Handbook" (1966).

New York State Department of Health, "Manual of Instruction for Sewage Plant Operators" (1966).

PPG Industries, Inc., Chemical Division, "Chlorine Safe Handling Pamphlet".

Snow, W.B., "Biochemical Oxygen Demand of Chlorinated Sewage", Sewage and Industrial Wastes, 24, 689 (1952).

U.S. Bureau of Mines, Technical Paper 248 (1955).

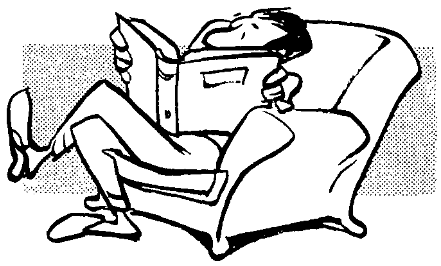
U.S. Public Health Service, "Drinking Water Standards" (1962).

Water Pollution Control Federation, Manual of Practice No. 1, "Safety in Waste Water Works".

Water Pollution Control Federation, Manual of Practice No. 4, "Chlorination of Sewage and Industrial Wastes" (under revision).

Water Pollution Control Federation, Manual of Practice No. 11, "Operation of Waste Water Treatment Plants" (1968).

10.9 ADDITIONAL READING



a. MOP 11, pages 127-135.

b. New York Manual, pages 73-83.

c. Texas Manual, pages 397-412.

d. "Chlorine--Safe Handling", PPG Industries, Inc., Chemical Division, One Gateway Center, Pittsburgh, Pennsylvania 15222.

e. Chlorination Guide, Water and Sewage Works Magazine, Scranton Publishing Company, 355 East Wacker Drive, Chicago, Illinois 60601. Price, $1.25.

f. Chlorine Manual (4th edition), The Chlorine Institute, Inc., 342 Madison Avenue, New York, New York 10017. Price $0.75.

g. Safety in Waste Water Works, MOP No. 1, Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016. Price to WPCF members, $0.75; others, $1.50.

Films on chlorine safety also are available from the Chlorine Institute and PPG Industries, Inc.

END OF LESSON 4 OF 4 LESSONS

on

DISINFECTION AND CHLORINATION

Please answer the discussion **and review** questions before continuing.

DISCUSSION AND REVIEW QUESTIONS

Chapter 10. Disinfection and Chlorination

(Lesson 4 of 4 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 3.

19. How is the rate of chlorine gas flow in a chlorinator controlled?

20. How often should the weights of chlorine cylinders be recorded?

21. Why must chlorination be continuous?

22. Why should the temperature of chlorine piping and control equipment be higher than the temperature of the chlorine containers?

23. Why must direct cross-connections be avoided between a public water supply and the injector water supply?

24. What is "sub-residual chlorination"?

25. Why should sulfides be controlled?

SUGGESTED ANSWERS

Chapter 10. Disinfection and Chlorination

10.0A The purpose of disinfection is to destroy pathogenic organisms. This is important to prevent the spread of water-borne diseases.

10.0B Pathogenic bacteria are destroyed or removed from water by (1) physical removal through sedimentation or filtration, (2) natural die-away in an unfavorable environment by storage and (3) destruction through chemical treatment.

10.0C Chlorine is used for disinfection because it meets the general requirements of disinfection so well, and because it has been found to be the most economically useful and available chemical for disinfection.

10.0D Sterilization of wastes is impractical and unnecessary and may be detrimental to other treatment processes that are dependent on the activity of non-pathogenic saprophytes.

10.0E Chlorine reacts with reduced substances in wastewater, organic matter to form chlororganic compounds, and nitrogenous compounds to form chloramines.

10.0F To produce an effective disinfecting action, sufficient chlorine must be added after the chlorine demand is satisfied to produce a chlorine residual likely to persist through the contact period.

10.0G Chlorine Demand = Chlorine Dose - Chlorine Residual

10.0H Chlorine Dose = Chlorine Demand + Chlorine Residual

10.0I
$$\text{Chlorine Dose} = \frac{70\ \text{lb/day}}{(1.2\ \text{MG/day})\ (8.34\ \text{lb/G})} = 7.0\ \frac{\text{lb}}{\text{M lb}}$$
$$= 7.0\ \text{mg/l}$$

$$\text{Chlorine Demand} = \text{Chlorine Dose} - \text{Chlorine Residual}$$
$$= 7.0\ \text{mg/l} - 0.4\ \text{mg/l}$$
$$= 6.6\ \text{mg/l}$$

10.0J Non-pathogenic intestinal bacteria designated as the coliform group are more resistant to chlorination than bacteria causing enteric diseases.

10.0K MPN is a probable measure based on a sample from a large population. Small samples from large amounts of material may not be representative from a non-uniform substance such as wastewater. Variability in environmental factors also affects the MPN.

10.0L Generally, MPN coliform densities decrease with increased chlorine residuals in laboratory and plant studies; but variability in individual plants, mixing, character of wastes, detention time, and other environmental factors make it difficult to apply a correlation determined from one plant to other plants.

10.0M The ultimate measure of effectiveness is the bacteriological result. The residual chlorine that yields satisfactory bacteriological results in a particular plant must be determined and used as a control in that plant.

10.1A The purpose of up-sewer chlorination is to control odors and septicity, prevent deterioration of structures, and decrease BOD load.

10.1B Chlorine should be applied in sewers where odor and H_2S control is necessary. These locations may be at several points in the main interceptor sewer or at the upper ends of feeder lines.

10.1C Prechlorination provides partial disinfection and odor control.

10.1D Plant chlorination provides control of odors, corrosion, sludge bulking, digester foaming, filter ponding, filter flies, or sludge thickening, but may interfere with biological treatment processes.

10.1E Postchlorination is employed primarily for disinfection.

10.2A Chlorine gas feed can be controlled by manual, start-stop, step-rate, timed program, flow proportional, chlorine residual, and compound loop controls.

10.2B Control of chlorine dosage depends on the bacterial <u>reduction</u> desired.

10.2C Amperometric is a method of measurement that records electric current flowing or generated, rather than recording voltage. Amperometric titration is an electrometric means of measuring concentrations of substances in water.

10.2D Feed in pounds per day can be calculated from the chlorine requirement and the rate of flow by the use of chlorination control nomogram.

10.2E (1) 4.2 lbs per 24 hrs
(2) 270 lbs per 24 hrs
(3) 1250 lbs per 24 hrs

10.2F Large plants: at least every hour
Medium-sized plants: every 2 to 4 hours
Small plants: every 8 hours

In small plants chlorine costs are relatively low in comparison to labor costs necessary for frequent adjustment.

10.2G Find chlorine dosage in pounds per day.

$$\text{Chlorine Dosage, lbs/day} = \text{Chlorine Dose, mg/l} \times \text{Flow, MGD} \times 8.34 \text{ lbs/gal}$$

$$= 12 \text{ mg/l} \times 0.55 \text{ MGD} \times 8.34 \text{ lbs/gal}$$

$$= 55 \text{ lbs/day}$$

$$\text{HTH Feed Rate, lbs/day} = \frac{\text{Chlorine Required, lbs/day}}{\text{Portion of Chlorine in pound of HTH}}$$

$$= \frac{55 \text{ lbs/day}}{0.67}$$

$$= 82 \text{ lbs/day}$$

10.2H Little mixing of chlorine solution with wastewater occurs in chlorine contact basins because of the low flow velocities in a basin.

10.2I Polyvinyl chloride (PVC) or black polyethylene flexible tubing. Rubber lined steel pipe has been used, but rubber hose is rarely used today.

10.3A Chlorine gas is extremely toxic and corrosive in moist atmospheres.

10.3B Self-contained air or oxygen supply type of breathing apparatus is recommended when repairing a chlorine leak.

10.3C First aid measures depend on the severity of the contact. Remove the victim from the gas area and keep him warm and quiet. Call a doctor and fire department immediately. Keep the patient breathing.

10.4A Chlorine may be delivered to a plant in 100- or 150-pound cylinders, ton containers, or tank cars.

10.4B Fusible plugs are provided as a safety device to prevent the building up of excessive pressures and the possibility of rupture due to a fire or high surrounding temperatures.

10.4C To look for a chlorine leak, wear a self-contained breathing apparatus to enter the area if the leak is severe. A rag or paint brush dipped in a strong solution of ammonia water and moved around the area will locate the leak if the room is not full of chlorine gas.

10.5A Chlorine is normally delivered (fed) to the point of application as a solution feed (under vacuum); however, in some cases it is fed as a direct feed (under pressure).

10.5B Chlorinators should be in a separate room because chlorine gas leaks can damage equipment and are hazardous to personnel.

10.5C Room temperature is important for proper chlorinator operation to prevent clogging, chlorine ice formation, and condensation in lines and chlorinator.

10.5D Not more than 40 pounds of chlorine per day should be drawn from a chlorine cylinder because of the danger of freezing and slowing up of chlorine flow.

10.5E Adequate ventilation is important in a chlorinator room to remove any leaking chlorine gas.

10.5F Chlorinator rooms can be ventilated using forced ventilation with the outlet near the floor because chlorine is heavier than air.

10.5G Chlorination rates can be checked by the use of scales and loss in weight recorders.

10.5H Disinfection must be continuous for the protection of downstream water users.

10.5I Continuous chlorination can be achieved by the use of a cylinder feed manifold so cylinders can be removed without interrupting feed of gas and provide duplicate units or emergency hypochlorinators.

10.5J The best material for conducting chlorine gas or liquid is extra heavy, black, genuine wrought iron pipe.

10.5K Plant effluent is used frequently as the chlorinator injector water supply.

10.6A Odors can be controlled by chlorination by the reaction with sulfides and the delay of decomposition and stabilization. Sulfides should be controlled because they smell like rotten eggs, are a source of corrosion, can paralyze your respiratory tract, and can form explosive mixtures with air.

10.6B Sulfuric acid damage to structures can be minimized by chlorination or oxygenation which destroys hydrogen sulfide. Hydrogen sulfide produces sulfuric acid which damages sewer systems and structures.

OBJECTIVE TEST

Chapter 10. Disinfection and Chlorination

Name ______________________________ Date ______________

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to each question.

1. Disease producing bacteria are called:

    1. Saprophytes
    2. Facultative
    3. Parasitic
    4. Pathogenic
    5. Coliform

2. Reduction in the number of pathogenic organisms in wastewater may be accomplished by:

    1. Sedimentation
    2. Prechlorination
    3. Postchlorination
    4. Providing chlorine contact time
    5. Adding orthotolidine

3. Chlorine may be applied for H_2S control in the:

    1. Collection lines
    2. Plant headworks
    3. Trickling filter
    4. Aeration tank
    5. Plant effluent

4. An operator should never enter a room containing high concentrations of chlorine gas without:

    1. Help standing by
    2. Notifying proper authorities
    3. A self-contained air or oxygen supply

5. You should never tamper with or apply heat to the fusible plug of a chlorine container.

    1. True
    2. False

6. Chlorine cylinders:

   1. Can easily be lifted by one man
   2. Can be handled safely
   3. Contain a fusible metal safety plug
   4. Should be rolled horizontally
   5. Should be stored at temperatures above 50°F and kept away from steam pipes

7. What should be the approximate chlorine feed rate for a flow of 1.5 MGD and a chlorine dosage of 15 mg/1?

   1. 200 lbs/24 hr
   2. 100 lbs/24 hr
   3. 20 lbs/24 hr
   4. 10 lbs/24 hr
   5. 2 lbs/24 hr

8. Chlorine should be applied continuously to:

   1. Keep the plant equipment from breaking down
   2. Keep the plant effluent disinfected
   3. Keep the chlorine pipes from developing leaks
   4. Keep the chlorine supplier in business
   5. Protect the downstream water users

9. Field chlorination studies have shown that:

   1. Constant vigilance is required to maintain a consistently high degree of disinfection at most wastewater treatment plants.
   2. Thorough mixing of chlorine solution with wastewater is essential to achieve maximum efficiency of coliform kill for a given chlorine dosage.
   3. Chlorine feed rates required to produce a desired disinfection level are constant from day to day.
   4. Actual contact time in most chlorine chambers is the same as the theoretical contact time.
   5. Chlorine residuals can be increased without limit and the coliform densities will always continue to be reduced with each increase in residual.

10. Chlorinators should be located:

    1. Near point of application
    2. Outdoors
    3. In a separate room
    4. In a room that will not allow chlorine to leak into rooms where operators work or where controls and equipment are located.
    5. In an adequately heated room

11. Postchlorination is generally more effective in a well-clarified effluent than in a turbid one.

    1. True
    2. False

12. Teflon tape makes a good:

    1. Joint lubricant
    2. Leak stopper

13. Hydrogen sulfide is found in most collection systems.

    1. True
    2. False

14. To protect the health of downstream water users, treatment plant effluents must be:

    1. Sterilized
    2. Disinfected

15. Hydrogen sulfide:

    1. Is associated with corrosion
    2. Causes odors
    3. Smells like chlorine
    4. Can paralyze your respiratory system
    5. Can form an explosive mixture with air

<u>Review Questions:</u>

A rectangular sedimentation tank 10 feet deep, 30 feet wide, and 120 feet long handles a flow of 3 MGD.

16. The detention time is:

    1. 1.5 hr
    2. 2.0 hr
    3. 2.15 hr
    4. 2.25 hr
    5. 2.5 hr

17. The surface loading rate is approximately:

    1. 500 gpd/sq ft
    2. 600 gpd/sq ft
    3. 700 gpd/sq ft
    4. 800 gpd/sq ft
    5. 900 gpd/sq ft

Please write on your IBM answer sheet the total time required to work Chapter 10.

CHAPTER 11

MAINTENANCE

GENERAL PROGRAM

by

Norman Farnum

MECHANICAL MAINTENANCE

by

Stan Walton

FLOW MEASUREMENT

by

Roger Peterson

UNPLUGGING PIPES, PUMPS AND VALVES

by

John Brady

TABLE OF CONTENTS

Chapter 11. Maintenance

The format of this section differs slightly from the others. It was designed specifically to assist you in planning an effective preventive maintenance program. The contents are at the beginning of the section, and the paragraphs are numbered for easy reference on equipment service record cards.

Page

PRE-TEST

Chapter 11. Maintenance

Name ____ Date __________

The objective of the Pre-Test is to indicate to you what items are important in this lesson. Please work this Pre-Test before reading the chapter. You are not expected to know many of the answers, if any at all.

Write your name, date, and mark your answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one answer to each question.

1. The duties of a wastewater treatment plant operator may include:

    1. Regulation of plant treatment processes
    2. Public relations
    3. Maintaining equipment and buildings
    4. Painting and cleaning plant buildings
    5. Keeping maintenance records

2. Equipment service cards and service record cards should:

    1. Identify the piece of equipment that the record card represents
    2. Record sick leave
    3. Maintain selective service records
    4. Indicate the work to be done
    5. Indicate the work done

3. What happens if you do not periodically drain and inspect plant tanks and channels?

    1. Serious maintenance problems could develop
    2. Costly repairs could result
    3. The operator will not know if cracks are developing in underground tanks and channels
    4. An emergency situation may develop and force you to discharge partially or improperly treated wastes into receiving waters during critical conditions.
    5. The operator will stay out of trouble

4. How can a chlorine leak be detected?

    1. By an explosiometer
    2. Smell
    3. Green or reddish deposits on metal
    4. By waving an ammonia soaked rag
    5. By checking the leak gage

5. A reciprocating pump:

   1. Has a rotating impeller
   2. Has a piston that moves back and forth
   3. Has two check valves
   4. Is used to pump sludge
   5. Makes a regular "thunk-thunk" sound when working properly

6. Before starting, a pump should:

   1. Have its shaft turned by hand to see that it rotates freely
   2. Run in the shipping crate so it can be returned if it doesn't work
   3. Be properly lubricated
   4. Be allowed to sit outside and become accustomed to adverse conditions
   5. Be checked to ensure that the shafts of the pump and motor are aligned

7. Float and electrode switches should be checked at least once a week to see that:

   1. Floatable solids are floating
   2. Controls respond to changing water levels in the wet well as expected
   3. Pump motor starts and stops at the proper time
   4. The switches change the direction of flow
   5. None of these

8. Level control systems in a wet well include:

   1. Electrodes
   2. Hearts
   3. Floats
   4. Diaphragms
   5. Bubblers

9. If a pump will not start, check for:

   1. Tripped circuit breakers
   2. Loose terminal connections
   3. Water in the wet well
   4. Nuts, bolts, scrap iron, wood, or plastic in the wrong places
   5. Shaft binding or sticking

10. Preventive maintenance of electric motors includes:

   1. Frequently starting and stopping the motor to give it a rest
   2. Lubricating bearings
   3. Checking temperature of motor
   4. Keeping motor free from dust, dirt, and moisture
   5. Keeping motor outdoors where it can stay cool

11. Maintenance of couplings between the driving and driven elements includes:

    1. Keeping proper alignment
    2. Keeping proper alignment even with flexible couplings
    3. Draining old oil in fast couplings
    4. Keeping the electrodes free of scum and corrosion
    5. Regular use of a crowbar to line them up

12. Pump maintenance includes:

    1. Preventing all water seal leaks around packing glands
    2. Operating two or more pumps of the same size alternately to equalize wear
    3. Checking operating temperature of bearings
    4. Checking packing gland
    5. Lubricating the impeller

13. Approximately how far down should the level in a wet well be lowered in one minute by a pump with a rated capacity of 200 gpm? The wet well is five feet wide and five feet long.

    1. 0.1 ft
    2. 0.5 ft
    3. 1.0 ft
    4. 1.1 ft
    5. 2.0 ft

14. Maintenance of gate valves includes:

    1. Lubricating with Prussian blue
    2. Tightening or replacing the stem stuffing box packing
    3. Operating inactive valves to prevent sticking
    4. Lubricating bearing
    5. Refacing leaky valve seats

15. Flow records provide:

    1. Data to control plant processes
    2. Nice listening music
    3. Information for regulatory agencies
    4. Something to keep the operator working
    5. For plant input and output determination

16. If a flow meter appears to be operating improperly, the operator should:

    1. Shake it
    2. Check connections
    3. Look for foreign objects in the system
    4. Check need for lubrication
    5. Hammer on it

17. If a flow meter does not read properly, what items should be checked as potential causes of error?

    1. Installation of sensor and readout devices
    2. Restrictions in the sensor and transmitter
    3. Power supply to instruments
    4. Check instruments according to manufacturer's instructions
    5. Blow the transmission lines out with high pressure air

18. Reciprocating pumps should be operated when:

    1. Suction and discharge line valves are closed
    2. Suction line valve open and discharge line valve closed
    3. Suction line valve closed and discharge line valve open
    4. Suction and discharge line valves are open

19. Modern gate valves can be repacked without removing them for service.

    1. True
    2. False

20. Old gaskets should be salvaged.

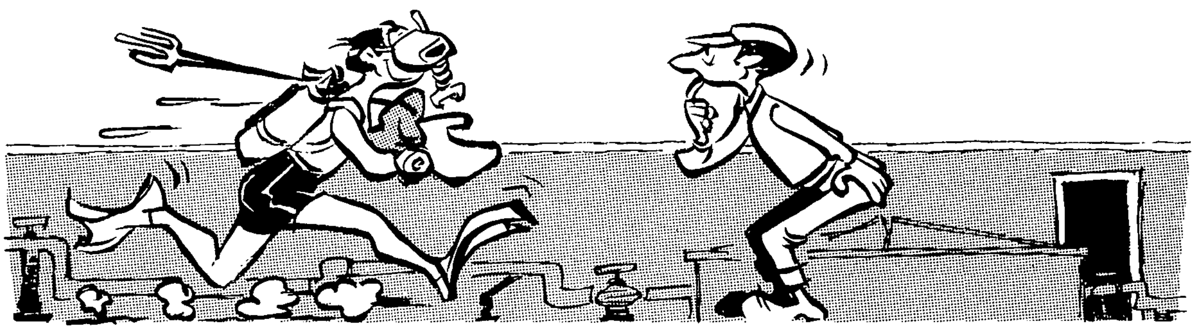
    1. True
    2. False

CHAPTER 11. MAINTENANCE

(Lesson 1 of 6 Lessons)

11.0 TREATMENT PLANT MAINTENANCE--GENERAL PROGRAM

A treatment plant operator has many duties. Most of them have to do with the efficient operation of his plant. It is his responsibility to discharge an effluent that will meet all the requirements established for his plant. By doing this, he will develop a good working relationship with the regulatory agencies, water sportsmen, water users, and plant neighbors.



Another duty an operator has is that of a plant maintenance man. A good maintenance program is a must in order to maintain successful operation of the plant. A good maintenance program will cover everything from mechanical equipment to the care of the plant grounds, buildings, and structures.

Mechanical maintenance is of prime importance as the equipment must be kept in good operating condition in order for the plant to maintain peak performance. Manufacturers provide information on the mechanical maintenance of their equipment. You should thoroughly read their literature on your plant equipment and understand the procedures. Contact the manufacturer or his local representative if you have any questions. Follow the instructions very carefully when performing maintenance on equipment. You also must recognize tasks that may be beyond your capabilities or repair facilities, and you should request assistance when needed.

For a successful maintenance program, your supervisors must understand the need for and benefits from equipment that operates continuously as intended. Disabled or improperly working equipment is a threat to the quality of the plant effluent, and repair costs for poorly maintained equipment usually exceed the cost of maintenance.

11.00 Preventive Maintenance Records

Preventive programs help operating personnel keep equipment in satisfactory operating condition and aid in detecting and correcting malfunctions before they develop into major problems.

A frequent occurrence in a preventive maintenance program is the failure of the operator to record the work he is doing. When this happens the operator must rely on his memory to know when to perform each preventive maintenance function. As days pass into weeks and months, the preventive maintenance program is lost in the turmoil of everyday operation.

The only way an operator can keep track of his preventive maintenance program is by good record keeping. Whatever record system he chooses to use, it should be kept up to date on a daily basis and not left to memory for some other time. Equipment service record cards (Fig. 11.1) are easy to set up and require little time to keep up to date.

An equipment service card (master card) should be filled out for each piece of equipment in the plant. Each card should have the equipment name on it, such as Sludge Pump No. 1, Primary Clarifier, etc.

1. List each required maintenance service with an item number.

2. List maintenance services in order of frequency of performance. For instance, show daily service as items 1, 2, and 3 on the card; weekly items as 4 and 5; monthly items as 6, 7, 8, and 9; and so on.

3. Describe each type of service under work to be done.

Make sure all necessary inspections and services are shown. For reference data, list paragraph or section numbers as shown in the mechanical maintenance section of this lesson (Section 11.1). Also list frequency of service as shown in the time schedule columns of the same section. Under time, enter day or month service is due. Service card information may be changed to fit the needs of your plant or particular equipment as recommended by the equipment manufacturer. Be sure the information on the cards is complete and correct.

The service record card should have the date and work done, listed by item number and signed by the operator who performed the service. Some operators prefer to keep both cards clipped together, while others place the service record card near the equipment.

EQUIPMENT SERVICE CARD				
EQUIPMENT: #1 Raw Wastewater Lift Pump				
Item No.	Work to be Done	Reference	Frequency	Time
1	Check water seal and packing gland	Par. 12	Daily	
2	Operate pump alternately	Par. 12	Weekly	Monday
3	Inspect pump assembly	Par. 12	Weekly	Wed.
4	Inspect and lube bearings	Par. 12	Quarterly	1-4-7-10*
5	Check operating temperature of bearings	Par. 12	Quarterly	1-4-7-10
6	Check alignment of pump and motor	Par. 12	Semi-Ann.	4 & 10
7	Inspect and service pumps	Par. 12	Semi-Ann.	4 & 10
8	Drain pump before shutdown	Par. 12		

* 1-4-7-10 represent the months of the year when the equipment should be serviced--1. January, 4. April, 7. July, and 10. October.

SERVICE RECORD CARD					
EQUIPMENT: #1 Raw Wastewater Lift Pump					
Date	Work Done (Item No.)	Signed	Date	Work Done (Item No.)	Signed
1-5-70	1 & 2	J.B.			
1-6-70	1	J.B.			
1-7-70	1-3-4-5	R.W.			

Fig. 11.1 Equipment service card and service record card

When the service record is filled, it should be filed for future reference and a new card attached to the master card. The equipment service card tells what should be done and when, while the service record card is a record of what you did and when you did it.

QUESTIONS

11.0A Why should you plan a good maintenance program for your treatment plant?

11.0B What general items would you include in your maintenance program?

11.0C Why should your maintenance program be accompanied by a good record keeping system?

11.0D What is the difference between an equipment service card and a service record card?

11.01 Building Maintenance

Building maintenance is another program that should be maintained on a regular schedule. Buildings in a treatment plant are usually built of sturdy materials to last for many years. It is important that they be kept in good repair. In selecting paint for a treatment plant, it is always a good idea to have a painting expert help the operator select the types of paint needed to protect the buildings from deterioration. He also will have some good ideas as to color schemes to help blend the plant in with the surrounding area. Consideration should also be given to the quality of paint. A good quality, more expensive material will usually give better service over a longer period of time than the economy type products.

Building maintenance programs depend on the age, type, and use of a building. New buildings require a thorough check to be certain essential items are available and working properly, while older buildings require careful watching and prompt attention to keep ahead of leaks, breakdowns, replacements when needed, and changing uses of the building. Attention must be given to the maintenance requirements of many items in all plant buildings, such as electrical systems, plumbing, heating, cooling, ventilating, floors, windows, roofs, and drainage around the buildings. Regularly scheduled examinations and necessary maintenance of these items can prevent many costly and time-consuming problems in the future.

In each plant building, periodically check all stairways, ladders, catwalks, and platforms for adequate lighting, head clearance, and sturdy and convenient guardrails. Protective devices should be around all moving equipment. Whenever any repairs, alterations, or additions are built, avoid building man traps such as pipes laid on top of floors or hung from the ceiling at head height which could create serious safety hazards.

Organized storage areas should be provided and maintained in an accessible and neat manner.

Keep all buildings clean and orderly. Janitorial work should be on a regular schedule. All tools and plant equipment should be kept clean and in their proper place. Floors, walls, windows, etc., should be cleaned at regular intervals in order to maintain a neat appearance. A treatment plant kept in a clean, orderly condition makes a safe place to work and aids in building good public and employer relations.

11.02 Plant Tanks and Channels

Plant tanks and channels such as clarifiers, channels, grit chambers, and wet wells should be drained at least once a year and inspected. Be sure the groundwater level is down far enough so the tanks will not float on the groundwater or rupture when empty.

Schedule inspections of tanks and channels during periods of low inflow. Route flows through alternate units, if available; otherwise provide the best possible treatment with remaining units not being inspected or repaired.

All metal and concrete surfaces that come in contact with wastewater or fumes should have a good protective coating. The coating should be reapplied where necessary at each inspection.

Digesters should also be drained and cleaned on a regular basis. Once every five years (actual times range from three to eight years) has been accepted as an approximate interval for this operation. Most digesters have a sludge inlet box on one side and a supernatant box on the opposite side. A sludge sampler can be lowered in the pipes in both of these boxes for a check for sand and grit build-up. To determine the amount of grit build-up, you must know the side wall depth of the digester. If the sludge sampler will only drop to within four feet of the bottom, you can assume that you have a four-foot build-up of sand and grit. By measuring the depth of sand and grit at periodic intervals, you can determine how fast the build-up is accumulating. In digesters, all metal and concrete surfaces are inspected for deterioration.

On surfaces where the protective coatings are dead and flake off, it is necessary to sand blast the entire surface before new coatings are applied. Usually two or more coats are needed for proper protection.

The protective coatings used on these types of tanks and channels are usually of black asphaltic type paint. These coatings should be used wherever practical. In areas where fumes and moisture are not severe, aluminum or a color scheme may be desirable. In these areas, a rubber base paint or some similar material may be used. Follow the recommendations of a paint expert.

CAUTION

PERIODIC DRAINAGE INSPECTION, AND REPAIR OF TANKS AND CHANNELS IS ESSENTIAL. FAILURE TO DO SO MAY RESULT IN COMPLETE DISRUPTION OF OPERATIONS DURING THE CRITICAL LOW FLOW-HIGH TEMPERATURE SEASON. SELECT A TIME FOR MAINTENANCE (REMOVING OBSTRUCTIONS, REPAIRING GATES, CONCRETE PIPES AND PUMPS) WHEN YOU CAN MINIMIZE THE DISCHARGE OF HARMFUL WASTES TO RECEIVING WATERS.

11.03 Plant Grounds

Plant grounds that are well groomed and kept in a neat condition will greatly add to the appearance of the overall plant area. This is important to the operator in building good relations with plant neighbors as well as the general public. It also aids in the eyes of management as to your ability as an operator.

If the plant grounds have not been landscaped, it is sometimes the responsibility of the operator to do so. This may consist of planting shrubs and lawns or, just keeping the grounds neat and weed free. Some plant grounds may be entirely paved. In any case they should be kept clean and orderly at all times.

Control rodents and insects so they won't spread diseases or cause nuisances.

For the convenience of visitors and new operators, signs directing people to the plant, indicating the way to different plant facilities, identifying plant buildings and the direction of flow and contents flowing in a pipe can all be very helpful. Well-lighted and well-maintained walks and roadways are very important. Plant grounds should be fenced to prevent unauthorized persons and animals from entering the area. Keep items occasionally used and old, discarded equipment neatly stored to avoid the appearance of a cluttered junk yard. Groom your plant grounds in a fashion that you will be proud of, and you will be amazed at the favorable impression your facility will convey to the public and administrators.

QUESTIONS

11.0E What items should be included in a building maintenance program?

11.0F When plant tanks and channels are drained, what items would you inspect?

11.0G Why are neat and well-groomed grounds important?

11.04 Chlorinators

11.040 Maintenance

Chlorine gas leaks around chlorinators or containers of chlorine will cause corrosion of equipment. Check every day for leaks. Large leaks will be detected by odor; small leaks may go unnoticed until damage results. A green or reddish deposit on metal indicates a chlorine leak. Any chlorine gas leakage in the presence of moisture will cause corrosion. Always plug the ends of any open connection to prevent moisture from entering the lines. Never pour water on a chlorine leak because this will only compound the problem by enlarging the leak. (Chlorine gas reacts with water to form hydrochloric acid.

WARNING

ANOTHER IMPORTANT REASON FOR PREVENTING CHLORINE LEAKS IS THAT THE GAS IS TOXIC TO HUMANS.

Ammonia water will detect any chlorine leak. A small piece of cloth, soaked with ammonia water and wrapped around the end of a short stick, makes a good applicator to detect leaks. If chlorine gas leakage is occurring, a white cloud of ammonium chloride will form. It is good practice to make this test at all gas pipe joints, both inside and outside the chlorinators, at regular intervals. Bottles of ammonia water should be kept tightly capped to avoid loss of strength. All pipe fittings must be kept tight to avoid leaks. New gaskets should be used for each new connection.

CAUTION

TO LOCATE A CHLORINE LEAK, **DO NOT SPRAY OR SWAB EQUIPMENT WITH AMMONIA WATER!** WAVE AN AMMONIA SOAKED RAG OR PAINT BRUSH IN THE GENERAL AREA AND YOU CAN DETECT THE PRESENCE OF MANY LEAKS. SOME OPERATORS PREFER TO WAVE A STICK WITH A CLOTH ON THE END IN FRONT OF THEM WHEN THEY ARE LOOKING FOR CHLORINE LEAKS.

Ammonia bottles are not recommended for use in rooms containing chlorine because after one squeeze, the entire area may be full of white smoke and you may have trouble locating the leak. An ammonia bottle may be used to look for chlorine leaks around connections and cylinders. Use a cloth soaked in ammonia water in a room.

The exterior casing of chlorinators should be painted as required; however, most chlorinators manufactured recently have plastic cases that do not require protective coatings. A clean machine is a better operating machine. Glass bell jars may be cleaned with water and a washing compound. Parts of a chlorinator handling chlorine gas must be kept dry to prevent the chlorine and moisture from forming hydrochloric acid. Some parts may be cleaned, when required, first with water to remove water soluble material, then with wood alcohol, followed by drying. The above chemicals leave no moisture residue. Another method would be to wash them with water and dry them over a pan or heater to remove all traces of moisture.

Water strainers on chlorinators frequently clog and require attention. They may be cleaned by flushing with water or, if badly fouled, they may be cleaned with dilute hydrochloric acid, followed with a water rinse.

The atmospheric vent lines from chlorinators must be open and free. These vent lines evacuate the chlorine to the outside atmosphere when the chlorinator is being shut down. It is advisable to place a screen over the end of the pipe to keep insects from building a nest in it and clogging it up.

When chlorinators are removed from service, as much chlorine gas as possible should be removed from the supply lines and machines. The chlorine valves at the containers are shut off and the chlorinator injector is operated for a period to remove the chlorine gas. With visible bell jar chlorinators, the absence of the characteristic yellow color of chlorine is an indication that the chlorine has been expelled. In "V" notch chlorinators (Chapter 10), the rotameter goes to the bottom of the manometer tube when the chlorine has been expelled.

All chlorinators will give continuous trouble-free operation if properly maintained and operated. Each chlorinator manufacturer provides with each machine a maintenance and operations instruction booklet with line diagrams showing the operation of the component parts of the machine. Manufacturer's instructions should be followed for maintenance and lubrication of your particular chlorinator. If you do not have an instruction booklet, you may obtain one by contacting the manufacturer's representative in your area.

QUESTIONS

11.0H Why should chlorine leaks be detected and repaired?

11.0I How would you search for chlorine leaks?

Taken in part from *Operating and Maintaining Chlorinator and Chlorine Containers*, by LeRoy W. VanKleek, reprinted from Waste Engineering, July 1965. Distributed by Wallace & Tiernan, Incorporated.

11.041 Chlorine Safety

For information on chlorine safety, see Chapter 10, Disinfection and Chlorination, and Chapter 12, Plant Safety and Good Housekeeping. READ these chapters BEFORE attempting maintenance on chlorinators, lines, or cylinders.

11.05 Library

A plant library can contain helpful information to assist in plant operation. Material in the library should be cataloged and filed for easy retrieval. Items in the library should include:

1. Plant plans and specifications.

2. Manufacturers' instructions.

3. Reference books on wastewater treatment.

4. Professional journals and publications.

5. Manuals of Practice and Safety Literature published by the Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016

6. First-aid book.

7. Reports.

8. A dictionary.

END OF LESSON 1 OF 6 LESSONS

on

MAINTENANCE

Please answer the discussion and review questions before continuing with Lesson 2.

DISCUSSION AND REVIEW QUESTIONS

Chapter 11. Maintenance

(Lesson 1 of 6 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson.

Write the answers to these questions in your notebook.

1. Why should the operator thoroughly read and understand manufacturers' literature before attempting to maintain plant equipment?
2. Why must administrators or supervisors be made aware of the need for an adequate maintenance program?
3. What is the purpose of a maintenance record keeping program?
4. What kinds of maintenance checks should be made periodically of stairways, ladders, and catwalks?
5. When should inspection and maintenance of the underwater portions of plant structures such as clarifiers and digesters be scheduled?
6. Why should rodents and insects be controlled?
7. What items should be included in a plant library?

CHAPTER 11. MAINTENANCE

(Lesson 2 of 6 Lessons)

11.1 MECHANICAL MAINTENANCE

Table of Contents

The format of this section differs from the other chapters. It was designed specifically to assist you in planning an effective preventive maintenance program. The table of contents is outlined on the preceding page, and the paragraphs are numbered for easy reference when you use the Equipment Service Cards and Service Record Cards mentioned in Section 11.0.

An entire book could be written on the topics covered in this section. Step-by-step details for maintaining equipment are not provided because manufacturers are continually improving their products and these details could soon be out of date. You are assumed to have some familiarity with the equipment being discussed. For details concerning a particular piece of equipment you should contact the manufacturer. This section indicates to you the kinds of maintenance you should include in your program and how you could schedule your work. Carefully read the manufacturer's instructions and be sure you clearly understand the material before attempting to maintain and repair equipment. If you have any questions or need any help, do not hesitate to contact the manufacturer or his local representative.

A glossary is not provided in this section because of the large number of technical words that require familiarization with the equipment being discussed. The best way to learn the meaning of these new words is from manufacturers' literature or from their representatives. Some new words are described in the lesson where necessary.

Paragraph 1: Repair Shop

Many large plants have fully equipped machine shops staffed with competent mechanics. But for smaller plants, adequate machine shop facilities often can be found in the community. In addition, most pump manufacturers maintain pump repair departments where pumps can be fully reconditioned.

The pump repair shop in a large plant commonly includes such things as welding equipment, lathes, drill press and drills, power hacksaw, flame-cutting equipment, micrometers, calipers, gauges, portable electric tools, grinders, a forcing press, metal-spray equipment, and sand-blasting equipment. You must determine what repair work you can and should do and when you need to request assistance from an expert.

Paragraph 2: Pumps

Pumps serve many purposes in wastewater collection systems and treatment plants. They may be classified by the character of the material handled: raw wastewater, grit, effluent, activated sludge, raw sludge, digested sludge, etc. Or, they may relate to the conditions of pumping: high lift, low lift, recirculation, high capacity, etc. They may be further classified by principle of operation, such as centrifugal, propeller, reciprocating, and turbine.

The type of material to be handled and the function or required performance of the pump vary so widely that the designing engineer must use great care in preparing specifications for the pump and its controls. Similarly, the operator must conduct a maintenance and management program adapted to the peculiar characteristics of the equipment.

Paragraph 3: Description of Pumps

A. Centrifugal Pumps

A centrifugal pump (Figs. 11.2 and 11.3) is fundamentally a very simple device, an impeller rotating in a casing. The impeller is supported on a shaft which is, in turn, supported by bearings. Liquid coming in at the center (eye) of the impeller (Fig. 11.4) is picked up by the vanes and by the rotation of the impeller and is thrown out by centrifugal force into the discharge.

Centrifugal pumps designed for pumping wastewater usually have smooth channels and impellers with large-sized openings to prevent clogging.

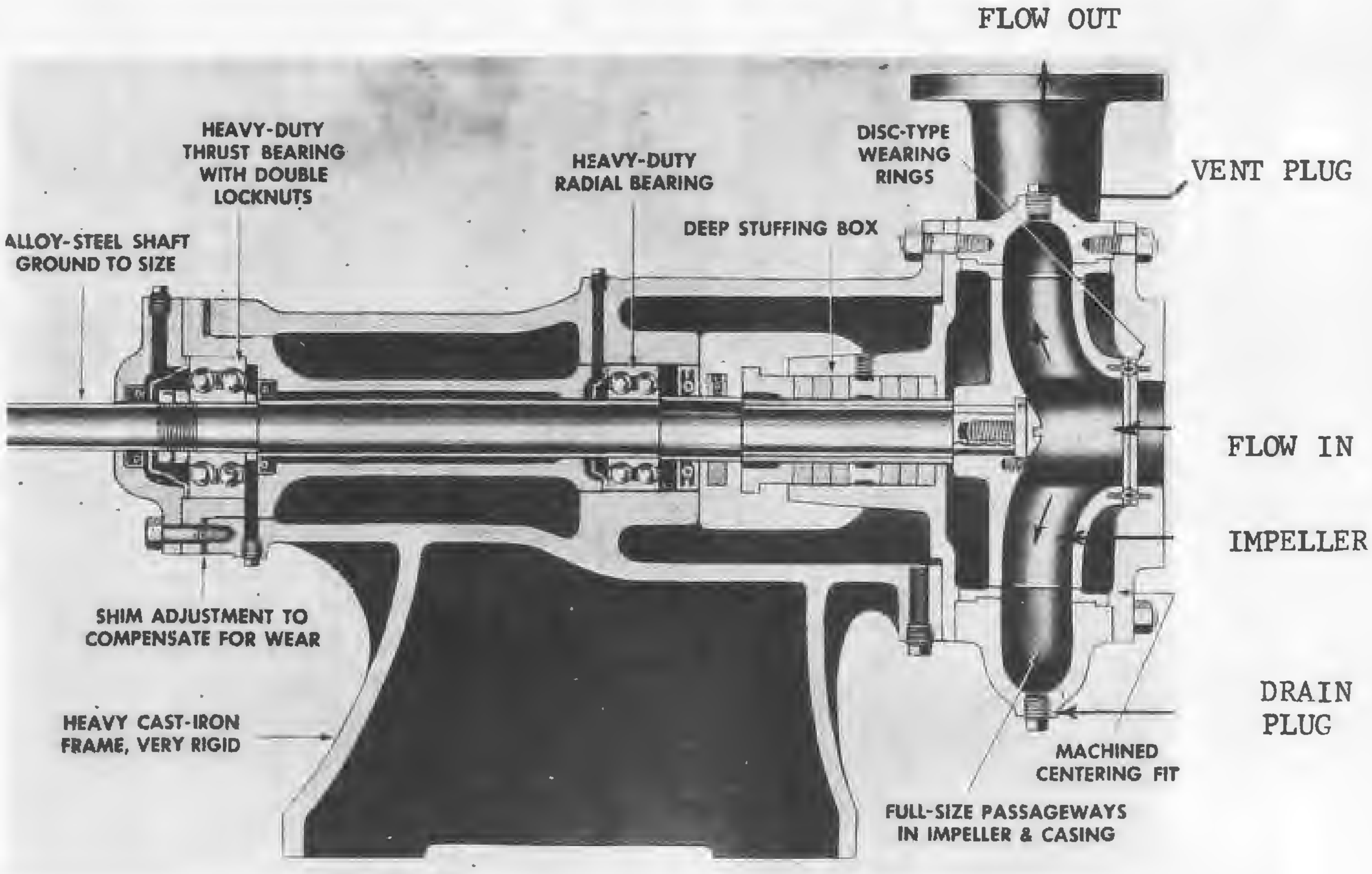


Fig. 11.2 Horizontal wastewater pump

(Source: War Department Technical Manual TM5-666)

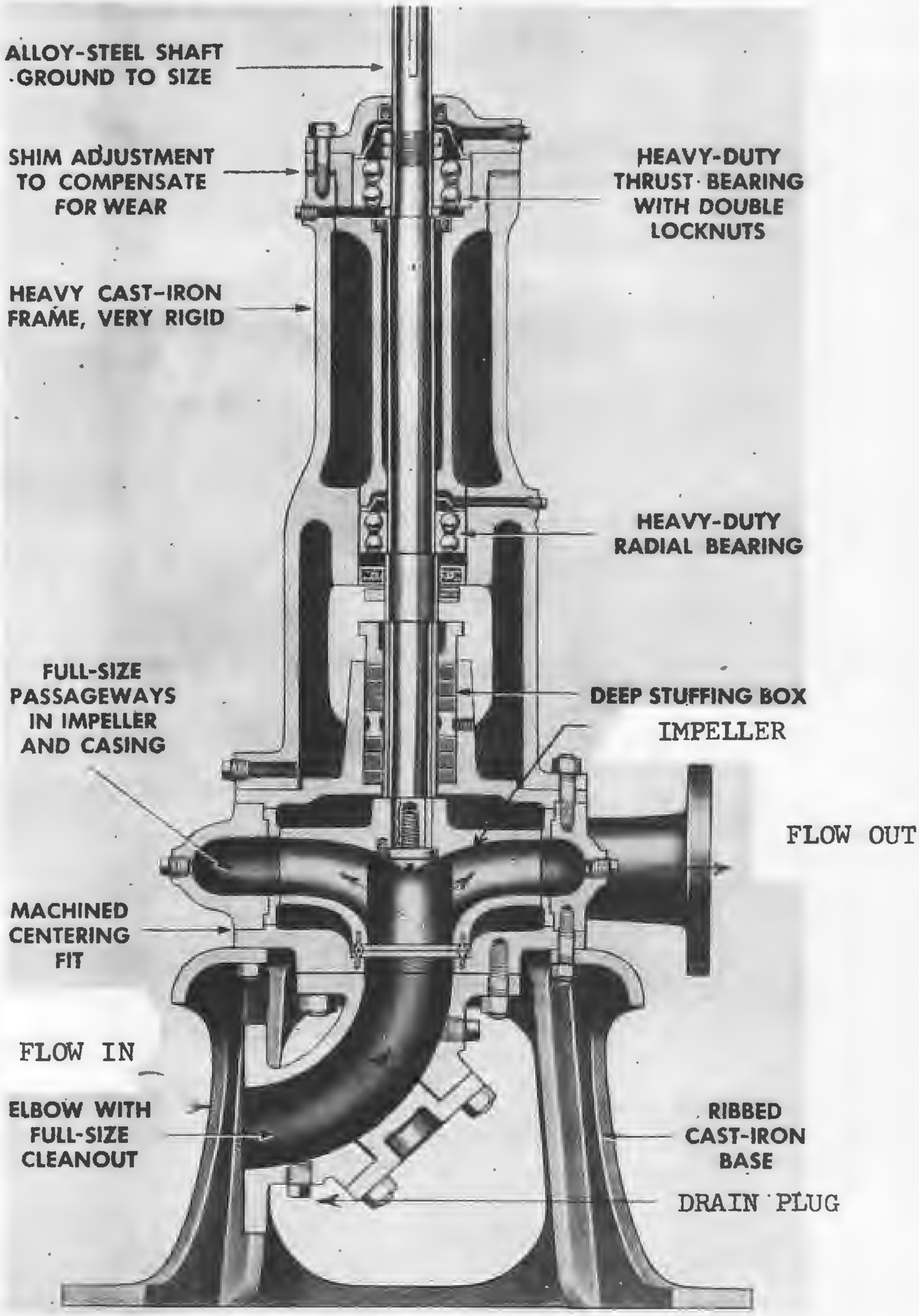
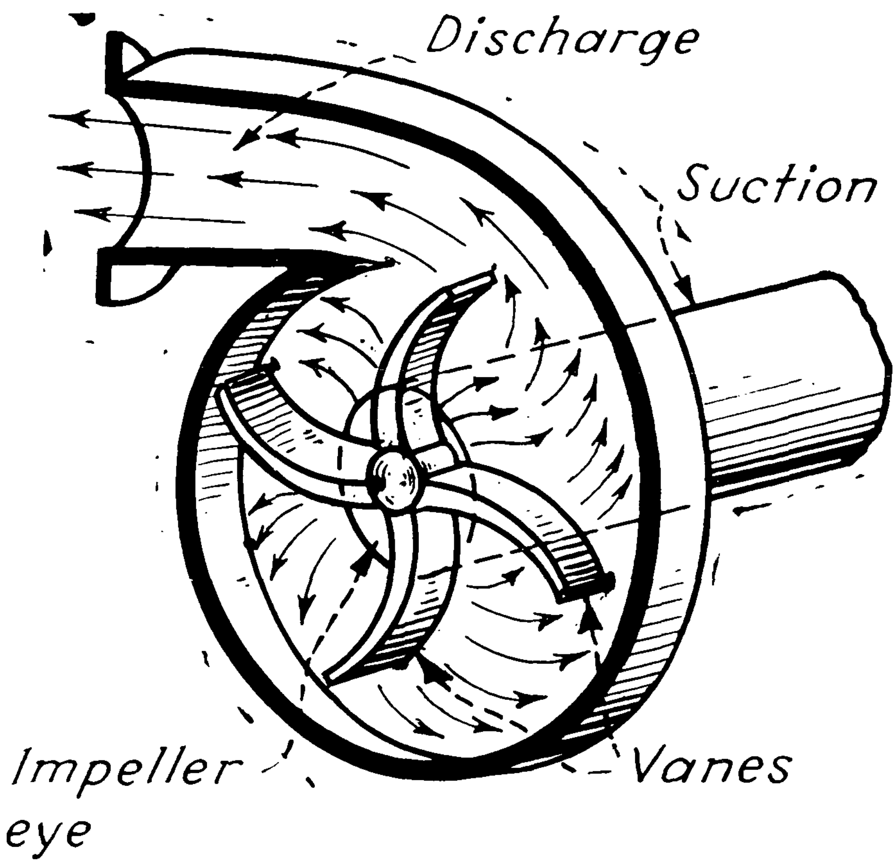


Fig. 11.3 Vertical ball-bearing type wastewater pump

(Source: War Department Technical Manual TM5-666)



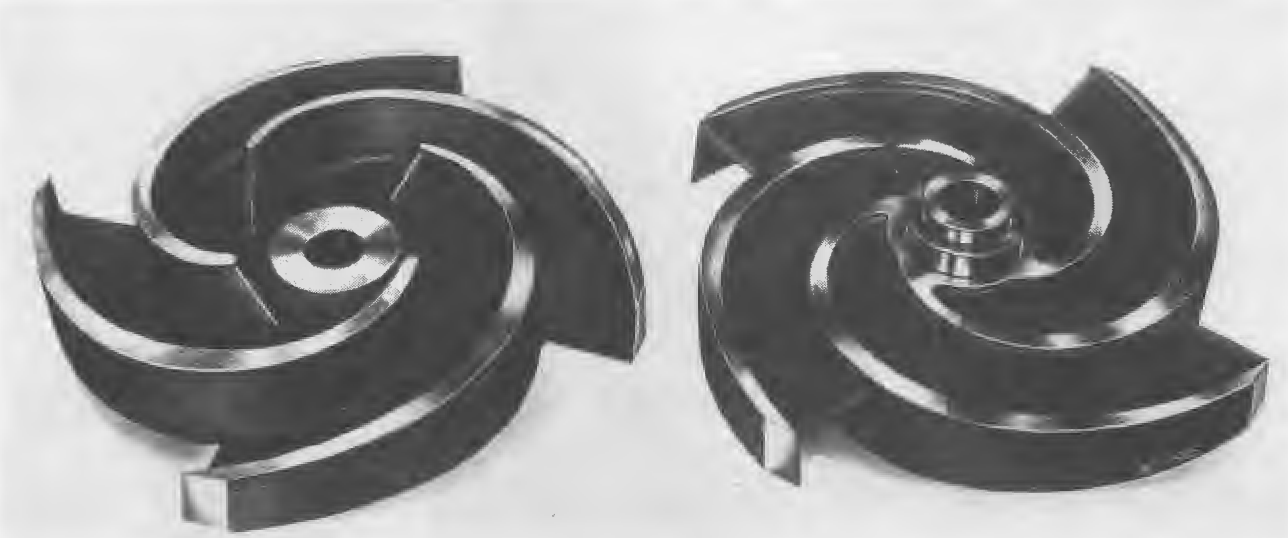
Refer to Fig. 11.3 for location of impeller in pump.

Fig. 11.4 Diagram showing details of centrifugal pump impeller

(Source: *Centrifugal Pumps* by Karassik and Carter of Worthington Corporation)

Closed Radial

(Closed radial impellers are used in wastewater treatment plants.)



Open Radial

Fig. 11.5 Impellers

(Source: *Centrifugal Pumps* by Karassik and Carter of Worthington Corporation)

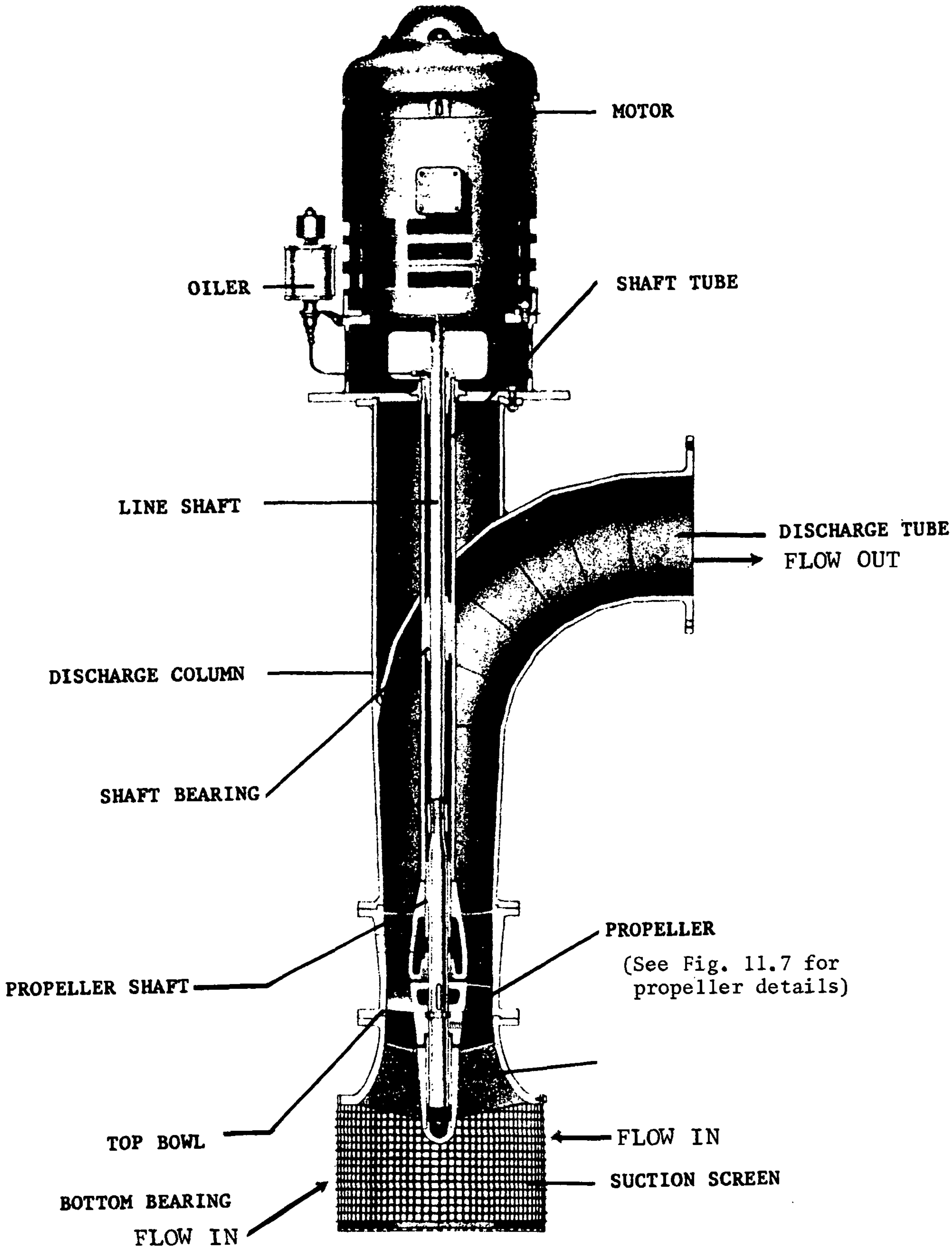
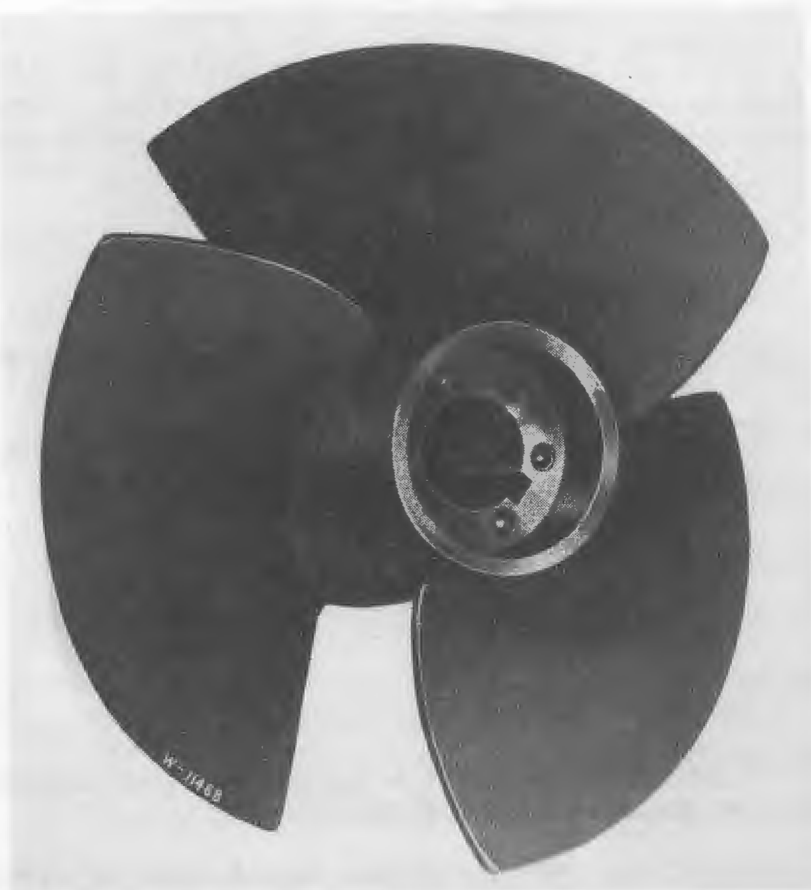


Fig. 11.6 Propeller pump

(Source: Unknown)

Mixed Flow



Propeller

Fig. 11.7 Impellers (continued)

(Source: *Centrifugal Pumps* by Karassik and Carter of Worthington Corporation)

Impellers may be of the open or closed type (Fig. 11.5), but most pumps are provided with the two-blade impeller. Single-blade impellers, however, are used successfully.

B. Propeller Pumps

There are two basic types of propeller pumps (Fig. 11.6), axial flow and mixed flow impellers. The axial flow propeller pump is one having a flow solely parallel to the axis[1] of the impeller (Fig. 11.7). The mixed flow propeller pump is one having a flow that is both radial[2] and axial[3] to the impeller (Fig. 11.7).

C. Reciprocating Pumps

The word reciprocating means moving back and forth, so a reciprocating pump is one that moves sludge by a piston that moves back and forth. A simple reciprocating pump is shown in Fig. 11.8. If the piston is pulled to the left, Check Valve A will open and sludge will enter the pump and fill the casing.

When the piston reaches the end of its travel to the left and is pushed back to the right, Check Valve A will close, Check Valve B will open, and wastewater will be forced out the exit line.

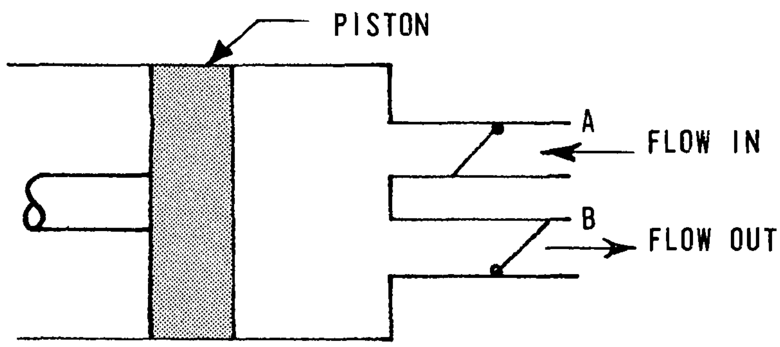


Fig. 11.8 Simple reciprocating pump
(See page 11-44 for pump details)

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[1] Axis of impeller. In line with the shaft.

[2] Radial to impeller. Material being pumped flows around the impeller or parallel to the shaft.

[3] Axial to impeller. Material being pumped flows at right angle to the impeller or perpendicular to the shaft.

D. Vertical Wet Well Pumps

A vertical wet well pump is a vertical shaft, diffuser type centrifugal pump with the pumping element suspended from the discharge piping (Fig. 11.9). The needs of a given installation determine the length of discharge column. The pumping bowl assembly may connect directly to the discharge head for shallow sumps, or may be suspended several hundred feet for raising water from wells. Vertical turbine pumps are used to pump water from deep wells, and may be of the single-stage or multi-stage type.[4]

Paragraph 4: Pump Lubrication

Pumps, motors, and drives should be oiled and greased in strict accordance with the recommendations of the manufacturer. Cheap lubricants may often be the most expensive in the end. Oil should not be put in the housing while the pump shaft is rotating because the rotary action of the ball bearings will pick up and retain a considerable amount of oil which will drain down when the unit comes to rest, resulting in an overflow of oil around the shaft or out of the oil cup.

Paragraph 5: Starting a Pump

The initial start-up work described in this paragraph should be done by a competent and trained person, such as a manufacturer's representative, consulting engineer, or an experienced operator. The operator can learn considerable about pumps and motors by accompanying and helping a competent person put new equipment into operation.

Before starting, a pump should be lubricated according to the lubrication instructions. The shaft should be turned by hand to see that it rotates freely, after which a check should be made to see that the shafts of the pump and motor are aligned and the flexible coupling adjusted. (Refer to Paragraph 19.) If the unit is belt driven, sheave (pulley) alignment and belt adjustment should be checked. (Refer to Paragraph 16.) The electric current characteristics should be checked with the motor characteristics and the

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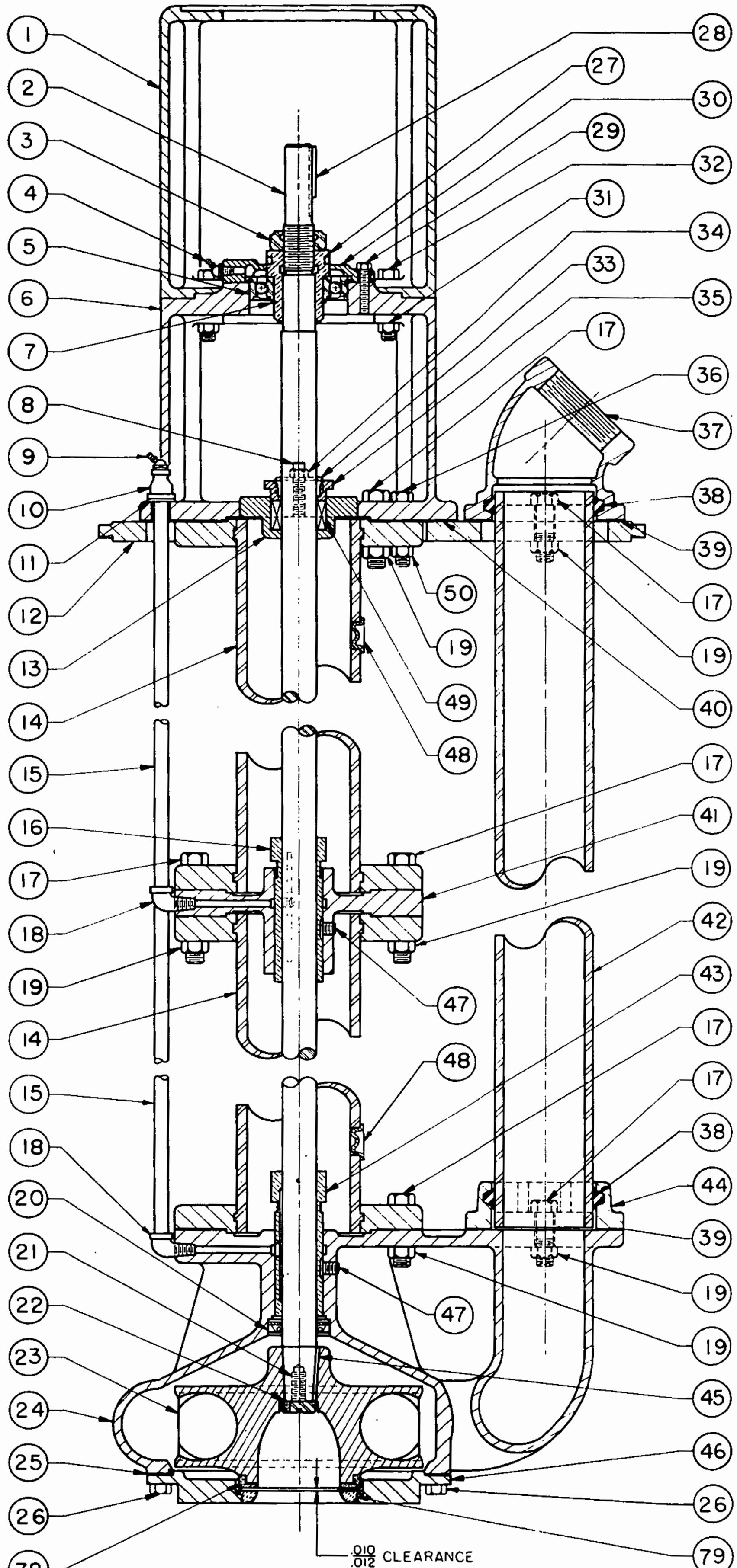
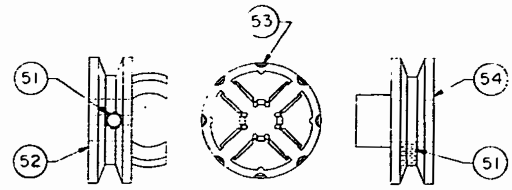
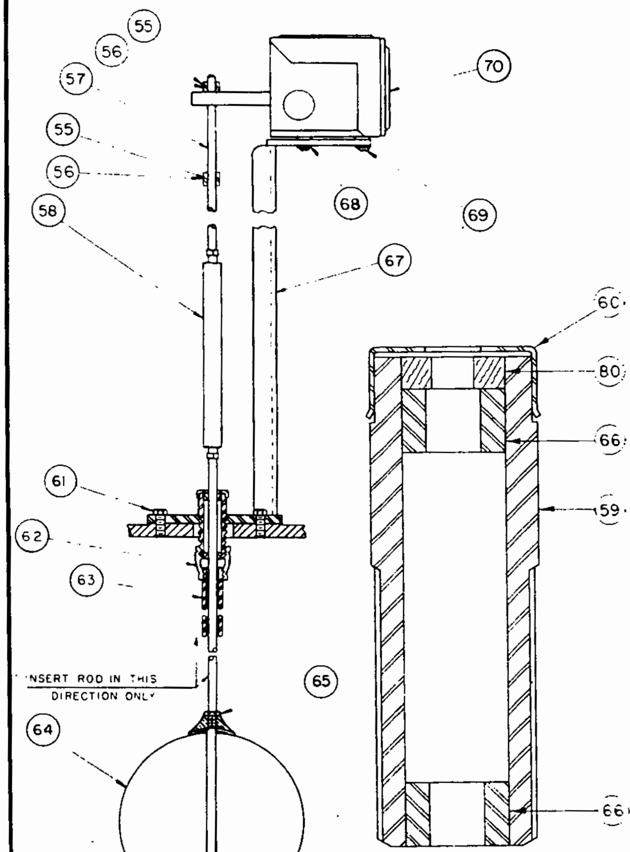
[4] Multi-Stage Pump. Has more than one impeller. Single-stage has one.





Principal parts are <u>underlined</u> on page 11-27.



FLOAT ROD
SEAL ASSEMBLY

Fig. 11.9 Vertical wet well pump
(Courtesy Chicago Pump)

Part No.	Description	Part No.	Description
1.	Motor Adapter	43.	Discharge Casing Bearing
2.	Shaft	44.	Packing Ring Flange
3.	Elastic Stop Nut	45.	Impeller Key
4.	Grease Fitting	46.	Suction Cover
5.	Bearing, Ball	47.	Hollow Head Cup Point Set Screw
6.	Bearing, Pedestal	48.	Cap Plug Protector
7.	Truarc Retaining Ring	49.	Packing
8.	Packing Gland Stud	50.	Hex Nut
9.	Grease, Fitting	51.	Set Screw Coupling
10.	Pipe Reducing Coupling	52.	Pump Coupling Half
11.	Leather Washer	53.	Coupling Disc
12.	Floor Plate	54.	Motor Coupling Half
13.	Packing Box	55.	Float Rod Button
14.	Hanger Pipe	56.	Hollow Head Set Screw
15.	Grease Line	57.	Float Rod
16.	Bronze Sleeve Bearing	58.	Mechanical Alternator (duplex units only)
17.	Hex Head Cap Screw	59.	Float Rod Seal Housing
18.	Street Ell	60.	Cap, Float Rod Seal
19.	Hex Nut	61.	Hex Head Cap Screw
20.	Perfect Seal Ring	62.	Reducing Coupling
21.	Impeller Lock Screw	63.	Float Rod Guide Pipe
22.	Impeller Set Screw	64.	Float
23.	Impeller (See Part No. 78)	65.	Float Lock Nut
24.	Discharge Casing	66.	Float Rod Seals
25.	Suction Gasket	67.	Switch Stand Assembly
26.	Hex Head Cap Screw	68.	Lock Washer
27.	Bearing Adapter	69.	Round Head Machine Screw
28.	Pump Coupling Key	70.	Float Switch
29.	Hex Head Cap Screw	71.	Upper Shaft
30.	Bearing Cap	72.	Taper Pin
31.	Hex Nut	73.	Auxiliary Coupling
32.	Hex Head Cap Screw	74.	Lower Discharge Pipe
33.	Gland Clamp	75.	Discharge Ell
34.	Hex Nut	76.	Upper Discharge Pipe
35.	Split Packing Gland	77.	Positioning Pins
36.	Hex Head Cap Screw	78.	Impeller Wearing Ring
37.	Discharge Ell	79.	Casing Wearing Ring
38.	Packing Gasket	80.	Felt Washer, Float Rod Seal
39.	Rubber Gasket		
40.	Pedestal Gasket		
41.	Intermediate Bearing Plate		
42.	Discharge Pipe		

Fig. 11.9 Vertical wet well pump (contd.)

(Courtesy Chicago Pump)

wiring should be inspected. Thermal units in the starter should be checked to be sure that they are set properly. Motor rotation should be determined by momentary contact to be certain that the motor will turn the pump in the direction indicated by the rotational arrows on the pump. If separate water seal units or vacuum primer systems are used, these should be started. Finally, it must be made certain that all valves in the suction and discharge lines are open. Sometimes there is an exception (see following paragraph) in the case of the discharge valve.

A pump should not be run without first having been primed. To prime a pump, the pump must be completely filled with water or wastewater. In some cases, automatic primers are provided. If they are not, it is necessary to vent the casing. Most pumps are provided with a valve to accomplish this. The trapped air should be allowed to escape until water or wastewater flows from the vent, after which the vent cap should be replaced. In the case of suction-lift applications, the pump must be filled with water unless a self-primer is provided. In nearly every case, it is permissible to start a pump with the discharge valve open. Exceptions to this, however, are where water hammer or velocity distrubances might result, or where the motor does not have sufficient margin of safety or power. Sometimes there are no check valves used in the discharge line. In this case (with the exception of positive displacement pumps) it is necessary to start the pump and then open the discharge lines. Where there are common discharge headers, it is essential to start the pump and then open the discharge valve. A positive displacement pump (reciprocating, etc.) should never be operated against a closed discharge.

After starting the pump, again check to see that the direction of rotation is correct. Packing-gland boxes (stuffing boxes) should be observed for slight leakage as described in Paragraph 12. Check to see that the bearings do not overheat from over- or under-lubrication. The flexible coupling should not be noisy; if it is, the noise may be caused by misalignment or improper clearance or adjustment. Check to be sure pump anchorage is tight. Compare delivered pump flows and pressures with pump performance curves. If pump delivery falls below performance curves, look for obstructions in the pipelines. Inspect piping for leaks.

Paragraph 6: Pump Shutdown

When shutting down a pump for a prolonged period, the motor disconnect switch should be opened, locked out, and tagged with reason for tag noted; all valves on the suction, discharge, and water-seal lines should be shut tightly, and the pump should be completely drained by removing the vent and drain plugs. Sludge should not be permitted to remain in pumps or piping for any length of time; cases are on record where the gas produced has ruptured pipes and sludge pumps.

It is also a good policy to inspect the pump and bearings thoroughly so that all necessary servicing may be done during the inactive period. The bearing housing should be drained and subsequently replenished with fresh lubricant.

Paragraph 7: Float and Electrode Switches

To ensure the best operation of the pump, a systematic inspection of the water level controls should be made at least once a week. Check to see that:

1. Controls respond to a rising water level in the wet well.

2. The unit starts when the float switch or electrode system makes contact, and the pump stops at the prescribed level in the wet well.

3. The motor speed comes up quickly and is maintained.

4. A brush-type motor does not spark profusely in starting or running.

5. Grease and trash are not interfering with controls. Be sure to remove scum from water-level float controls.

6. Any necessary adjustments are properly completed.

Paragraph 8: Pump Driving Equipment

Driving equipment used to operate pumps includes electric motors and internal combustion engines. In rare instances, pumps are driven with steam turbines, steam engines, air and hydraulic motors.

In all except the large installations, electric motors are used almost exclusively, with synchronous and induction types being the most commonly used. Synchronous motors operate at constant speeds and are used chiefly in large sizes. Three-phase, squirrel-cage induction motors are most often used in treatment plants. These motors require little attention and, under average operating conditions, the factory lubrication of the bearing will last approximately one year. (Check with the manufacturer as to what he considers average operating hours.) In lubricating motors, it should be remembered that too much grease may cause bearing trouble or damage the winding.

Clean and dry all electrical contacts. Check for loose electrical contacts. Make sure that hold-down bolts on motors are secure. Check voltage while the motor is starting and running. Examine bearings and couplings.

Paragraph 9: Electrical Controls

A variety of electrical equipment is used to control the operation of wastewater pumps or to protect electric motors. The simplest type of control unit consists of a counter-weighted float which actuates a switch. When the float is raised by the wastewater to a predetermined level, a switch is tripped which starts the pump; and when the wastewater level falls to the cutoff level, the float switch stops the pump. The time required for each cycle and the length of time between cycles depend on the pumping rate and the quantity of wastewater flow.

Where starters, disconnect switches, and cutouts are used, they should be installed in accordance with the local regulations (city and/or county codes) regarding this equipment. In the case of larger motors, the power company often requires starters which do not overload the power lines.

The electrode type, bubbler type, and diaphragm type water level control systems are all similar in effect to the float-switch system.

QUESTIONS

11.1A How would you find out how to lubricate a pump?

11.1B What problems can develop if too much grease is used in lubricating a motor?

Paragraph 10: Operating Troubles

The following list of operating troubles includes most of the causes of failure or reduced operating efficiency. The remedy or cure is either obvious or may be identified from the description of the cause.

SYMPTOM A--Pump Will Not Start

CAUSES:

1. Blown fuses or tripped circuit breakers attributed to:

    A. Rating of fuses or circuit breakers not correct

    B. Switch (breakers) contacts corroded or shorted

    C. Terminal connections loose or broken somewhere in the circuit

    D. Automatic control mechanism not functioning properly

    E. Motor shorted or burned out

    F. Wiring hookup or service not correct

    G. Switches not set for operation

    H. Contacts of the control relays dirty and arcing

    I. Fuses or thermal units too warm

    J. Wiring short-circuited

    K. Shaft binding or sticking by reason of rubbing impeller, tight packing glands, or clogging of pump

2. Loose connection, fuse, or thermal unit

SYMPTOM B--Reduced Rate of Discharge

CAUSES:

1. Pump not primed
2. Mixture of air in the wastewater
3. Speed of motor too low
4. Improper wiring
5. Defective motor
6. Discharge head too high
7. Suction lift higher than anticipated
8. Impeller clogged
9. Discharge line clogged
10. Pump rotating in wrong direction
11. Air leaks in suction line or packing box
12. Inlet to suction line too high, permitting air to enter
13. Valves partially or entirely closed
14. Check valves stuck or clogged
15. Incorrect impeller adjustment
16. Impeller damaged or worn
17. Packing worn or defective
18. Impeller turning on shaft because of broken key
19. Flexible coupling broken
20. Loss of suction during pumping may be caused by leaky suction line, ineffective water or grease seal

SYMPTOM C--High Power Requirements

CAUSES:

1. Speed of rotation too high
2. Operating heads lower than rating for which pump was designed, resulting in excess pumping rates
3. Check valves open, draining long force main back into well
4. Specific gravity or viscosity of liquid pumped too high
5. Clogged pump
6. Sheaves on belt drive misaligned or maladjusted
7. Pump shaft bent
8. Rotating elements binding
9. Packing too tight
10. Wearing rings worn or binding
11. Impeller rubbing

SYMPTOM D--Noisy Pump

CAUSES:

1. Pump not completely primed
2. Inlet clogged
3. Inlet not submerged
4. Pump not lubricated properly
5. Worn impellers
6. Strain on pumps caused by unsupported piping fastened to the pump
7. Foundation insecure
8. Mechanical defects in pump
9. Misalignment of motor and pump where connected by flexible shaft

QUESTIONS

11.1C What items would you check if a pump will not start?

11.1D How would you attempt to increase the discharge from a pump if the flow rate is lower than expected?

END OF LESSON 2 OF 6 LESSONS

on

MAINTENANCE

Please answer the discussion and review questions before continuing with Lesson 3.

DISCUSSION AND REVIEW QUESTIONS

Chapter 11. Maintenance

(Lesson 2 of 6 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 1.

8. What should you do if you can't understand the manufacturer's instructions?

PICK THE CORRECT WORD:

9. Cheap lubricants may be the (1) most or (2) least expensive in the end.

10. Start-up of a new pump should be done by (1) a new operator or (2) a trained person.

11. How can you determine if a new pump will turn in the direction intended?

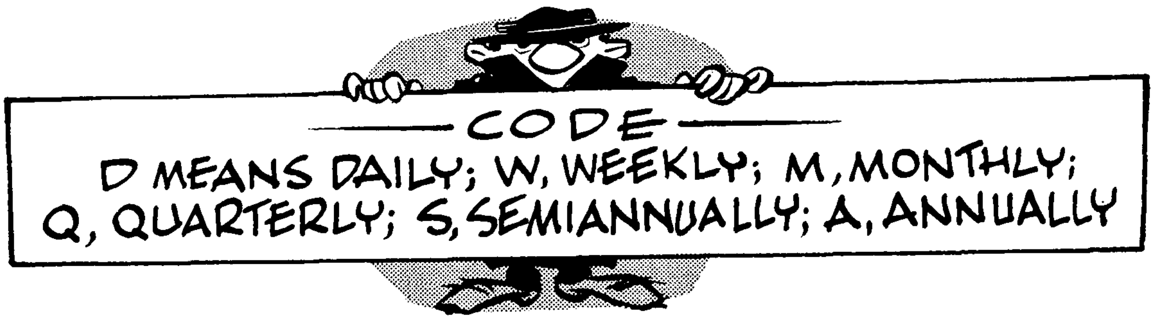
12. When shutting down a pump for a prolonged period, what precautions should be taken with the motor-disconnect switch?

13. How can you tell if a new pump is delivering design flows and pressures?

14. What is a maintenance problem with water-level float controls?

Paragraph 11: Preventive Maintenance

The following paragraphs list some general preventive maintenance services and indicate frequency of performance. There are many makes and types of equipment and the wide variation of functions cannot be included; therefore, you will have to use some judgment as to whether the services and frequencies will apply to your equipment. If something goes wrong or breaks in your plant, you may have to disregard your maintenance schedule and fix the problem now.



Frequency of Service	
	Paragraph 12: Pumps, General
	This paragraph lists some general preventive maintenance services and indicates frequency of performance. Typical centrifugal pump sections are shown in Figs. 11.2 and 11.3.
D	1. CHECK WATER-SEAL PACKING GLANDS FOR LEAKAGE. See that the packing box is protected with a clear-water supply from an outside source, making sure that water seal pressure is at least 3 psi greater than maximum pump discharge pressure. See that there are no cross-connections.[5] Check packing glands for leakage during operation. Allow a slight seal leakage when

[5] Cross-Connection. A cross-connection is a connection where wastewater or water from the seal could enter a water supply.

Frequency of Service		
		pumps are running to keep packing cool and in good condition. The proper amount of leakage depends on equipment and operating conditions. If excessive leakage is found, <u>hand tighten</u> glands' nuts evenly, but not too tight. After adjusting packing glands, be sure shaft turns freely by hand. If serious leakage continues, renew packing, shaft, or shaft sleeve.
D	2.	CHECK GREASE-SEALED PACKING GLANDS. When grease is used as a packing gland seal, maintain constant grease pressure on packing during operation. When a spring-loaded grease cup is used, keep it loaded with grease. Force grease through packing at rate of about one ounce per day.
W	3.	OPERATE PUMPS ALTERNATELY. If two or more pumps of the same size are installed, alternate their use to equalize wear, keep motor windings dry, and distribute lubricant in bearings.
W	4.	INSPECT PUMP ASSEMBLY. Check float controls noting how they respond to rising water level. See that unit starts when float switch makes contact and that pump empties basin at a normal rate. Apply light oil to moving parts. Service stand-by pump and run assembly long enough to obtain normal motor temperature rise.
D	5.	CHECK MOTOR CONDITION. See Paragraph 15.
W	6.	CLEAN PUMP. <u>First</u> lock out power. Clean-out handholes are provided on the pump volute. To clean pump, close all valves, drain pump, remove handhold cover, and remove all solids.
W	7.	CHECK PACKING GLAND ASSEMBLY. Check packing gland, the unit's most abused and troublesome part. If stuffing box leaks excessively when gland is pulled up with mild pressure, remove packing and examine shaft sleeve carefully. Replace grooved or scored shaft sleeve because packing cannot be held in stuffing box with roughened shaft or shaft sleeve. Replace the packing a strip at a time, tamping each

Frequency of Service		
		strip thoroughly and staggering joints. (See Fig. 11.10.) Position lantern ring (water-seal ring) properly. If grease sealing is used, completely fill lantern ring with grease before putting remaining rings of packing in place. The type of packing used is less important than the manner in which packing is placed. Never use a continuous strip of packing. This type packing wraps around and scores the shaft sleeve or is thrown out against outer wall of stuffing box, allowing wastewater to leak through and score the shaft.
Q	8.	INSPECT AND LUBRICATE BEARINGS. Unless otherwise specifically directed for a particular pump model, drain lubricant and wash out oil wells and bearing with solvent. Check sleeve bearings to see that oil rings turn freely with the shaft. Repair or replace if defective. Refill with proper lubricant. Measure bearings and replace those worn excessively. Generally, allow clearance of 0.002 inch plus 0.001 inch for each inch or fraction of inch of shaft-journal diameter.
Q	9.	CHECK OPERATING TEMPERATURE OF BEARINGS. Check bearing temperature with thermometer, not by hand. If antifriction bearings are running hot, check for over-lubrication and relieve if necessary. If sleeve bearings run too hot, check for lack of lubricant. If proper lubrication does not correct condition, disassemble and inspect bearing. Check alignment of pump and motor if high temperatures continue.
S	10.	CHECK ALIGNMENT OF PUMP AND MOTOR. For method of aligning pump and motor, see Paragraph 19. If misalignment recurs frequently, inspect entire piping system. Unbolt piping at suction and discharge nozzles to see if it springs away, indicating strain on casing. Check all piping supports for soundness and effective support of load.

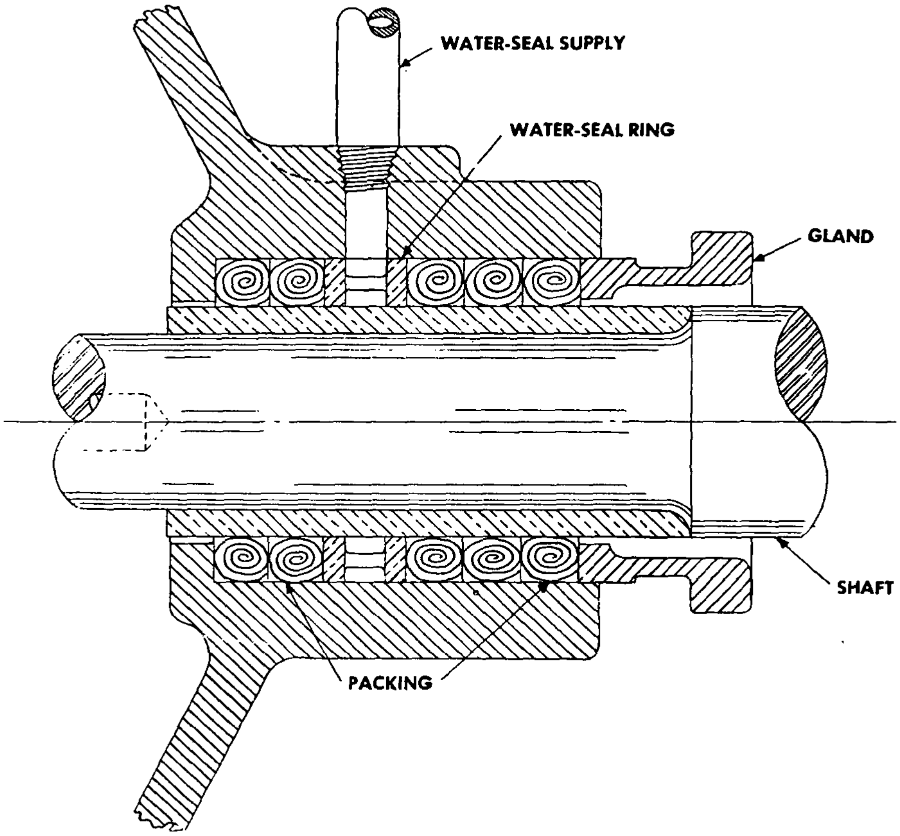


Fig. 11.10 Method of packing shaft

(Source: War Department Technical Manual TM5-666)

Frequency of Service		

Vertical pumps usually have flexible shafting which permits slight angular misalignment; however, if solid shafting is used, align exactly. If beams carrying intermediate bearings are too light or are subject to contraction or expansion, replace beams and realign intermediate bearings carefully.

S 11. INSPECT AND SERVICE PUMPS.

a. Remove rotating element of pump and inspect thoroughly for wear. Order replacement parts where necessary.

b. Remove any deposit or scaling. Clean out water-seal piping.

c. Determine pump capacity by pumping into empty tank of known size or by timing the draining of pit or sump.

$$\text{Pump Capacity, gpm} = \frac{\text{Volume, gallons}}{\text{Time, minutes}}$$

d. Test pump efficiency. Refer to pump manufacturer's instructions on how to collect data and perform calculations. Or see Chapter 15 on Mathematics and Treatment Plant Problems.

e. Measure total dynamic suction and discharge lifts to test pump and pipe condition. Record figures for comparison with later tests.

f. Inspect foot and check valves, paying particular attention to check valves, which can cause water hammer when pump stops. (See Paragraph 22 also.)

g. Examine wearing rings. Replace seriously worn wearing rings to improve efficiency. Check wearing ring clearances which generally should be no more than 0.003 inch per inch of wearing diameter.

CAUTION: To protect rings and casing, never allow pump to run dry through lack of proper priming when starting or loss of suction when operating.

Frequency of Service	
A	12. DRAIN PUMP BEFORE PROTRACTED SHUTDOWN. When shutting down pump for a long period, open motor-disconnect switch; shut all valves on suction, discharge, water-seal, and priming lines; drain pump completely by removing vent and drain plugs. This procedure protects pump against corrosion, sedimentation, and freezing. Inspect pump and bearings thoroughly and perform all necessary servicing. Drain bearing housings and replenish with fresh oil, purge old grease and replace. When a pump is out of service, run it monthly to warm it up and to distribute lubrication so the packing will not "freeze" to the shaft. Resume periodic checks after pump is put back in service.

QUESTIONS

11.1E What is a cross-connection?

11.1F Is a slight water-seal leakage desirable when a pump is running? If so, why?

11.1G How would you measure the capacity of a pump?

11.1H Estimate the capacity of a pump (in GPM) if it lowers the water in a 10-foot wide x 15-foot long wet well 1.7 feet in five minutes.

11.1I What should be done to a pump before it is shut down for a long time, and why?

Frequency of Service

Paragraph 13: Reciprocating Pumps, General (See Fig. 11.11)

The general procedures in this paragraph apply to all reciprocating sludge pumps described in this section.

W

1. CHECK SHEAR PIN ADJUSTMENT. Set eccentric by placing shear pin through proper hole in eccentric flanges to give required stroke. Tighten the two 5/8- or 7/8-inch hexagonal nuts on connecting rods just enough to take spring out of lock washers. (See Paragraph 20.) When a shear pin fails, eccentric moves toward neutral position, preventing damage to the pump. Remove cause of obstruction and insert new shear pin. Shear pins fail because of one of three common causes:

   (1) Solid object lodged under piston
   (2) Clogged discharge line
   (3) Stuck or wedged valve

D

2. CHECK PACKING ADJUSTMENT. Give special attention to packing adjustment. If packing is too tight, it reduces efficiency and scores piston wells. Keep packing just tight enough to keep sludge from leaking through gland. Before pump is installed or after it has been idle for a time, loosen all nuts on packing gland. Run pump with sludge suction line closed and valve covers open for a few minutes to break in the packing. Turn down gland nuts no more than necessary to prevent sludge from getting past packing. Tighten all packing nuts uniformly.

   When packing gland bolts cannot be taken up farther, replace packing. Remove old packing and thoroughly clean cylinder and piston walls. Place new packing into cylinder, staggering packing-ring joints, and tamp each ring into place. Break in and adjust packing as explained above. When chevron type packing is used, tighten gland nuts only finger tight because excessive pressure ruins packing and scores plunger.

Principal parts are underlined on page 11-45.

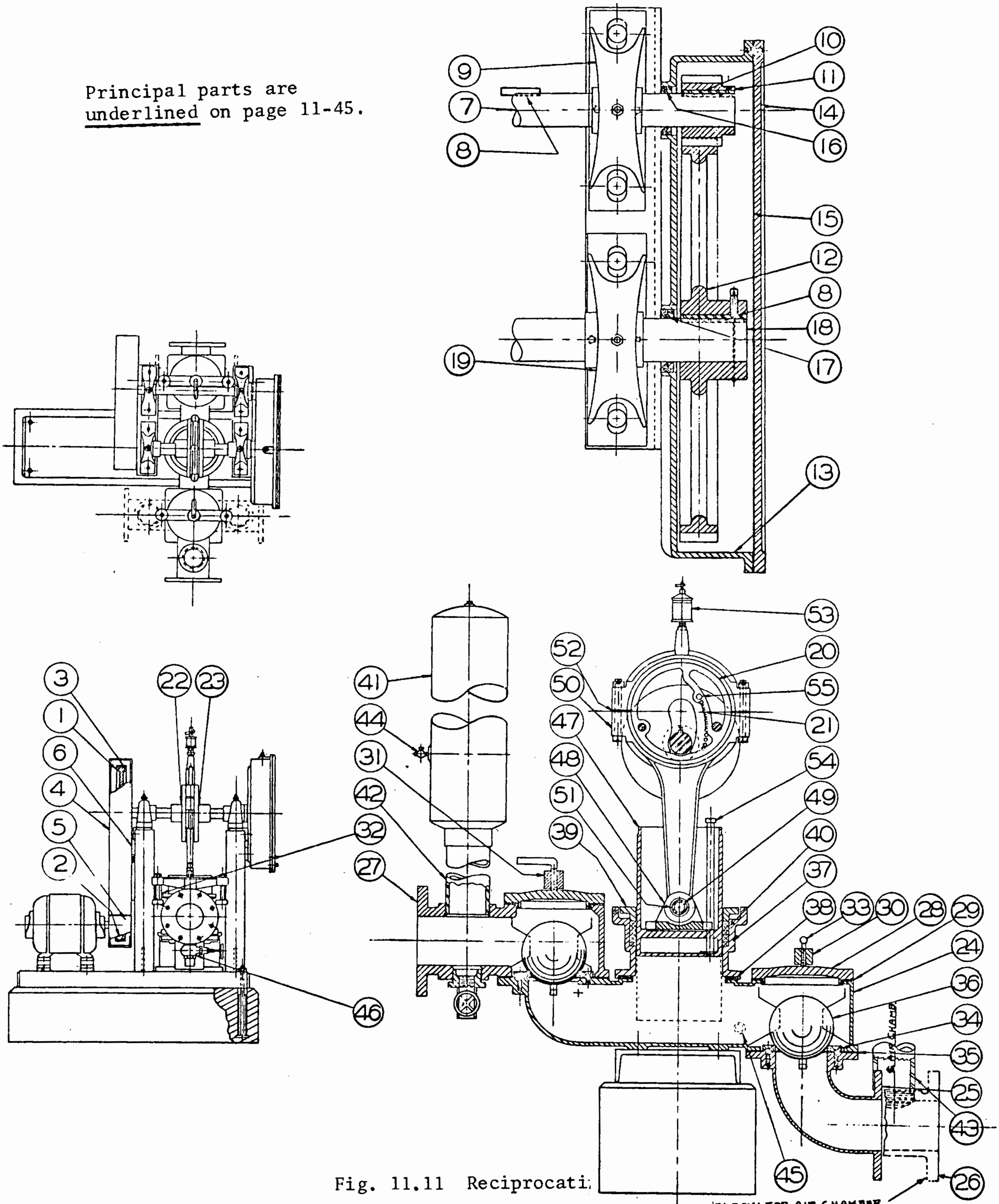


Fig. 11.11 Reciprocati

(Courtesy ITT Marlow, a Unit of International Telephone and Telegraph Corp.)

ITEM	DESCRIPTION
1	Countershaft Pulley
2	Motor Pulley
3	"V" Belts
4	Belt Guard Hood
5	Belt Guard Bottom Section
6	Belt Guard Back Plate
7	Countershaft
8	Key
9	Pillow Block Bearings
10	Key, Pinion
11	Pinion
12	Gear
13	Gear Case
14	Gear Case Cover
15	Gasket, Gear Case
16	Grease Retainer 1-3/8" I. D.
17	Grease Retainer 1-3/4" I. D.
18	Main Shaft
19	Pillow Block Bearings
20	Eccentric
21	Eccentric Bushing
22	Driving Flange
23	Driven Flange
24	Pump Body
25	Suction Elbow
26	Suction Elbow, Air Chamber
27	Discharge Valve Chamber
28	Valve Chamber Cover
29	Gasket, Cover
30	Valve Chamber Yoke Right
31	Valve Chamber Yoke, Left
32	Yoke Spacer
33	Valve Chamber Handle
34	Valve Seat
35	Gasket, Valve Seat
36	Ball Valve, 5-1/8" Dia.
37	Stuffing Box
38	Gasket, Stuff. Box to Pump
39	Gland
40	Packing
41	Air Chamber
42	Nipple, 8" long (Discharge)
43	Nipple, 16" long
44	1/4" #64T Pet Cock
45	1/4" Ball Snifter Cock
46	1" Bronze Gate Valve
47	Plunger
48	Crosshead
49	Crosshead Wrist Pin
50	Connecting Rod
51	Connecting Rod Bushing
52	Connecting Rod Shim
53	Sight Feed Oiler
54	Drain Rod Assembly
55	Driving Flange Bushing

Fig. 11.11 Reciprocating pump (contd.)

(Courtesy ITT Marlow, a Unit of International Telephone and Telegraph Corp.)

Frequency of Service	
Q	3. CHECK BALL VALVES. When valve balls are so worn that diameter is 5/8 inch smaller than original size, they may jam into guides in valve chamber. Check size of valve balls and replace if badly worn.
Q	4. CHECK VALVE-CHAMBER GASKETS. Valve-chamber gaskets on most pumps serve as a safety device and blow out under excessive pressure. Check gaskets and replace if necessary. Keep additional gaskets on hand for replacement.
A	5. CHECK ECCENTRIC ADJUSTMENT. To take up babbitt bearing, remove brass shims provided on connecting rod. After removing shims, operate pump for at least one hour and check to see that eccentric does not run hot.
D	6. NOTE UNUSUAL NOISES. Check for noticeable water hammer when pump is operating. This noise is most pronounced when pumping water or very thin sludge; it decreases or disappears when pumping heavy sludge. Eliminate noise by opening the 1/4-inch petcock on pump body slightly; this draws in a small amount of air, keeping discharge air chamber full at all times.
D	7. CHECK CONTROL VALVE POSITIONS. Because any plunger pump may be damaged if operated against closed valves in the pipeline, especially the discharge line, make all valve setting changes with pump shut down; otherwise pumps which are installed to pump from two sources or to deliver to separate tanks at different times may be broken if all discharge line valves are closed simultaneously for a few seconds or discharge valve directly above pump is closed.
W	8. GEAR REDUCER. Check oil level by removing plug on the side of the gear case. Unit should not be in operation.
Q	9. CHANGE OIL AND CLEAN MAGNETIC DRAIN PLUG.

Frequency of Service		
W	10.	CONNECTING RODS. Set oilers to disperse two drops per minute.
W	11.	PLUNGER CROSSHEAD. Fill plunger as required to half cover the wrist pin with oil.
D	12.	PLUNGER TROUGH. Keep small quantity of oil in trough to lubricate the plunger.
M	13.	MAIN SHAFT BEARING. Grease bearings monthly. Pump should be in operation when lubricating to avoid excessive pressure on seals.
	14.	CHECK ELECTRIC MOTOR. See Paragraph 15.

Paragraph 14: Propeller Pumps, General (Fig. 11.6)

D	1.	CHECK MOTOR CONDITION. See Paragraphs 15-1 and 15-2.
D	2.	CHECK PACKING GLAND ASSEMBLY. See Paragraph 12-7.
W	3.	INSPECT PUMP ASSEMBLY. See Paragraph 12-4.
W	4.	LUBE LINE SHAFT AND DISCHARGE BOWL BEARING. Maintain oil in oiler at all times. Adjust feed rate to approximately four drops per minute.
W	5.	LUBE SUCTION BOWL BEARING. Lube through pressure fitting. Usually three or four strokes of gun are enough.
W	6.	OPERATE PUMPS ALTERNATELY. See Paragraph 12-3.
A	7.	LUBE MOTOR BEARINGS. See Paragraph 15.

QUESTIONS

11.1J What are some of the common causes of shear pin failure in reciprocating pumps?

11.1K What may happen when water or a thin sludge is being pumped by a reciprocating pump?

END OF LESSON 3 OF 6 LESSONS

on

MAINTENANCE

Please answer the discussion and review questions before continuing with Lesson 4.

DISCUSSION AND REVIEW QUESTIONS

Chapter 11. Maintenance

(Lesson 3 of 6 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 2.

15. What would you do if considerable water was leaking from the water-seal of a pump?

16. When two or more pumps of the same size are installed, why should they be operated alternately?

17. What should be checked if pump bearings are running hot?

18. What happens when the packing is too tight on a reciprocating pump?

19. Why should changes in control valves for reciprocating pumps be adjusted when the pump is shut down?

Frequency of Service	
	Paragraph 15: Electric Motors
	In order to ensure the proper and continuous function of electric motors, the items listed in this paragraph must be performed at the designated intervals. If operational checks indicate a motor is not functioning properly, these items will have to be checked to locate the problem.
D	1. CHECK MOTOR CONDITIONS.
	a. Keep motors free from dirt, dust and moisture.
	b. Keep operating space free from articles which may obstruct air circulation.
	c. Check for excessive grease leakage from bearings.
W	2. NOTE ALL UNUSUAL CONDITIONS.
	a. Unusual noises in operation.
	b. Motor failing to start or come to speed normally, sluggish operation.
	c. Motor or bearings which feel or smell hot.
	d. Continuous or excessive sparking commutator or brushes. Blackened commutator.
	e. Intermittent sparking at brushes.
	f. Fine dust under coupling having rubber buffers or pins.
	g. Smoke, charred insulation, or solder whiskers extending from armature.

Frequency of Service	
	h. Excessive humming.
	i. Regular clicking.
	j. Rapid knocking.
	k. Brush chatter.
	l. Vibration.
	m. Hot commutator.
A	3. LUBRICATE BEARINGS.
	a. Check grease in ball bearings and replenish when necessary.
	Follow instructions below when preparing bearings for grease.
	b. Wipe pressure gun fitting, bearing housing, and relief plug to make sure that no dirt gets into bearing with grease.
	c. Before using grease gun always remove relief plug from bottom of bearing to prevent excessive pressure in housing which might rupture bearing seals.
	d. Use clean screw driver or similar tool to remove hardened grease from relief hole and permit excess grease to run freely from bearing.
	e. While motor is running, add grease with hand operated pressure gun until it flows from relief hole, purging housing of old grease. If there is no bottom or relief plug on bearing housing, insert grease cautiously through upper plug. Usually four or five strokes of gun are enough. If bearing is over-lubricated, seal may be ruptured. If lubricating a running motor is dangerous, follow above procedure with motor at a standstill.

Frequency of Service		
		f. Allow motor to run for five minutes or until all excess grease has drained from bearing housing.
		g. Stop motor and replace relief plug tightly with wrench.
A	4.	USING A STETHOSCOPE,[6] CHECK BOTH BEARINGS. Listen for whines, gratings, or uneven noises. Listen all around the bearing and as near as possible to the bearing. Listen while the motor is being started and shut off. If unusual noises are heard, pinpoint the location.
	5.	IF YOU THINK THE MOTOR is running unusually hot, check with a thermometer. Place thermometer on the casting near the bearing, holding it there with putty or clay.
A	6.	DATEOMETER.[7] If there is a dateometer on the motor, after changing the oil in the motor, loosen the dateometer screw and set to the corresponding year.

QUESTION

11.1L What are the major items you would include when checking an electric motor?

[6] Stethoscope. An instrument used to magnify sounds and carry them to the ear.

[7] Dateometer. A small calendar disc.

Frequency
of
Service

Paragraph 16: Belt Drives

1. GENERAL. Maintaining a proper tension and alignment of belt drives ensures long life of belts and sheaves. Incorrect alignment causes poor operation and excessive belt wear. Inadequate tension reduces the belt grip, causes high belt loads, snapping, and unusual wear.

   a. Cleaning belts. Keep belts and sheaves clean and free of oil, which causes belts to deteriorate. To remove oil, take belts off sheaves and wipe belts and sheaves with a rag moistened in a non-oil base solvent. Carbon tetrachloride is not recommended because exposure to its fumes has many toxic effects on humans. It also is absorbed into the skin on contact and is cumulative.

   b. Installing belts. Before installing belts, replace worn or damaged sheaves, then slack off on adjustments. Do not try to force belts into position. Never use a screw driver or similar lever to get belts onto sheaves. After belts are installed, adjust tension; recheck tension after eight hours of operation. (See Table I.)

   c. Replacing belts. Replace belts as soon as they become frayed, worn, or cracked. NEVER REPLACE ONE V-BELT ON A MULTIPLE DRIVE. Replace the complete set with a set of matched belts, which can be obtained from any supplier. All belts in a matched set are machine-checked to ensure equal size and tension.

   d. Storing spare belts. Store spare belts in a cool dark place. Tag all belts in storage to identify them with the equipment on which they can be used.

2. V-BELTS. A properly adjusted V-belt has a slight bow in the slack side when running; when idle it has an alive springiness when thumped with the hand. An improperly tightened belt feels dead when thumped.

Frequency of Service	
	If the slack side of the drive is less than 45° from the horizontal, vertical sag at the center of the span may be adjusted in accordance with Table I below.

TABLE I. HORIZONTAL BELT TENSION

Span (inches)		10	20	50	100	150	200
Vertical Sag (inches)	From	.01	.03	.20	.80	1.80	3.30
	To	.03	.09	.58	2.30	4.90	8.60

M a. Check tension. If tightening belt to proper tension does not correct slipping, check for overload, oil on belts, or other possible causes. Never use belt dressing to stop belt slippage. Rubber wearings near the drive are a sign of improper tension, incorrect alignment, or damaged sheaves.

M b. Check sheave (pulley) alignment. Lay a long straight edge or string across outside faces of pulley, and allow for differences in dimensions from center lines of grooves to outside faces of the pulleys being aligned. Be especially careful in aligning drives with more than one V-belt on a sheave, as misalignment can cause unequal tension.

Paragraph 17: Chain Drives

1. GENERAL. Chain drives may be designated for slow, medium, or high speeds.

   a. Slow-speed drives. Because slow-speed drives are usually enclosed, adequate lubrication is difficult. Heavy oil applied to the outside of the chain seldom reaches the working parts; in addition, the oil catches dirt and grit and becomes abrasive. For lubricating and cleaning methods, see 5 and 6 below.

Frequency of Service	
	b. Medium- and high-speed drives. Medium-speed drives should be continuously lubricated with a device similar to a sightfeed oiler. High-speed drives should be completely enclosed in an oiltight case and the oil maintained at proper level.
D	2. CHECK OPERATION. Check general operating condition during regular tours of duty.
Q	3. CHECK CHAIN SLACK. The correct amount of slack is essential to proper operation of chain drives. Unlike other belts, chain belts should not be tight around the sprocket; when chains are tight, working parts carry a much heavier load than necessary. Too much slack is also harmful; on long centers particularly, too much slack causes vibrations and chain whip, reducing life of both chain and sprocket. A properly installed chain has a slight sag or looseness on the return run.
S	4. CHECK ALIGNMENT. If sprockets are not in line or if shafts are not parallel, excessive sprocket and chain wear and early chain failure result. Wear on inside of chain, side walls, and sides of sprocket teeth are signs of misalignment. To check alignment, remove chain and place a straight edge against sides of sprocket teeth.
S	5. CLEAN. On enclosed types, flush chain and enclosure with solvent. On exposed types, remove chain and soak and wash it in solvent. Clean sprockets, install chain, and adjust tension.
	NOTE: If chains are too large to soak them conveniently, wash them by applying solvent with a brush.
S	6. CHECK LUBRICATION. Soak exposed type chains in oil to restore lubricating film. Remove excess lubricant by hanging chains up to drain.

Frequency of Service	

Do not lubricate underwater chains which operate in contact with considerable grit. If water is clean, lubricate by applying waterproof grease with brush while chain is running.

Do not lubricate chains on elevators or on conveyors of feeders which handle dirty or gritty materials. Dust and grit combine with lubricants to form a cutting compound which reduces chain life.

S 7. CHANGE OIL. On enclosed types only, drain oil and refill case to proper level.

S 8. INSPECT. Note and correct abnormal conditions before serious damage results. Do not put a new chain on worn sprockets. Always replace worn sprockets when replacing a chain because out-of-pitch sprockets cause as much chain wear in a few hours as years of normal operation.

9. TROUBLE SHOOTING. Some common symptoms of improper chain-drive operation and their remedies follow:

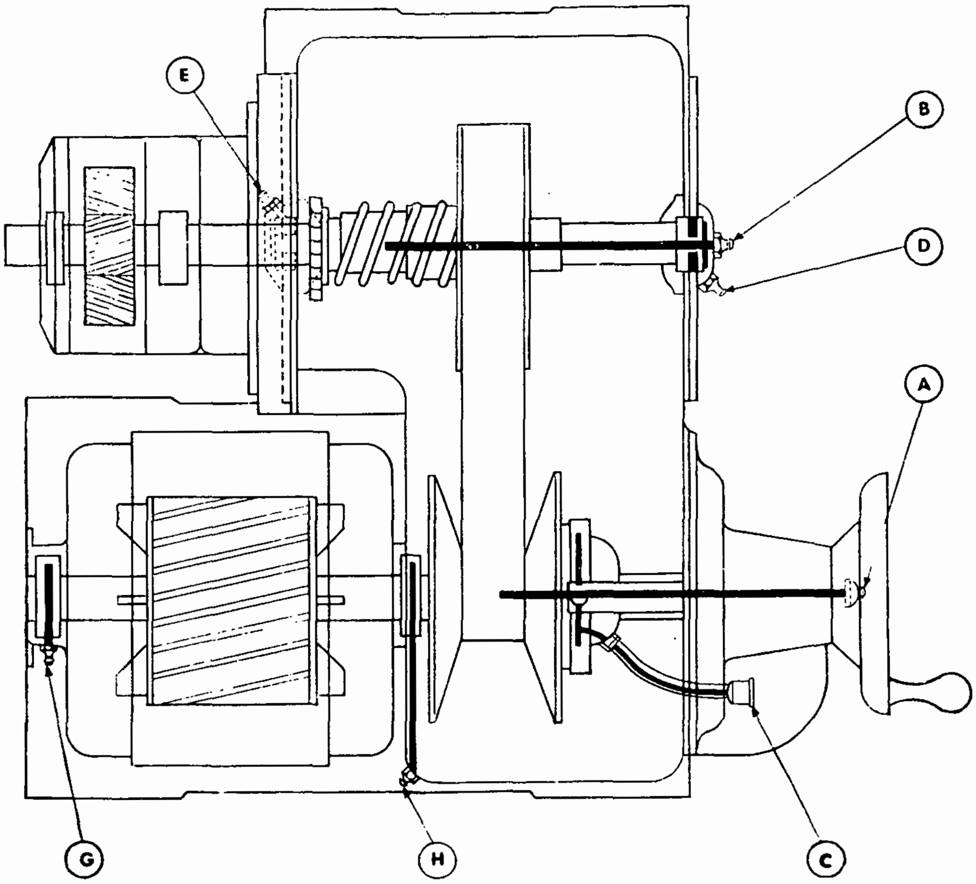
   a. Excessive noise. Correct alignment, if misaligned. Adjust centers for proper chain slack. Lubricate in accordance with aforementioned methods. Be sure all bolts are tight. If chain or sprockets are worn, reverse or renew if necessary.

   b. Wear on chain, side walls, and sides of teeth. Remove chain and correct alignment.

   c. Chain climbs sprockets. Check for poorly fitting sprockets and replace if necessary. Make sure tightener is installed on drive chain.

   d. Broken pins and rollers. Check for chain speed which may be too high for the pitch, and substitute chain and sprockets with shorter pitch if necessary. Breakage also may be caused by shock loads.

Frequency of Service	
	e. Chain clings to sprockets. Check for incorrect or worn sprockets or heavy, tacky lubricants. Replace sprockets or lubricants if necessary.
	f. Chain whip. Check for too-long centers or high pulsating loads and correct cause.
	g. Chains get stiff. Check for misalignment, improper lubrication, or excessive overloads. Make necessary corrections or adjustments.
	<u>Paragraph 18: Variable Speed Belt Drives</u> (See Fig. 11.12)
D	1. CLEAN DISKS. Remove grease, acid, and water from disk faces.
D	2. CHECK SPEED-CHANGE MECHANISM. Shift drive through entire speed range to make sure shafts and bearings are lubricated and disks move freely in lateral direction on shafts.
W	3. CHECK V-BELT. Make sure it runs level and true. If one side rides high, a disk is sticking on shaft because of insufficient lubrication or wrong lubricant. In this case, stop the drive at once, remove V-belt, and clean disk hub and shaft thoroughly with solvent until disk moves freely. Relubricate with soft ball-bearing grease and replace V-belt in opposite direction from that in which it formerly ran.
M	If drive is not operated for 30 days or more, shift unit to minimum speed position, placing spring on variable speed shaft at minimum tension and relieving belt of excessive pressure.
	4. LUBRICATE DRIVE. Make sure to apply lubricant at all the six force-feed lubrication fittings (Fig. 11.12: A, B, D, E, G, and H) and the one cup type fitting (C).
	NOTE: If the drive is used with a reducer, Fitting E is not provided.



NOTE: A, B, D, E, G, and H are force-feed lubrication fittings.
C is a cup type lubrication fitting.

Fig. 11.12 Reeves varidrive

(Source: War Department Technical Manual TM5-666)

Frequency of Service		
W	a.	Once every ten days to two weeks, use two or three strokes of a grease gun through fittings A and B at ends of shifting screw and variable speed shaft, respectively, to lubricate bearings of movable disks. Then, with unit running, shift drive from one extreme speed position to the other to ensure thorough distribution of lubricant over disk-hub bearings.
Q	b.	Add two or three shots of grease through fittings D and E to lubricate frame bearing on variable speed shaft.
Q	c.	Every 90 days add two or three cupfuls of grease to Cup C which lubricates thrust bearing on constant speed shaft.
Q	d.	Every 90 days use two or three strokes of grease gun through Fitting G and H to lubricate motor-frame bearings. CAUTION: Be sure to follow manufacturer's recommendation on type of grease. After lubricating, wipe excessive grease from sheaves and belt.

QUESTIONS

11.1M How can you tell if a belt on belt drive equipment has proper tension and alignment?

11.1N Why should sprockets be replaced when replacing a chain in a chain drive unit?

Frequency of Service	
	Paragraph 19: Couplings
	1. GENERAL. Unless couplings between the driving and driven elements of a pump or any other piece of equipment are kept in proper alignment, breaking and excessive wear results in either or both the driven machinery and the driver. Burned-out bearings, sprung or broken shaft, and excessively worn or ruined gears are some of the damages caused by misalignment. To prevent outages and the expense of installing replacement parts, check the alignment of all equipment before damage occurs.
	a. Improper original installation of the equipment may not necessarily be the cause of the trouble. Settling of foundations, heavy floor loadings, warping of bases, excessive bearing wear, and many other factors cause misalignment. A rigid base is not always security against misalignment. The base may have been mounted off level, which could cause it to warp.
	b. Flexible couplings permit easy assembly of equipment, but they must be aligned as exactly as flanged couplings if maintenance and repair are to be kept to a minimum. Rubber-bushed types cannot function properly if the bolts cannot move in their bushings.
S	2. CHECK COUPLING ALIGNMENT. Excessive bearing and motor temperatures caused by overload, noticeable vibration, or unusual noises may all be warnings of misalignment. Realign when necessary (Fig. 11.13) using a straight edge and thickness gage or wedge. To ensure satisfactory operation, level up to within 0.005 inch as follows:
	a. Remove coupling pins.
	b. Rigidly tighten driven equipment; slightly tighten bolts holding drive.

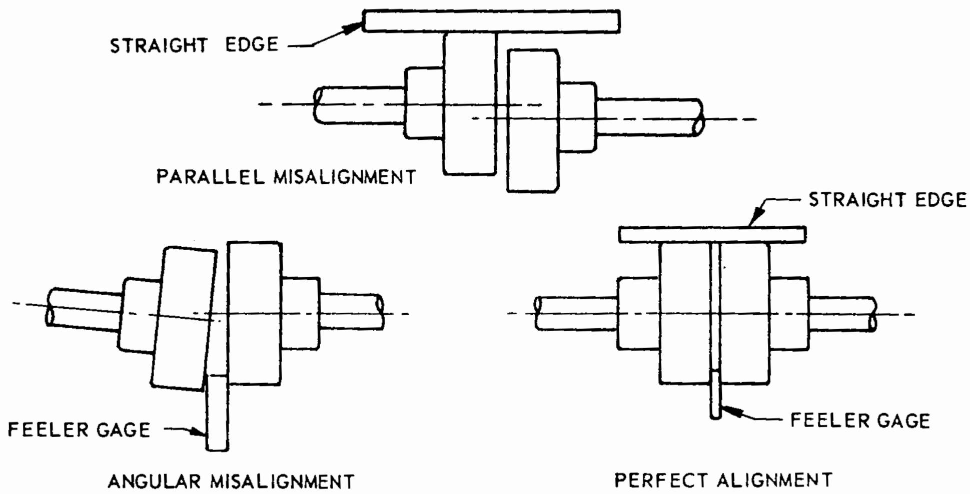


Fig. 11.13 Testing alignment, straight edge

(Source: Unknown)

Frequency of Service

c. To correct horizontal and vertical misalignment, shift or shim drive to bring coupling halves into position so no light can be seen under a straight edge laid across them. Place straight edge in four positions, holding a light back of straight edge to help ensure accuracy.

d. Check for angular misalignment with a thickness or feeler gage inserted at four places to make certain space between coupling halves is equal.

e. If proper alignment has been secured, coupling pins can be put in place easily using only finger pressure. Never hammer pins into place.

f. If equipment is still out of alignment repeat the procedure.

A — 3. CHANGE OIL IN FAST COUPLINGS. Drain out old oil and add gear oil to proper level. Correct quantity is given on instruction card supplied with each coupling.

Paragraph 20: Shear Pins

Many wastewater treatment units utilize shear pins as protective devices to prevent damage in case of sudden overloads. To serve this purpose these devices must be in operational condition at all times. Under some operating conditions shearing surfaces of a shear pin device may freeze together so solidly that an overload fails to break them.

Manufacturers' drawings for particular installations usually specify shear pin material and size. If this information is not available, obtain the information from the manufacturer, giving him model, serial number, and load conditions of unit. When necessary to determine shear pin size, select the lowest strength which does not break under the unit's usual loads. When proper size is determined never use a pin of greater strength, such as a bolt or a nail.

Frequency of Service	
	If necked pins are used, be sure the necked-down portion is properly positioned with respect to shearing surfaces. When a shear pin breaks, determine and remedy the cause of failure before inserting new pin and starting drive in operation.
M	1. GREASE SHEARING SURFACES.
Q	2. REMOVE SHEAR PIN. Operate motor for a short time to smooth out any corroded spots.
A	3. CHECK SPARE INVENTORY. Make sure an adequate supply is on hand, properly identified and with record of proper pin size, necked diameter, and longitudinal dimensions.

QUESTIONS

11.1O What factors could cause couplings to become out of alignment?

11.1P What is the purpose of shear pins?

END OF LESSON 4 OF 6 LESSONS

on

MAINTENANCE

Please answer the discussion and review questions before continuing with Lesson 5.

DISCUSSION AND REVIEW QUESTIONS

Chapter 11. Maintenance

(Lesson 4 of 6 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 3.

20. Why would you use a stethoscope to check an electric motor?

21. How would you determine if a motor is running unusually hot?

22. How would you clean belts on belt drive?

23. Why should you never replace only one belt on a multiple drive unit?

24. What do rubber wearings near a belt drive indicate?

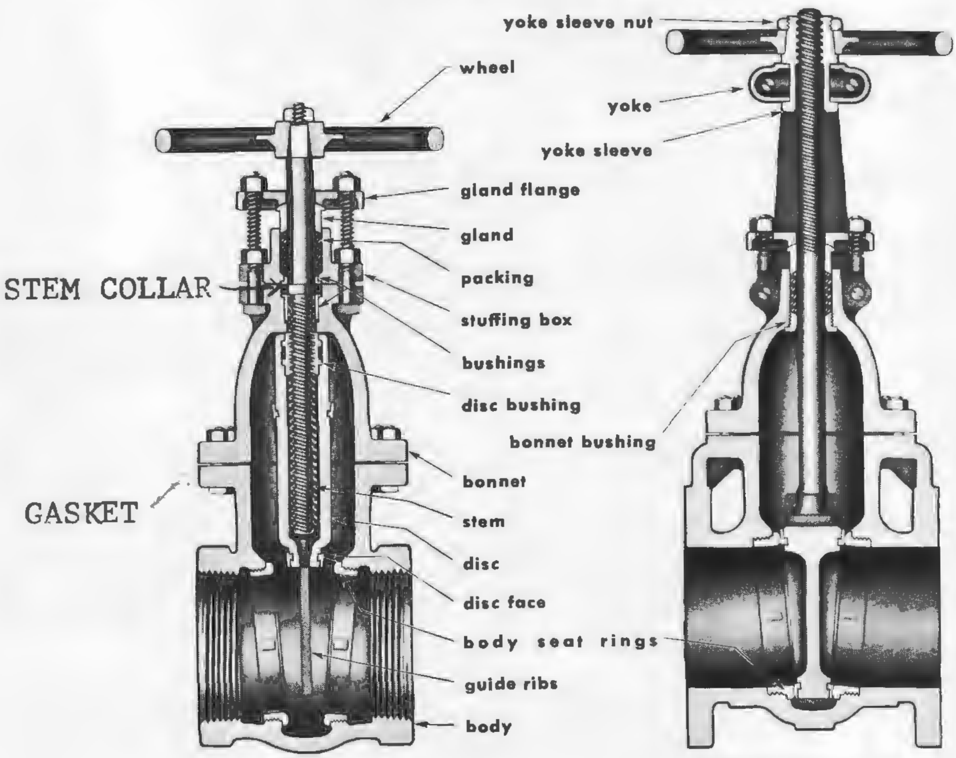
25. How can you determine if a chain in a chain drive unit has the proper slack?

26. What happens when couplings are not in proper alignment?

Frequency of Service	
	Paragraph 21: Gate Valves (Fig. 11.14)
	The most common maintenance required by gate valves (Fig. 11.14) is oiling, tightening, or replacing the stem stuffing box packing.
A	1. REPLACE PACKING. Modern gate valves can be repacked without removing them from service. Before repacking, open valve wide. This prevents excessive leakage when the packing or the entire stuffing box is removed by drawing stem collar stem tightly against bonnet on a nonrising stem valve, and tightly against bonnet bushing on rising stem valve.
	a. Stuffing box. Remove all old packing from stuffing box with a packing hook or a rat-tail file with bent end. Clean valve stem of all adhering particles and polish it with fine emery cloth. After polishing remove the fine grit with a clean cloth to which a few drops of oil have been added.
	b. Insert packing. Insert new split-ring packing in stuffing box and tamp it into place with packing gland. Stagger ring splits. After stuffing box is filled, place a few drops of oil on stem, assemble gland, and tighten it down on packing.
S	2. OPERATE VALVE. Operate inactive gate valves to prevent sticking.
A	3. LUBRICATE GEARING. Lubricate gate valves as recommended by manufacturer. Lubricate thoroughly any gearing in large gate valves. Wash open gears with solvent and lubricate with grease.
S	4. LUBRICATE RISING-STEM THREADS. Clean threads on rising-stem gate valves and lubricate with grease.

125-Pound Ferrosteel Wedge Gate Valves

Names of Parts



Non-Rising Stem Valve
Bronze Trimmed — Open

Outside Screw and Yoke Valve
Bronze Trimmed — Closed

These illustrations are representative of sizes 12-inch and smaller only

CHECK VALVES

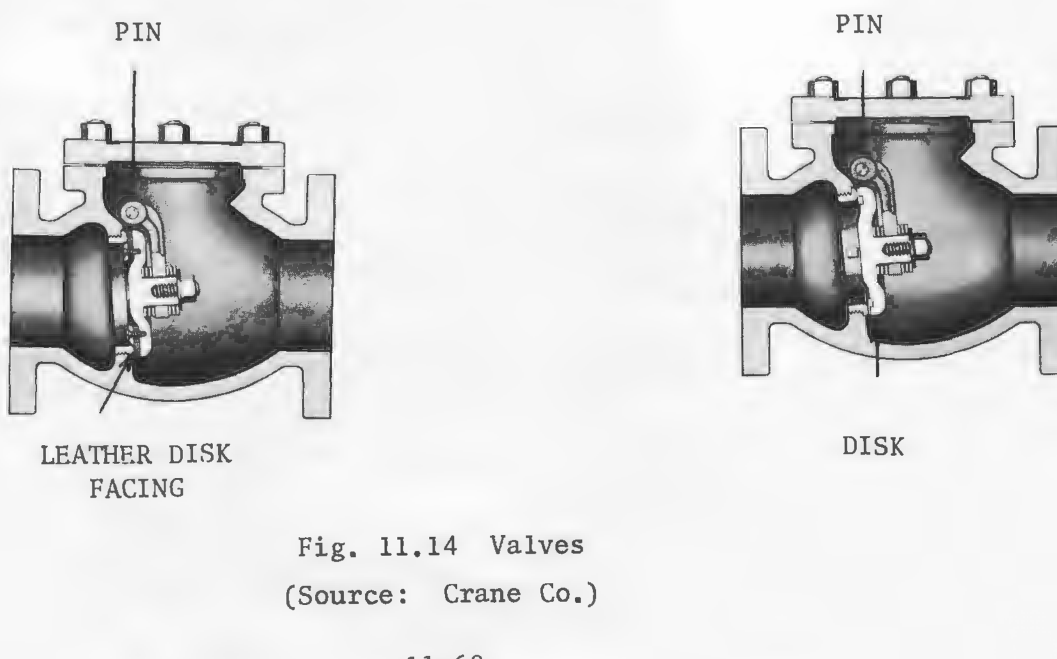


Fig. 11.14 Valves
(Source: Crane Co.)

Frequency of Service	
A	5. LUBRICATE BURIED VALVES. If a buried valve works hard, lubricate it by pouring oil down through a pipe which is bent at the end to permit oiling the packing follower below the valve nut.
A	6. REFACE LEAKY GATE VALVE SEATS. If gate valve seats leak, reface them immediately, using the method discussed below. A solid wedge disk valve is used for illustration, but the general method also applies to other types of reparable gate valves. Proceed as follows:

a. Remove bonnet and clean and examine disk and body thoroughly. Carefully determine extent of damage to body rings and disk. If corrosion has caused excessive pitting or eating away of metal, as in guide ribs in body, repairs may be impractical.

b. Check and service all parts of valve completely. Remove stem from bonnet and examine it for scoring and pitting where packing makes contact. Polish lightly with fine emery cloth to put stem in good condition. Use soft jaws if stem is put in vise.

c. Remove all old packing and clean out stuffing box. Clean all dirt, scale, and corrosion from inside of valve bonnet and other parts.

d. Do not salvage an old gasket. Remove it completely and replace with one of proper quality and size.

e. After cleaning and examining all parts, determine whether valve can be repaired by removing cuts from disk and body seat faces or by replacement of body seats. If repair can be made, set disk in vise with face leveled, wrap fine emery cloth around a flat tool, and rub or lap off entire bearing surface on both sides to a smooth, even finish. Remove as little metal as possible.

Frequency of Service

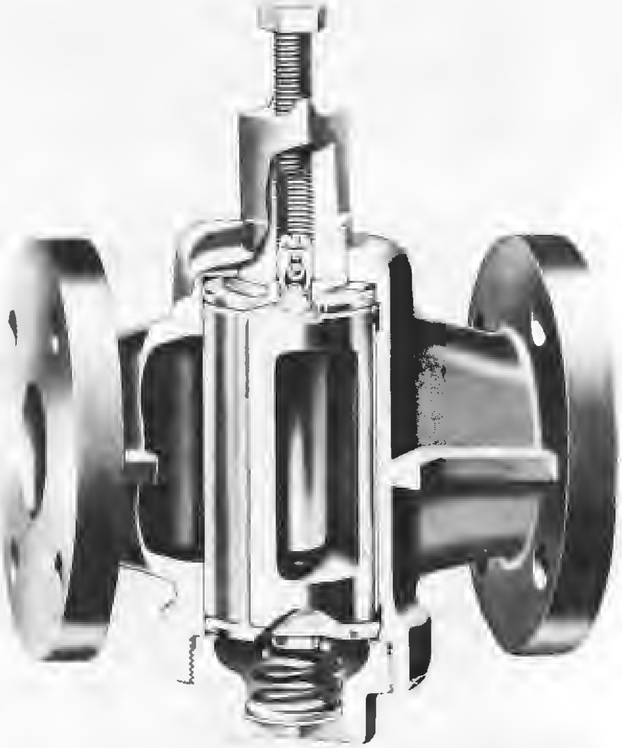
f. Repair cuts and scratches on body rings, lapping with an emery block small enough to permit convenient rubbing all around rings. Work carefully to avoid removing so much metal that disk will seat too low. When seating surfaces of disk and seat rings are properly lapped in, coat faces of disk with Prussian blue[8] and drop disk in body to check contact. When good, continuous contact is obtained, the valve is tight and ready for assembly. Insert stem in bonnet, install new packing, assemble other parts, attach disk to stem, and place assembly in body. Raise disk to prevent contact with seats so bonnet can be properly seated on body before tightening the joint.

g. Test repaired valve before putting it back in line to ensure that repairs have been properly made.

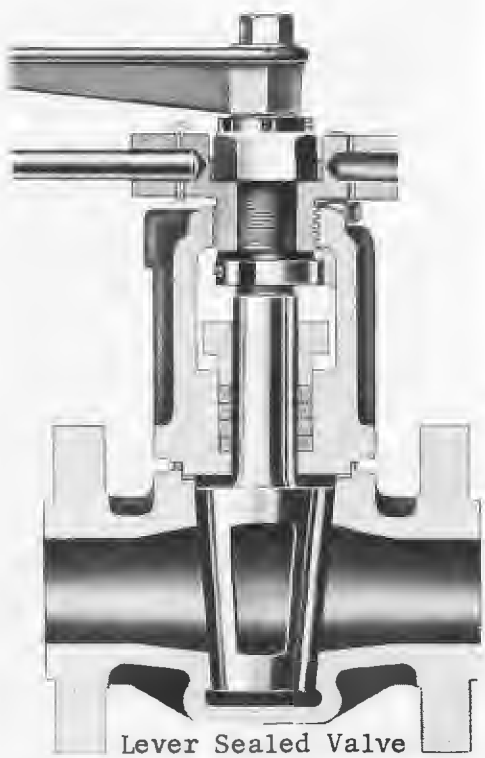
h. If leaky gate valve seats cannot be refaced, remove and replace seat rings with a power lathe. Check up body with rings vertical to arbor and use a strong steel bar across ring lugs to unscrew them. They can be removed by hand with a diamond point chisel if care is taken to avoid damaging threads. Drive new rings home tightly. Use a wrench on a steel bar across lugs when putting in rings by hand. Always coat threads with a good lubricant before putting them in. Lap in rings to fit disk perfectly.

[8] Prussian Blue. A paste or liquid used to show a contact area.

Frequency of Service	
	Paragraph 22: Check Valves (Fig. 1.14)
A	1. INSPECT DISK FACING. Open valves to observe condition of facing on swing check valves equipped with leather or rubber seats on disk. If metal seat ring is scarred, dress it with a fine file and lap with fine emery paper wrapped around a flat tool.
A	2. CHECK PIN WEAR. Check pin wear on balanced disk check valve, since disk must be accurately positioned in seat to prevent leakage.
	Paragraph 23: Plug Valves (Figs. 11.15 and 11.16)
M	1. ADJUST GLAND. The adjustable gland holds the plug against its seats in body and acts through compressible packing which functions as a thrust cushion. Keep gland tight enough at all times to hold plug in contact with its seat. If this is not done, the lubricant system cannot function properly; and solid particles may enter between the body and plug and cause damage.
M	2. LUBRICATE ALL VALVES. Apply lubricant by removing lubricant screw and inserting stick of plug valve lubricant for stated temperature conditions. Check valve fitting within shank prevents line pressure from blowing out when lubricant screw is removed. Inject lubricant into valve by turning screw down to keep valve in proper operating condition. If lubrication has been neglected, several sticks of lubricant may be needed before lubricant system is refilled to operating condition. Be sure to lubricate valves which are not used often to ensure that they are always in operating condition. Leave lubricant chamber nearly full so extra supply is available by turning screw down. Use lubricant regularly to increase valve efficiency and service, promote easy operation, reduce wear and corrosion, and seal valve against internal leakage.



Lubricated Plug Valve



Lever Sealed Valve

Fig. 11.15 Plug valves
(Source: Homestead Valve Manufacturing Co.)

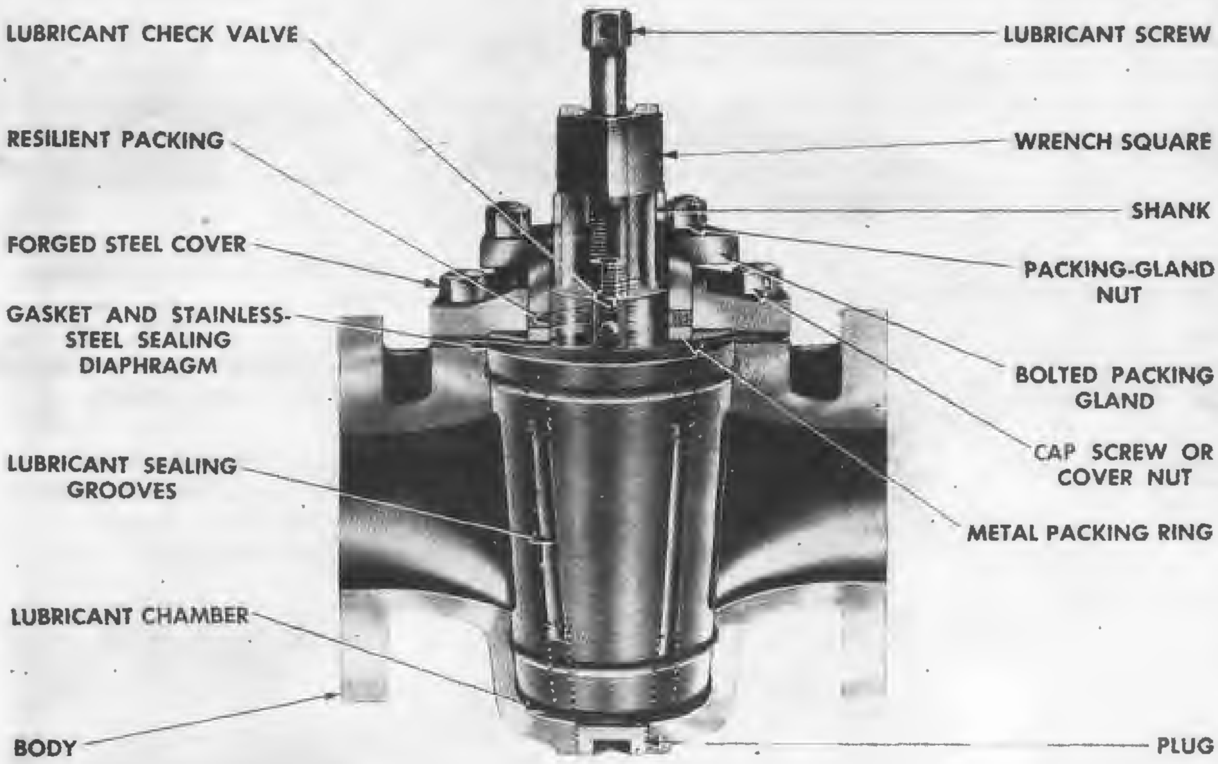


Fig. 11.16 Plug valves (contd.)

(Source: War Department Technical Manual TM5-666)

Frequency of Service	
	Paragraph 24: Sluice Gates (Fig. 11.17)
	There are two general types of sluice gates: those which seat with the pressure (Fig. 11.17), and those which seat against the pressure. Both are maintained similarly.
M	1. TEST FOR PROPER OPERATION. Operate inactive sluice gates. Oil or grease stem screws.
A	2. CLEAN AND PAINT. Clean sluice gate with wire brush and paint with proper corrosion-resistant paint.
A	3. ADJUST FOR PROPER CLEARANCE. For valves seating against pressure, check and adjust top, bottom, and side wedges until in closed position each wedge applies nearly uniform pressure against gate. (Fig. 11.18)

QUESTIONS

11.1Q What maintenance is required by:

a. gate valves?

b. sluice gates?

Fig. 11.17 Sluice gate
(Source: ARMCO)

Paragraph 25: Acknowledgment

Major portions and basic concepts in this section on mechanical maintenance are from the War Department Technical Manual, TM5-666, *Inspections and Preventive Maintenance Services, Sewage Treatment Plants and Sewer Systems at Fixed Installations*, War Department, September 1945.

END OF LESSON 5 OF 6 LESSONS

on

MAINTENANCE

Please answer the discussion and review questions before continuing with Lesson 6.

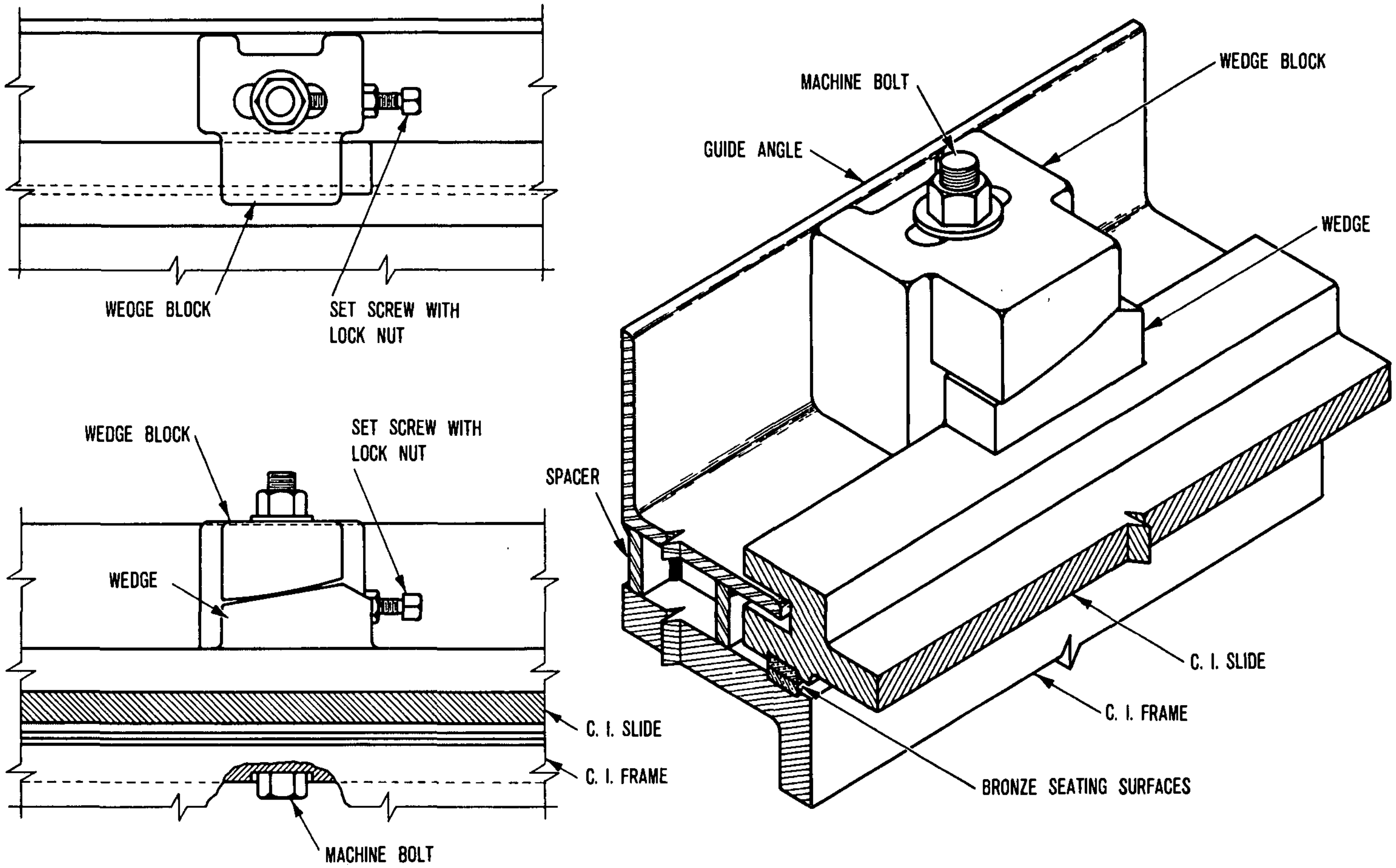


Fig. 11.18 Adjustment of sluice gate wedges

(Source: ARMCO)

DISCUSSION AND REVIEW QUESTIONS

Chapter 11. Maintenance

(Lesson 5 of 6 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 4.

27. Why should inactive gate valves be operated periodically?

28. Why should plug valves which are not used very often be lubricated regularly?

11.2 FLOW MEASUREMENTS--METERS AND MAINTENANCE

11.20 Flow Measurements, Use and Maintenance

Flow measurement is the determination of the quantity of a mass in movement within a known length of time (Fig. 11.19). Usually the mass which may be solid, liquid, or gas is contained within physical boundaries such as tanks, pipelines, and open channels or flumes. The limits of such physical or mechanical boundaries provide a measurable dimensional area that the mass is passing through. The speed at which the mass passes through these boundaries is related to dimensional distance and units of time; it is referred to as velocity. Therefore, we have the basic flow formula:

$$\text{Quantity} = \text{Area} \times \text{Velocity}$$

$$Q = AV$$

or

$$Q, \text{ cu ft/sec} = (\text{Area, sq ft})(V, \text{ ft/sec})$$

The performance of a treatment facility cannot be evaluated or compared with other plants without flow measurement. Individual treatment units or processes in a treatment plant must be observed in terms of flow to determine their efficiency and loadings. Flow measurement is important to plant operation as well as to records of operation. It is essential that the devices used for such measurement be understood, be used properly, and most important, be maintained so that information obtained is accurate and dependable.

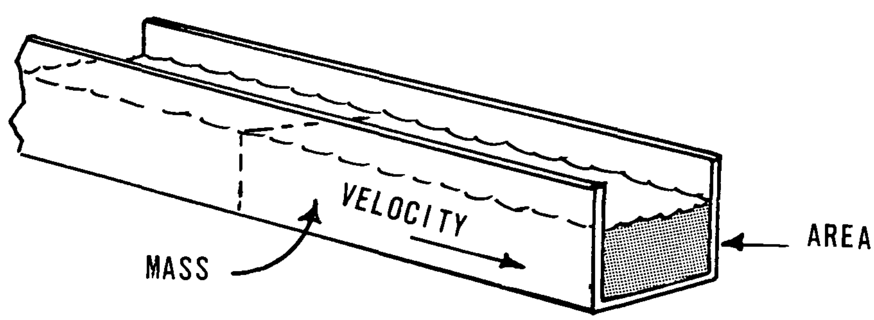


Fig. 11.19 Flow mass

11.21 Manufacturers' and Operators' Responsibilities

Equipment and instrument manufacturers should be required to furnish instruction manuals and parts lists. In the parts list it should be required that the manufacturer designate recommended spare parts, and such parts should be obtained and be available for use.

Instrumentation and flow measurement devices should be considered as fragile mechanisms. Rough handling will damage the units in as serious a manner as does neglect. Treat the devices with care, keep them clean, and they will perform their designated functions with accuracy and dependability.

11.22 Various Devices for Flow Measurement

The selection of a type of flow metering device, and its location, is made by the designer in the case of new plant construction. It is also possible that a metering device will have to be added to an existing facility. In both cases the various types available, their limitations, and criteria for installation should be known. Often the criteria for installation must be understood for the proper use and maintenance of a fluid flow meter. Metering devices commonly used in treatment facilities include:

Type	Common Name	Application
Constant Differential	Rotameter	Liquids and Gases a. Chlorination
Head Area	Weirs Rectangular Cipoletti V-Notch Proportional	Liquids--partially filled channels, basins, or clarifiers a. Influent b. Basin control c. Effluent d. Distribution
	Flumes Parshall Palmer-Bowlus Nozzles	Liquids--partially filled pipes and channels a. Influent b. Basin control c. Effluent d. Distribution
Velocity Meter	Propeller	Liquids--channel flow, clean water piped flow

Type	Common Name	Application
Velocity Meter	Magnetic	Liquids and sludge in closed pipe a. Influent b. Basin control c. Sludge recirculation d. Distribution
	Shuntflo	Gases--closed pipe a. Digester gas
Differential Head	Venturi Tube Flow Nozzle Orifice	Gases and liquids in closed pipes a. Influent b. Basin control c. Effluent d. Digester gas e. Distribution
Displacement	Piston Diaphragm	Gases and liquids in closed pipes a. Plant water b. Digester gas

A description of how each device works is in reality a definition of the meter type.

Constant Differential--A mechanical device called the "float" is placed in a tapered tube in the flow line. The difference in pressures above and below the float causes the float to move with flow variations. Instantaneous rate of flow is read out directly on a calibrated scale attached to the tube.

Head Area--A mechanical constriction or barrier is placed in the open flow line causing an upstream rise in liquid level. The rise or "head" (H) is a function of velocity of flow and when referenced to empirical flow formula provides an indication of the flow rate. When first starting to pump sludge in a long line, the pressure may increase considerably before the sludge starts flowing.

Velocity Meters--The velocity of the liquid flowing past the measurement point through a given area gives a direct relation to flow rate. The propeller type is turned by fluid flow past propeller vanes which move gear trains. These gear trains are used to indicate the fluid velocity or flow rate. The velocity of liquid flow past the probes of a magnetic meter is related to electrical formula and read out as the flow rate through secondary instrumentation. (See Section 11.24.) Pitot tubes are used to measure the velocity head (H) in flowing water to give the flow velocity ($V = \sqrt{2gH}$). (Fig. 11.20)

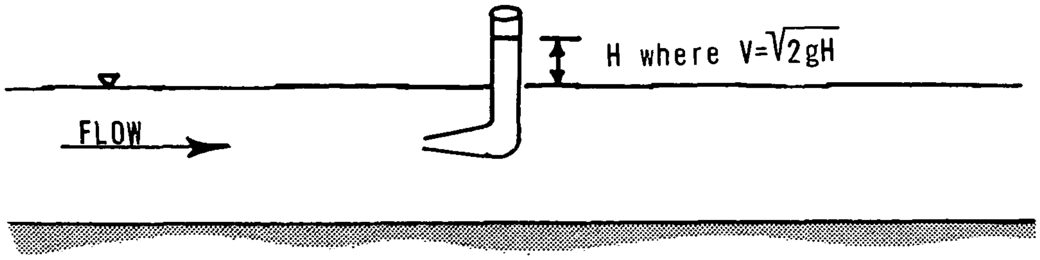


Fig. 11.20 Pitot tube

Differential Producers--A mechanical constriction (Fig. 11.21) in pipe diameter (reduction in pipe diameter) is placed in the flow line shaped to cause the velocity of flow to increase through the restriction. When the velocity increases, a pressure drop is created at the restriction. The difference between line pressure at the meter inlet and reduced pressure at the throat section is used to determine the flow rate which is indicated by a secondary instrument.

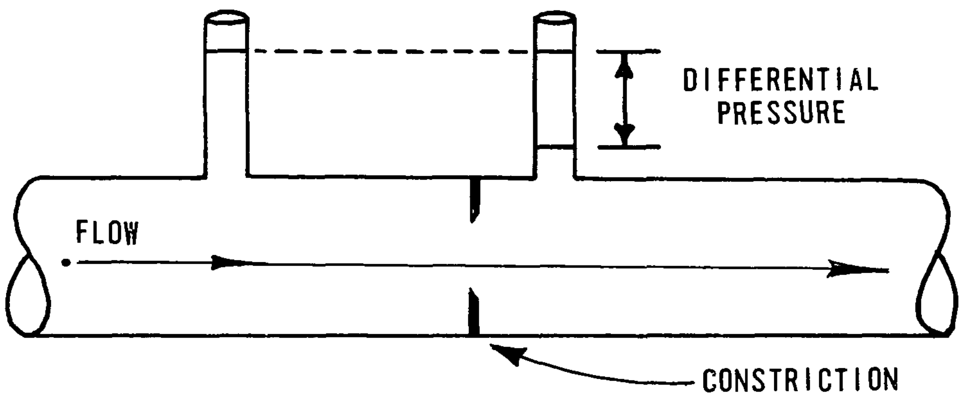


Fig. 11.21 Differential producer

Displacement Units--Liquids or gas enters, fills a tank or chamber of known dimensions, activates a mechanical counter, and empties the tank in readiness for another filling. Mechanical gearing activated by chamber fill and evacuation actuates a counter which is referenced to time and thus flow rate is determined.

11.23 Meter Location

The selection of a particular type of meter or measuring device and its location in a particular flow line or treatment facility is usually a decision made by the plant designer. Ideally the flow should be in a straight section before the meter. In open channels the flow should not be changing directions, nor should waves be present in the metering section above the measuring device. Valves, elbows, and other items that chould disrupt the flow ahead of a meter can upset the accuracy and reliability of a flow meter. Most flow meters are calibrated (checked for accuracy) in the factory, but they also should be checked in their actual field installation. When a properly installed and field calibrated meter starts to give strange results, check for obstructions in the flow channel and the flow metering device.

QUESTIONS

11.2A What is flow measurement?

11.2B Write the fundamental flow formula.

11.2C Why should flow be measured?

11.2D List several types of flow measuring devices.

11.2E If a flow meter does not read properly, what items should be checked as potential causes of error?

11.24 Conversion and Readout Instruments and Controls

Conversion and readout instrumentation is used to convert the initial measurement (for example, depth of water) to a more commonly used number or value (depth of water in a Parshall flume to flow of water in MGD). The type of device depends upon what the sensor (device) measures and what kind of results are desired. Often the conversion device only will transmit the signal (depth of water) to another meter which will interpret the signal and convert it to a usable number (flow in MGD). Instruments used with flow measurement equipment are classified as transmitters, receivers, recorders, controllers, and summators or totalizers. All of the different devices available are too numerous to list. Most devices used today will fall into the classifications outlined in the following paragraphs.

11.240 Mechanical Meters

Mechanical meters are those devices which measure the variable flow indicator and convert this value into a usable number. Conversion of the flow variable to a scale or meter giving the usable number may be by gear trains, hydraulic connections, magnetic sensing, electrical connections, and many other devices.

11.241 Transmitters

Transmitters send the flow variable, as measured by the measuring device, to another device for conversion to a usable number. Variables are transmitted mechanically, electrically, and pneumatically.

11.242 Receivers

Receivers pick-up the transmitted signal and convert it to a usable number. Receivers may present the measurement as an instantaneous flow rate, record the flow on a chart against time, and total or sum the flow during a time period. Receivers may have one, two, or all three of these features.

11.243 Controllers

Controllers are similar to receivers except they are capable of comparing received signals with other values and sending corrective or adjusting signals when necessary. The compared value may be manually set or it may be based on another received signal. The correction or adjustment may be proportional to the size of the deviation of the compared values, may be a gradual adjustment, or may provide a predetermined correction based on the size of the deviation and your objectives.

Selection and adjustment of controllers should be done by a specialist in the field or the manufacturer's representative. Maintenance must be done according to manufacturer's instructions.

11.25 Sensor Maintenance

Each individual sensing meter will have its own maintenance requirements. In any instrument, the sensor is the most common source of problems. Fortunately, the electronics or drive are easy to check. The important and common maintenance requirements are tabulated below in relation to meter types. Not all the maintenance problems can be listed. It is a proven fact that if preventive maintenance is regularly applied the uncommon problem is a rare occurrence.

The most important single item to be considered in maintenance is good housekeeping. This must take many forms since it is applied to various devices. Good housekeeping, the act of providing preventive maintenance for each of the various sensors, includes being sure that foreign bodies are not interfering with the measuring device. Check for and remove deposits which will accumulate from normal use. Repair the sensor or measuring device whenever it is damaged.

Common preventive maintenance suggestions:

Motor Type	Suggested Maintenance
Constant Differential Rotameters	Disassemble and clean tube and float when deposits are observed.
Head Area	
Weirs: Rectangular, Cipoletti, V-Notch, Proportional	Flow formula is based on square clean edges to the meter shape with free fall over the weir. Clean and brush off deposits as accumulated. Keep clear of foreign bodies and interference.

Motor Type	Suggested Maintenance
Head Area	
Flumes: Parshall Palmer-Bowlus Nozzles	Normally used with float wells, keep sensor line between well and flume clean; clean off deposits.
Velocity Meter	
Propeller	Should not be used on anything but clear water. Grease and check yearly.
Shuntflo	Keep dampening chamber fluid level to line; periodically drain to remove collected sediment.
Magnetic	Manufacturers are providing various cleaning mechanisms to clean the internal parts regularly. If you as an operator manually operate, be sure to perform maintenance on schedule; if automatically, check action frequently. Provide for periodic meter removal from line and physically clean meter.
Differential Producers	Venturi, nozzle, and orifice hydraulic connections should be back-flushed regularly. Installation should be arranged for internal surface cleaning on a reasonable schedule.
Displacement	Periodically drain and flush. Keep greased as necessary; check frequently on operation.

External connections between the sensing and conversion and readout devices should be checked to ensure such connections are clean in appearance and connections are firm. Be sure no foreign obstruction will interfere or promote wear. On mechanical connections, grease as directed; on hydraulic or pneumatic connections, disconnect and ensure free flow in the internal passage.

11.26 Conversion and Readout Instrument Maintenance

Both the mechanically actuated unit and the transmitters will have direct sensor connections. Cleaning and checking on a regular schedule is essential to avoid problems with the usual accumulation of foreign material. Maintenance for the internal parts to either device is minimized when the sensor connections are clean and operable. Normal wear will occur and is increased when sediments and deposits are not removed regularly as directed. Lubricate mechanical components as directed by the equipment manufacturers' instrument manuals. Do not over-lubricate, because it causes other difficulties equally as troublesome as under-lubrication.

Receiver maintenance is limited to periodic checking of mechanical parts, proper lubrication, and good housekeeping within the unit. Moisture should be eliminated by heat if required. Pneumatic instruments should be watched carefully to ensure that foreign particles which might be introduced by the air supply do not cause clogging in the actuating elements. Pneumatic systems are usually protected by air filters or traps at the supply source and individual units at the instrument. Filters should be cleaned and blown down on a regular schedule to ensure their efficient operation in cleaning the air supply. In the case of clogging of small orifices and devices of the pneumatic system, do not attempt to pressurize the system at higher than normal operating pressure for cleaning. Such action will damage internal parts. Follow procedures as outlined by the manufacturer and as shown in the instruction manuals.

Most reputable manufacturers are equipped to provide repair service in the case of worn parts, or mechanical failure. It is recommended that major service be left to trained employees of the manufacturer. It is preferred that manufacturers have field service available for repair on the plant premises; however, if such service is not available, the device should be returned to the factory.

Many manufacturers have a maintenance contract service available wherein a trained service employee periodically, on a prescribed schedule, checks the instrument in all ways including accuracy and wear factors. Such periodic checking allows for replacement of parts prior to a complete breakdown. Parts which would normally wear over a time period are replaced by this serviceman who will anticipate such need from an experience factor.

> Do not attempt instrument service, parts replacement, or repair work unless you have read the instruction manual thoroughly and you understand what you are doing. Follow the procedures as set forth in the instruction manual carefully.

All instruments are connected to a power supply of some source. That power supply is potentially dangerous unless handled properly. Be sure all electrical power is shut off and secured so that others cannot unintentionally switch the source on. On electrical and electronic devices the electrical power used and/or generated within the device is exceptionally dangerous, both to the man and to the other component equipment. Do not attempt service unless you are qualified to do so.

Recording charts often seem to accumulate at a rapid rate, and a decision must be made whether to store or destroy old records. Inconvenient as it may be, records should be retained. They are the backbone of reference information needed for future planning and plant expansion when necessary. Above all, if properly used, they are an index for efficiency checks unparalleled in value. Storage space may be minimized by preparing summary records, microfilm photocopy, or selective sampling and storage of the usual and unusual.

QUESTIONS

11.2F What is the purpose of transmitting instruments?

11.2G What is the most important item in maintaining flow meters?

11.2H What should you do with old recording chart records?

11.3 UNPLUGGING PIPES, PUMPS AND VALVES

11.30 Plugged Pipelines

Plugged pipelines are encountered in lines transporting scum, raw sludge, digested sludge, or grit. The frequency of a particular line plugging depends on the type of material passing through the line, the construction material of the line, the type of pumps or system used to move the material, and the routine maintenance performed on the line. This section outlines the preventive maintenance measures to reduce plugging problems in the different lines in a wastewater treatment plant and the methods of unplugging pipes, pumps, and valves.

11.31 Scum Lines

Scum will cause more problems in pipelines than any other substance pumped in a wastewater treatment plant. Problems are more frequent and more severe in colder weather when grease tends to coagulate faster.

Preventive maintenance includes:

1. Hose down scum troughs, hoppers, and flush lines to scum box at least every two hours when an operator is on duty and problems are occurring.

2. Clean lines monthly using:

   a. Rods equipped with cutters
   b. High pressure hydraulic pipe cleaning units
   c. Steam cleaning units
   d. Chemicals such as "Sanfax" or "Hot Rod" (strong hydroxides). This method is least desirable because of costs and the possibility that the chemicals could be harmful to biological treatment processes.

11.32 Sludge Lines

Sludge lines will plug more often when scum and raw sludge are pumped through the same line, or storm waters carry in grit and silt that are not effectively removed by the grit removal facilities.

Preventive maintenance includes:

1. Flush lines monthly with plant effluent or wastewater.

2. If possible, recirculate warm digested sludge for an hour through the line each week if grease tends to build-up on pipe walls.

3. Rod or high pressure clean lines monthly or quarterly, depending on severity of problem.

4. If possible, force cleaning tool (pig) through line using pressures produced by pump. Line must be equipped with valves and wyes to install and remove pig. Pumps must be located to allow pig to be forced through the line. A plastic bag full of ice cubes makes an excellent cleaning tool or pig. Force the bag down the line with hot water. If the line plugs, the ice will melt to the point where the bag will continue down the line.

11.33 Digested Sludge Lines

Problems develop in digested sludge lines of small plants from infrequent use, ineffective grit removal, and failure to remove sludge from the line after withdrawing sludge to a drying bed.

Preventive maintenance includes checking:

1. Condition of pipeline for wear or obstructions, such as sticks and rags.

2. Pump impellers for wear. A worn impeller will not maintain desired velocity and pressure in the line.

11.34 Unplugging Pipelines

Selection of a method to unplug a pipe depends on the location of the blockage and access to the plugged line. Pressure methods and cutting tools are the most common techniques used to clear stopped lines.

11.340 Pressure Methods

Requirements:

1. Must be able to valve off or plug one end of pipeline in order to move obstruction or blockage down the line and out other end to a free discharge.

2. Pressure may be developed using water or air pressure. Maximum available pressures are usually less than 80 psi.

3. Pipeline must have tap and control valves to control applied water or air pressure.

Precautions:

1. Never use water connected to a domestic water supply because you may contaminate the water supply.

2. Do not exceed pipeline design pressures, usually 125 psi.

3. Never attempt to use a positive displacement pump by over-riding the safety cut-out pressure switches. This practice may damage the pump.

Procedure:

1. Plug or valve off one end of pipe, but leave other end open. For example, (1) close valve to digester but open line to the drying beds, or a raw sludge line, or (2) close suction valve on raw sludge pump, and open pipe back to primary clarifier hopper.

2. Connect hose from pressure supply to tap and valve on pipeline as close as possible to the plugged or valved-off end.

3. Apply pressure to supply hose and then slowly open control tap valve and allow pressure to build-up until obstruction is moved.

Do Not Exceed Pipeline Working Design Pressure.

11.341 Cutting Tools

Cutting tools are usually available from sewer maintenance crews and may consist of hand rods, power rods, snakes, or high pressure (600-1000 psi) hydroflush units.

Requirements:

1. One end of the line must be open and reasonably accessible.

2. Cutting tools should be able to remove material causing stoppage when line is cleared.

Limitations:

1. Most of these units can not clean lines with sharp bends or pass through some of the common types of plug valves used in sludge lines.

2. A 4-inch cutter may have to be used on a 6-inch line due to 90-degree bends.

3. A part of the line may have to be dismantled to use a cutting tool.

4. Rods are difficult to hand push over 300 feet. The operator must have firm footing and room to work.

Hand Rods:

1. Use sufficient sections to clean full length of line.

2. Insert cutter in the open end of the pipeline and twist rods as they are pushed up the line.

3. If rods start to twist up due to torque, pull back and let rod unwind.

Power Rods:

1. Power drive unit must be located over plugged line. Don't attempt to run 40 feet across a clarifier and then into sludge line.

2. Don't run rods into line too fast because you may hit obstruction or valve and break cutter off of rods which are very difficult to recover.

11.342 Hydraulic Nozzle Pressure Unit

This unit is very good for removing grease, sludge or grit from pipelines.

Procedure:

1. Insert nozzle and hose 3 feet into line.

2. Increase pressure in cleaning system to 600 to 1000 psi and let hose off reel slowly into pipeline.

3. Keep track of hose footage in line in order to prevent nozzle from attempting to go through an open valve. The nozzle and hose may catch on the valve and require dismantling the valve to free the nozzle.

4. Run water through nozzle while reeling in hose.

11.343 Last Resort

If the methods described in this section fail, the only solution is to attempt to locate the position of the stoppage, drain the line, dismantle the plugged section of the pipeline, and remove the obstruction.

11.35 Plugged Pumps and Valves

Isolate plugged pump or valve from the remainder of treatment plant by valving-off plugged section and locking-out power supply to pump. Remove pump inspection plate or dismantle valve and remove material causing blockage. Exercise caution when removing materials to avoid damaging the pump or valve.

11.4 SUMMARY

1. Establish and follow a regular maintenance program.

2. Thoroughly read and understand manufacturers' maintenance instructions. Ask for assistance if you do not understand them. Follow the manufacturers' instructions in your maintenance program.

3. Critically evaluate the maintenance and repair capabilities of yourself and your facilities. Request the help of an expert when necessary.

11.5 ADDITIONAL READING

a. MOP 11, pages 9-16 and 164-172.

b. New York Manual, pages 157-168.

c. Texas Manual, pages 102-133, 134-159, and 445-460.

END OF LESSON 6 OF 6 LESSONS

on

MAINTENANCE

Please answer the discussion and review questions before continuing with the Objective Test.

DISCUSSION AND REVIEW QUESTIONS

Chapter 11. Maintenance

(Lesson 6 of 6 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 5.

29. Calculate the quantity of flow in cubic feet per second when wastewater flows through an area of 2.5 square feet at a velocity of 1.5 feet per second.

30. What type of flow meter is used to measure the flow of chlorine gas?

31. What does a pitot tube measure?

32. Why should a flow meter be calibrated in its field installation?

33. What is the most common source of problems in flow meter instruments?

34. Why should major repairs of instrumentation be conducted by trained employees of the manufacturer?

35. How can scum lines be kept from plugging?

SUGGESTED ANSWERS

Chapter 11. Maintenance

11.0A A good maintenance program is essential for a wastewater treatment plant to operate continuously at peak design efficiency.

11.0B The most important item is maintenance of the mechanical equipment--pumps, valves, scrapers, and other moving equipment. Other items include plant buildings and grounds.

11.0C A good record system tells when maintenance is due and also provides a record of equipment performance. Poor performance is a good justification for replacement or new equipment.

11.0D Both cards are vital in a good record keeping system. The equipment service record card is a permanent or master card that indicates when or how often certain maintenance work should be done. The service record card is a record of who did what work on what date and is helpful in determining when the future maintenance work is due. It may keep your warranty in force.

11.0E A building maintenance program will keep the building in good shape and includes painting when necessary. Attention also must be given to electrical systems, plumbing, heating, cooling, ventilating, floors, windows, and roofs. The building should be kept clean, tools should be stored in their proper place, and essential storage should be available.

11.0F When plant tanks and channels are drained, the operator should check surfaces for wear and deterioration from wastewater or fumes. Protective coatings should be applied where necessary to prevent further damage.

11.0G Well-groomed and neat grounds are important because many people judge the ability of the operator and the performance of his plant on the basis of the appearance of the plant.

11.0H Chlorine is toxic to humans and will cause corrosion damage to equipment.

11.0I Large chlorine leaks can be detected by smell. Small leaks are detected by soaking a cloth with ammonia water and holding the cloth near areas where leaks might develop. A white cloud will indicate the presence of a leak.

11.1A Pumps must be lubricated in accordance with manufacturers' recommendations. Quality lubricants should be used.

11.1B In lubricating motors, too much grease may cause bearing trouble or damage the winding.

11.1C If a pump will not start, check for blown fuses or tripped circuit breakers and the cause, such as a loose connection, fuse, or thermal unit.

11.1D To increase the rate of discharge from a pump, you should look for something causing the reduced rate of discharge, such as pumping air, motor malfunction, plugged lines or valves, impeller problems, or other factors.

11.1E A cross-connection is a connection between two piping systems where an undesirable water (water from water seal) could enter a domestic water supply.

11.1F Yes. A slight leakage is desirable when the pumps are running to keep the packing cool and in good condition.

11.1G To measure the capacity of a pump, measure the volume pumped during a specific time period.

$$\text{Capacity, GPM} = \frac{\text{Volume, gallons}}{\text{Time, minutes}}$$

11.1H

$$\begin{aligned}\text{Capacity, GPM} &= \frac{\text{Volume, gallons}}{\text{Time, minutes}} \\ &= \frac{10\text{ ft} \times 15\text{ ft} \times 1.7\text{ ft} \times 7.5\text{ gal/cu ft}}{5\text{ minutes}} \\ &= 382.5\text{ GPM}\end{aligned}$$

11.1I Before a prolonged shutdown the pump should be drained to prevent damage from corrosion, sedimentation, and freezing. Also, the motor-disconnect switch should be opened to disconnect motor.

11.1J Shear pins commonly fail in reciprocating pumps because of (1) a solid object lodged under piston, (2) a clogged discharge line, or (3) a stuck or wedged valve.

11.1K A noise may develop when pumping thin sludge due to water hammer, but will disappear when heavy sludge is pumped.

11.1L When checking an electric motor, the following items should be checked periodically, as well as when trouble develops:

1. Motor condition
2. Note all unusual conditions
3. Lubricate bearings
4. Listen to motor
5. Check temperature

11.1M A properly adjusted horizontal belt has a slight bow in the slack side when running. When idle, it has an alive springiness when thumped with the hand. Vertical belts should have a springiness when thumped. To check for proper alignment, place a straight edge against the pulley face or faces. If a ruler won't work, use a transit for long runs, or the belt may be examined for wear.

11.1N Always replace sprockets when replacing a chain because old, out-of-pitch sprockets cause as much chain wear in a few hours as years of normal operation.

11.1O Improper original installation of equipment, settling of foundations, heavy floor loadings, warping of bases, and excessive bearing wear could cause couplings to become out of alignment.

11.1P Shear pins are designed to fail if a sudden overload occurs that could damage expensive equipment.

11.1Q The most common maintenance required by (a) gate valves is oiling, tightening, or replacing the stem stuffing box packing. The most common maintenance required by (b) sluice gates is testing for proper operation, cleaning and painting, and adjusting for proper clearance.

11.2A Flow measurement is the determination of the <u>rate</u> of flow past a certain point, such as the inlet to the headworks structure of a treatment plant. It is measured and recorded as a quantity (gallons or cubic feet) moving past a point during a specific time interval (seconds, minutes, hours, or days). Thus we obtain a flow rate or quantity in cu ft/sec or MGD.

11.2B Quantity = Area x Velocity, or Q = AV.

11.2C Flow should be measured in order to determine wastewater treatment plant loadings and efficiency.

11.2D Different types of flow measuring devices include constant differential, head area, velocity meter, differential head, and displacement.

11.2E Potential causes of flow meter errors include foreign objects fouling the system or the meter may not be installed in the intended location. (Liquids should flow smoothly through the meter and flow should not be changing directions, nor should waves be present on the liquid surface above the measuring device.) Check the primary sensor, transmitter, receiver, and power supply.

11.2F Transmitting instruments can take a reading (depth measurement) from a flow metering device (Parshall flume) and send it to a readout instrument which converts the depth measurement to a flow rate (MGD).

11.2G The most important item in flow meter maintenance is good housekeeping. Your instruments must be kept clean and in good working condition.

11.2H Old recording charts should be stored for future reference, such as checks on plant performance, budget justifications, and information needed for future planning. Storage space may be minimized by preparing summary records, microfilm photocopy, or selective sampling and storage of the usual and unusual.

OBJECTIVE TEST

Chapter 11. Maintenance

Name ______________________________ Date ______________

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one answer to each question.

1. The duties of a wastewater treatment plant operator may include:

    1. Regulation of plant treatment processes
    2. Public relations
    3. Maintaining equipment and buildings
    4. Painting and cleaning plant buildings
    5. Keeping maintenance records

2. Equipment service cards and service record cards should:

    1. Identify the piece of equipment that the record card represents
    2. Record sick leave
    3. Maintain selective service records
    4. Indicate the work to be done
    5. Indicate the work done

3. What happens if you do not periodically drain and inspect plant tanks and channels?

    1. Serious maintenance problems could develop
    2. Costly repairs could result
    3. The operator will not know if cracks are developing in underground tanks and channels
    4. An emergency situation may develop and force you to discharge partially or improperly treated wastes into receiving waters during critical conditions
    5. The operator will stay out of trouble

4. How can a chlorine leak be detected?

    1. By an explosiometer
    2. Smell
    3. Green or reddish deposits on metal
    4. By waving an ammonia soaked rag
    5. By checking the leak gage

5. A reciprocating pump:

    1. Has a rotating impeller
    2. Has a piston that moves back and forth
    3. Has two check valves
    4. Is used to pump sludge
    5. Makes a regular "thunk-thunk" sound when working properly

6. Before starting, a pump should:

    1. Have its shaft turned by hand to see that it rotates freely
    2. Run in the shipping crate so it can be returned if it doesn't work
    3. Be properly lubricated
    4. Be allowed to sit outside and become accustomed to adverse conditions
    5. Be checked to ensure that the shafts of the pump and motor are aligned

7. Float and electrode switches should be checked at least once a week to see that:

    1. Floatable solids are floating
    2. Controls respond to changing water levels in the wet well as expected
    3. Pump motor starts and stops at the proper time
    4. The switches change the direction of flow
    5. None of these

8. Level control systems in a wet well include:

    1. Electrodes
    2. Hearts
    3. Floats
    4. Diaphragms
    5. Bubblers

9. If a pump will not start, check for:

    1. Tripped circuit breakers
    2. Loose terminal connections
    3. Water in the wet well
    4. Nuts, bolts, scrap iron, wood, or plastic in the wrong places
    5. Shaft binding or sticking

10. Preventive maintenance of electric motors includes:

    1. Frequently starting and stopping the motor to give it a rest
    2. Lubricating bearings
    3. Checking temperature of motor
    4. Keeping motor free from dust, dirt and moisture
    5. Keeping motor outdoors where it can stay cool

11. Maintenance of couplings between the driving and driven elements includes:

   1. Keeping proper alignment
   2. Keeping proper alignment even with flexible couplings
   3. Draining old oil in fast couplings
   4. Keeping the electrodes free of scum and corrosion
   5. Regular use of a crowbar to line them up

12. Pump maintenance includes:

   1. Preventing all water seal leaks around packing glands
   2. Operating two or more pumps of the same size alternately to equalize wear
   3. Checking operating temperature of bearings
   4. Checking packing gland
   5. Lubricating the impeller

13. Approximately how far down should the level in a wet well be lowered in one minute by a pump with a rated capacity of 200 gpm? The wet well is five feet wide and five feet long.

   1. 0.1 ft
   2. 0.5 ft
   3. 1.0 ft
   4. 1.1 ft
   5. 2.0 ft

14. Maintenance of gate valves includes:

   1. Lubricating with Prussian blue
   2. Tightening or replacing the stem stuffing box packing
   3. Operating inactive valves to prevent sticking
   4. Lubricating bearing
   5. Refacing leaky valve seats

15. Flow records provide:

   1. Data to control plant processes
   2. Nice listening music
   3. Information for regulatory agencies
   4. Something to keep the operator working
   5. For plant input and output determination

16. If a flow meter appears to be operating improperly, the operator should:

   1. Shake it
   2. Check connections
   3. Look for foreign objects in the system
   4. Check need for lubrication
   5. Hammer on it

17. If a flow meter does not read properly, what items should be checked as potential causes of error?

    1. Installation of sensor and readout devices
    2. Restrictions in the sensor and transmitter
    3. Power supply to instruments
    4. Check instruments according to manufacturer's instructions
    5. Blow the transmission lines out with high pressure air

18. Reciprocating pumps should be operated when:

    1. Suction and discharge line valves are closed
    2. Suction line valve open and discharge line valve closed
    3. Suction line valve closed and discharge line valve open
    4. Suction and discharge line valves open

19. Modern gate valves can be repacked without removing them from service.

    1. True
    2. False

20. Old gaskets should be salvaged.

    1. True
    2. False

<u>Review Questions:</u>

A trickling filter 95 feet in diameter and four feet deep receives a flow of 3 MGD with a BOD of 120 mg/l.

21. The hydraulic loading on the trickling filter is approximately:

    1. 200 gpd/sq ft
    2. 400 gpd/sq ft
    3. 600 gpd/sq ft
    4. 800 gpd/sq ft
    5. 1000 gpd/sq ft

22. The organic loading on the trickling filter is approximately:

    1. 25 lbs BOD/1000 cu ft
    2. 50 lbs BOD/1000 cu ft
    3. 100 lbs BOD/1000 cu ft
    4. 200 lbs BOD/1000 cu ft
    5. 300 lbs BOD/1000 cu ft

Please write on your IBM answer sheet the total time required to work Chapter 11.

CHAPTER 12

PLANT SAFETY AND GOOD HOUSEKEEPING

by

Robert Reed

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Chapter 12. Plant Safety and Good Housekeeping

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S SANENESS, COMMON SENSE, SUSPICIOUS OF TROUBLE
A ALWAYS, ALERTNESS
F FIRST
E EFFORT
T THINK
Y YOU

ACCIDENTS DON'T JUST HAPPEN...
THEY ARE CAUSED!

PRE-TEST

Chapter 12. Plant Safety and Good Housekeeping

The objective of the Pre-Test is to indicate to you some of the important items in the chapter. You are not expected to know all of the answers.

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to each question.

1. To prevent coming in contact with infections and infectious diseases, the operator should:
    1. Wash his hands before eating
    2. Wear protective gloves when in contact with wastewater and sludges
    3. Not wear his work clothes home
    4. Never repair equipment that comes in contact with sludge
    5. Wash his hands before going to the lavatory

2. An oxygen deficiency, or dangerous concentrations of toxic or suffocating gases, may be found in:
    1. Manholes
    2. Wet wells
    3. Empty digesters
    4. Chlorinator rooms
    5. Pump rooms

3. Manholes may be lifted with:
    1. Your fingers
    2. Your back
    3. A manhole hook

4. Traffic may be warned of a job in a street or other traffic area by:
    1. High-level signs and flags far enough ahead of the job to adequately alert drivers
    2. Leaving some manholes open so everyone can see that you are working
    3. Traffic cones arranged to guide traffic around work area
    4. Hoping autos headed toward the work area will be warned by other drivers
    5. A flagman directing traffic

5. When working on any piece of electrical equipment, the circuit breaker should be (pick only the best answer):

    1. Open
    2. Closed
    3. Tagged
    4. Locked out
    5. Locked out and tagged

6. Good housekeeping around a treatment plant means:

    1. Reading magazines
    2. Hosing down all spills immediately
    3. Keeping the coffee fresh and warm
    4. Providing a proper place for equipment and tools
    5. Keeping all walking areas clean and free of slimes, oils, and greases

7. Why should explosion-proof lights be used when working in an empty digester?

    1. If there is an explosion, the lights won't go out.
    2. Explosion-proof lights will not produce a spark which could cause an explosion.

8. The greatest hazard working in a clarifier is:

    1. Explosions
    2. Asphyxiation
    3. Slipping

9. When working in an empty digester, an operator should:

    1. Ventilate the digester
    2. Test for H_2S
    3. Test for explosive gas mixtures
    4. Use explosion-proof lights
    5. Wear nonsparking shoes

10. Gases may accumulate in sludge pump rooms from:

    1. Chlorinators
    2. Leakage
    3. Blowers
    4. Normal pump cleaning

11. When working around a trickling filter, the operator should:

    1. Never walk on the filter media while the rotating distributor is moving
    2. Ride on the distributor to get from one side to the other
    3. Wear rubber gloves when handling mercury from the seal
    4. Always provide a firm base when jacking up the distributor for repairs
    5. Never try to stop a rotating distributor by standing in front of it

12. When applying protective coatings in a tank, the operator should:

    1. Check with the manufacturer for safety precautions
    2. Provide adequate ventilation
    3. Wear protective clothing
    4. Apply protective creams to exposed skin areas
    5. Avoid breathing fumes from the protective coating

13. When working in the lab, you may:

    1. Smoke whenever you wish
    2. Use laboratory glassware for a coffee cup
    3. Add acid to water
    4. Never look into the end of a container during a reaction or when heating the container
    5. Hold a piece of glassware in your bare hands while heating it

14. The purpose of a safety meeting is to:

    1. Provide an awareness of the need for safety at all times
    2. Review potential safety hazards and outline the necessary precautions
    3. Get off work
    4. Discuss vacation plans
    5. Discuss the causes of accidents

CHAPTER 12. PLANT SAFETY AND GOOD HOUSEKEEPING

(Lesson 1 of 3 Lessons)

12.0 INTRODUCTION--WHY SAFETY?

A cat may have nine lives, but you have only one! Protect it! Others may try, but only your efforts in thinking and acting safely can ensure you the opportunity of continuing to live your single life!

You are working at an occupation that has an accident frequency rate second only to that of the mining industry! Not a very desirable record.

Your employer has the responsibility of providing you with a safe place to work. But you, the operator who has overall responsibility for your treatment plant, must accept the task of seeing to it that your plant is maintained in such a manner as to continually provide a safe place to work. This can only be done by constantly thinking safety.

You have the responsibility of protecting yourself and other plant personnel or visitors by establishing safety procedures for your plant and then by seeing that they are followed. Train yourself to analyze jobs, work areas, and procedures from a safety standpoint. Learn to recognize potentially hazardous actions or conditions. When you do recognize a hazard, take immediate steps to eliminate it by corrective action. If correction is not possible, guard against the hazard by proper use of warning signs and devices and by the establishing and maintaining of safety procedures. As an individual, you can be held liable for injuries or property damage as a result of an accident caused by your negligence.

REMEMBER: "ACCIDENTS DON'T JUST HAPPEN--THEY ARE CAUSED"!! How true it is! Behind every accident there is a chain of events which lead to an unsafe act, unsafe condition, or a combination of both. THINK SAFETY!

Accidents may be prevented by using good common sense, applying a few basic rules, and particularly by acquiring a good knowledge of the hazards peculiar to your job as a plant operator.

The Bell system has one of the best safety records of any industry. A variation of their successful policy statement is:

> "There is no job so important
> nor emergency so great
> that we cannot take time
> to do our work safely."

Although this chapter is intended primarily for the wastewater treatment plant operator, the operators of many small plants have the responsibility of sewer maintenance also. Therefore the safety aspects of both sewer maintenance and plant operation will be discussed.

12.1 KINDS OF HAZARDS

You are equally exposed to accidents whether working on the collection system or working in a treatment plant. As a worker, you may be exposed to:

1. Physical injuries
2. Infections and infectious diseases
3. Oxygen deficiency
4. Toxic or suffocating gases or vapors
5. Radiological hazards
6. Explosive gas mixtures
7. Fire
8. Electrical shock
9. Noise

12.10 Physical Injuries

The most common of physical injuries are cuts, bruises, scrapes, and broken bones. Injuries can be caused by moving machinery. Falls from or into tanks, deep wells, catwalks, or conveyors can be disabling. Most of these can be avoided by the proper use of ladders, hand tools, and safety equipment, and by following established safety procedures.

12.11 Infections and Infectious Diseases[1]

Although treatment plants and plant personnel are certainly not expected to be "pristine pure", personal cleanliness is a great deterrent to infections and infectious diseases. Immunization shots for protection against typhoid and tetanus are essential.

Make it a habit to thoroughly wash your hands before eating or smoking, or going to the lavatory. If you have any cuts or other broken skin areas on your hands, wear proper protective gloves when in contact with wastewater or sludge in any form. Bandages covering wounds should be changed frequently.

Do not wear your work clothes home, because diseases may be transmitted to your family. Provisions should be made in your plant for a locker room where each employee has a locker. Work clothes should be placed or hung in lockers and not thrown on the floor. Your work clothes should be cleaned at least weekly or more often if necessary.

If your employer does not supply you with uniforms and laundry service and you must take your work clothes home, launder them separately from your regular family wash.

All of these precautions will reduce the possibility of you and your family becoming ill because of your contact with wastewater.

[1] You must attempt to avoid skin infections and infectious diseases such as typhoid fever, dysentery, hepatitis, and tetanus.

12.12 Oxygen Deficiency

Oxygen deficiency may exist in any enclosed, and particularly below grade (ground level), unventilated structure where a gas heavier than air, such as carbon monoxide, has displaced the air.

NEVER ENTER AN ENCLOSED, BELOW GRADE, UNVENTILATED STRUCTURE, WHETHER A MANHOLE, SUMP PUMP, OR OTHER STRUCTURE WITHOUT FIRST CHECKING FOR OXYGEN DEFICIENCY AND PROVIDING VENTILATION.

Ventilation may be provided by fans or blowers. Equipment is available to measure oxygen deficiency and must be used whenever you enter a potentially hazardous area. Try your local fire department for sources of this type of equipment in your area.

12.13 Toxic or Suffocating Gases or Vapors

Toxic or suffocating gases may come from industrial waste discharges or from the decomposition of domestic wastewater. You must become familiar with the waste discharges into your system.

On pages 174 and 175 of The New York Manual, Table 10, Common Dangerous Gases Encountered in Sewers and at Sewage Treatment Plants, contains information on the simplest and cheapest safe method of testing for gases.

12.14 Radiological Hazards

The newest of hazards to plant operators is a result of the increasing use of radioactive isotopes in hospitals, research labs, and various industries. Check your sewer service area for the possible use of these materials. If you are receiving a discharge that may contain a radioactive substance, contact the contributor of the discharge. He will usually cooperate with monitoring this type of waste.

12.15 Explosive Gas Mixtures

Explosive gas mixtures may develop in confined areas in treatment plants from mixtures of air and methane, natural gas, manufactured fuel gas, or gasoline vapors. Explosive ranges can be detected by using a combustible gas indicator. Avoid explosions by keeping open flames away from areas potentially capable of developing explosive mixtures by providing adequate ventilation with fans or blowers.

12.16 Fire

Burns from fires can cause very serious injury. Avoid the accumulation of flammable material and store any material of this type in approved containers at proper locations. Know the location of fire fighting equipment and the proper use of the equipment.

12.17 Electrical Shock

Electrical shock frequently causes serious injury. Do not attempt to repair electrical equipment unless you know what you are doing.

12.18 Noise

Loud noises from gas engines and gas or electric blowers can cause permanent ear damage. Operators and maintenance men must wear the proper ear protecting devices whenever working in noisy areas for any length of time.

QUESTIONS

12.1A How can you prevent the spread of infectious diseases from your job to you and your family?

12.1B What should you do before entering an unventilated, enclosed structure?

12.1C What are potential sources of toxic or suffocating gases or vapors?

12.2 SPECIFIC HAZARDS

In the remainder of this chapter an attempt will be made to acquaint you with the specific hazards, by location and/or types of work, that you may expect to encounter in the field of wastewater collection and treatment.

12.20 Collection Systems

Good design and the use of safety equipment will not prevent physical injuries in sewer work unless safety practices are understood by the entire crew and are enforced.

Never attempt to do a job unless you have sufficient help, the proper tools, and the necessary safety equipment. There are no shortcuts to safety!

12.200 Manholes[2]

Manhole work usually requires job site protection by barricades and warning devices. These devices are necessary to warn highway traffic and pedestrians for the protection of the public and the workmen.

Never use your fingers or hands to remove a manhole cover! Always use a tool such as a pick with the point bent in the form of a hook, or a special tool specifically designed for this purpose. You have only ten fingers. Protect them!

When lifting a cover, the use of the rule "Lift with your legs, not with your back" will help eliminate back strains. (Fig. 12.1)

Once the cover is removed, leave it flat on the ground and far enough away from the manhole to provide adequate room for a working area. This is usually at least two to three feet.

If there are ladder rungs or steps installed in the side of the manhole, be very cautious when using these. Be alert for loose or corroded steps. Always test each step individually before placing your weight upon it.

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[2] Also see "Safe Work Procedure No. 1, Preparation for Manhole Work", Jour. Water Poll. Control Fed., Vol. 42, No. 2, p 331 (Feb. 1970).

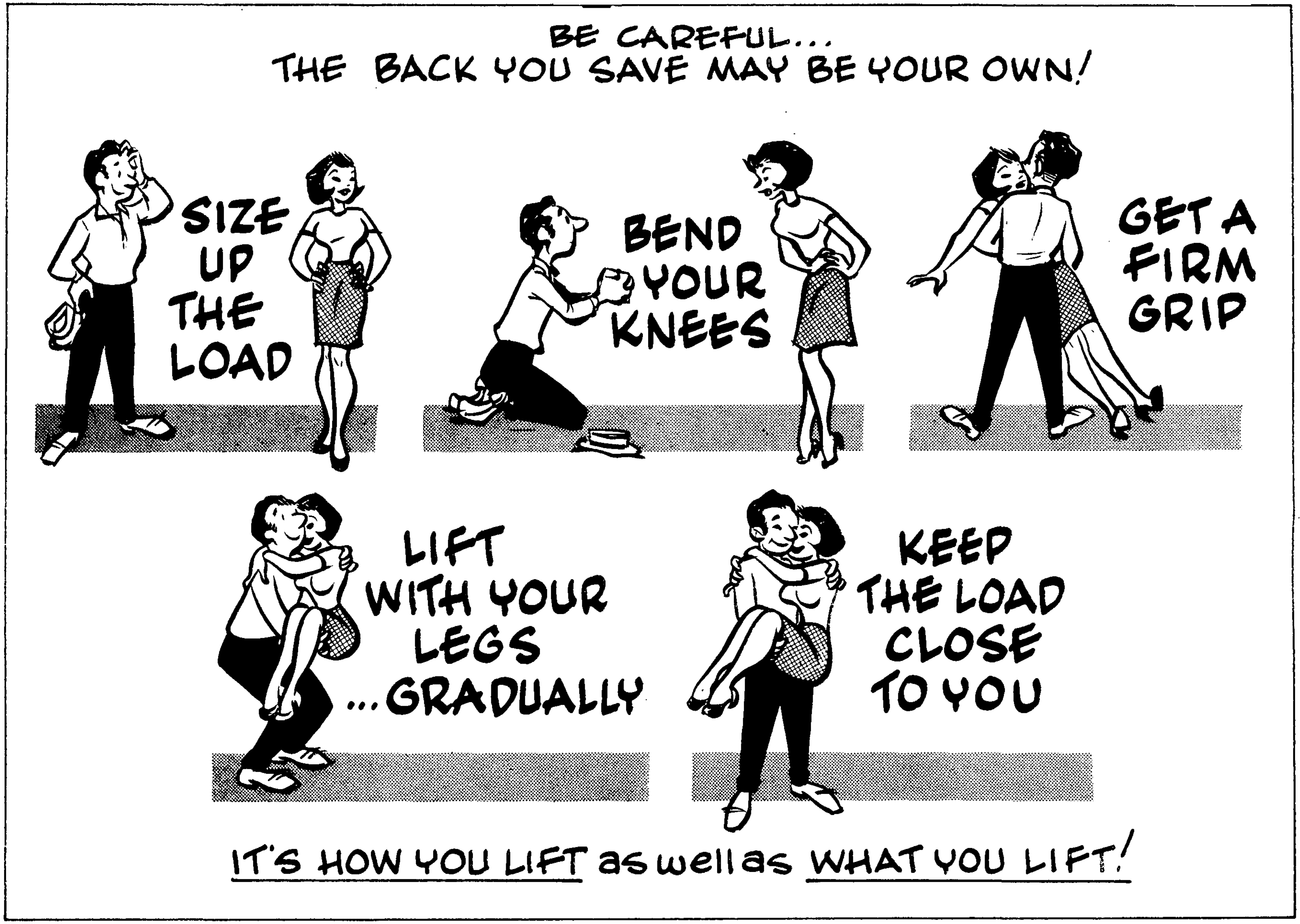

Fig. 12.1 Lifting

(Courtesy of Mr. William Frick, Sacramento City College)

If possible, it is much safer to use a ladder as a means of entering a manhole. Be certain, however, that the bottom feet are properly placed so that the ladder will not slip or twist when your weight is placed upon it.

No one should enter a manhole when by himself! There should always be at least one person standing by at the top of the manhole to observe the man as he enters, works, and leaves the manhole. There should always be at least one more person within hailing distance of the manhole in case it is necessary to remove the man from the manhole because of injury, or a truck wench or man lift may be used.

Before entering a manhole, put on an approved safety harness equipped with a hand line or life line. Both of these should be inspected by a fellow worker as well as the wearer. Be sure to wear a safety hat or cap.

If a man is to be working in wastewater, he should wear a properly fitted pair of rubber gloves, or an approved substitute that will provide protection from infection.

Never enter a manhole without first checking for explosive gases or other gases that may cause an oxygen deficiency. Provide for adequate ventilation to remove these gases. There are instruments available that can detect explosive gases or oxygen deficiency. Your local fire department can usually supply you with information on this type of equipment.

FOR DETAILED INFORMATION ON MEASUREMENT OF DANGEROUS CONCENTRATIONS OF GASES, REFER TO TABLE 10, PAGES 174 AND 175 IN THE NEW WORK MANUAL.

Tools and equipment should be lowered into a manhole by means of a bucket or basket. Do not drop them into the manhole for the man in the hole to catch. Attempting to carry tools in one hand while climbing down a ladder is an unsafe practice.

12.201 Excavations[3]

If it becomes necessary for you to excavate a sewer line, become familiar with the fundamentals of excavating and the proper, safe approach for shoring a ditch. Check with your State Safety Office or Industrial Accident Commission. They can usually provide you with pamphlets on these subjects. Don't wait until an emergency arises to obtain the information.

12.202 Sewer Cleaning

Never use a cleaning tool or piece of equipment unless you have been properly trained in its use or operation. Insist that the vendor provide you with this training. Know the limitations and capabilities of your tools and equipment. Do not use tools or equipment improperly because you could be seriously injured.

If you use chemicals of any kind for root or grease control in your system, be thoroughly familiar with their use, and specifically, with any hazards involved.

12.203 Traffic Hazards

Before starting any job in a street or other traffic area, even if you are just going to open a manhole, adequate warning to and protection from traffic must be provided.

Traffic may be warned by high-level signs and flags far enough ahead of the job to adequately alert the driver, by traffic cones (the newer fluorescent red cones do an excellent job) arranged to guide traffic around your work area, by signs or barricades to direct traffic, by a flagman to direct and control traffic, or by any combination of these. The local police department, state highway police, or road department may be able to provide you with some basic patterns on the use of cones, barricades, and other

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[3] Also see "Wastewater Wisdom Talk, Trench Shoring", Jour. Water Poll. Control Fed., Vol. 42, No. 6, p 1273 (June 1970).

warning or traffic control devices. Traffic warning devices must be placed in such a fashion to avoid causing confusion and congestion.

An added protection, whenever possible, is to place your work vehicle between you and the oncoming traffic. This will alert traffic to your presence. The use of flashing or revolving amber or red warning lights (whichever are permissible in your area) is an excellent means of alerting traffic to your presence.

QUESTIONS

12.2A Why should someone always be standing at the top of a manhole when you enter it?

12.2B How would you determine if there is an oxygen deficiency or toxic gas present in a manhole?

12.2C From whom should you learn the proper use of new sewer cleaning equipment?

12.2D List three ways to alert traffic that you are working in a street or traffic area.

END OF LESSON 1 OF 3 LESSONS

on

PLANT SAFETY AND GOOD HOUSEKEEPING

Please answer the discussion and review questions before continuing with Lesson 2.

DISCUSSION AND REVIEW QUESTIONS

Chapter 12. Plant Safety and Good Housekeeping

(Lesson 1 of 3 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in this lesson.

Write the answers to these questions in your notebook.

1. What is the operator's responsibility with regard to safety?
2. Accidents don't just happen--they are __________!
3. How can an operator avoid physical injuries?
4. Immunization shots protect against what infection and infectious disease?
5. What precautions should the operator take to avoid transmitting disease to his family?
6. What should the operator do when he discovers an area with an oxygen deficiency?
7. What kind of job site protection is usually required when you are working in a manhole?
8. Lift with your legs, not your ____________.
9. How should tools and equipment be transported to the bottom of a manhole?

CHAPTER 12. PLANT SAFETY AND GOOD HOUSEKEEPING

(Lesson 2 of 3 Lessons)

12.21 Treatment Plants and Pumping Stations

Because hazards found in pumping stations are identical to those found in treatment plants, the items discussed hereafter may be applied to both situations.

12.210 Headworks

Structures and equipment in this category may consist of bar screens, racks, comminuting or grinding equipment, pump rooms, wet pits, and chlorination facilities.

1. Bar Screens or Racks. These may be either manually or automatically cleaned. When manually cleaning screens or racks, be certain that you have a clean, firm surface to stand upon. Remove all slimes, rags, greases, or other material that may cause you to slip. GOOD HOUSEKEEPING IN THESE AREAS IS MANDATORY.

   When raking screens, leave plenty of room for the length of your rake handle so as not to be thrown off balance by striking a wall, railing, or light fixture. Wear gloves to avoid slivers from the rake handle or scraping your knuckles on concrete. Injury may allow an infection to enter your body.

   Place all material in a container that may be easily removed from the structure. Do not allow material to build up on the working surface.

   If your rack area is provided with railings, check to see that they are properly anchored before you lean against them. If removable safety chains are provided, never use these to lean against or as a means of providing extra leverage for removing large amounts of material.

   A hanging or mounting bracket of some type should be used to hold the rake when not in use. Do not leave it lying on the deck.

   If mechanically raked screens or racks are installed, never work on the electrical or mechanical part of this equipment without first turning the unit off by means of a push-button lockout for momentary stoppages, and by turning off, locking out, and tagging the main circuit breaker if it is necessary to remove or make a major adjustment or repair to the unit.

THE TAG SHOULD BE SECURELY FASTENED TO THE BREAKER HANDLE AND SHOULD BE OF A TERMINOLOGY SUCH AS "DANGER... DO NOT START-- MAN WORKING ON EQUIPMENT" (SEE FIGURES 12.2 AND 12.3)

The time and date the unit was turned off should be noted on the tag, as well as the reason it was turned off. The tag should be signed by the man who turned the unit off. No one should then turn on the main breaker and start the unit until the tag has been removed by the person who placed it there, or until he has specific instructions from the person who tagged the breaker. Your local safety equipment supplier can obtain these tags for you.

2. Comminuting or Grinding Equipment. This equipment may consist of barminutors, comminutors, grinders, or disintegrators.

NEVER work on the mechanical or electrical parts of the unit without first locking out the unit at either a push-button lockout or the main circuit breaker of the control panel. Be certain the breaker is properly tagged as explained in the previous section.

Good housekeeping is essential in the area of comminuting equipment. Keep all walking areas clean and free of slimes, oils, greases, or other materials. Hose down all spills immediately. Provide a proper place for equipment and tools used in this area.

See that proper guards are installed and kept in place around cables, cutters, hoists, revolving gears, and high-speed equipment such as grinders. If it is necessary to remove the guards prior to making adjustments on equipment, be certain that they are reinstalled before restarting the unit.

Fig. 12.2 Typical warning tag

(Source: State Compensation Fund of California)

DANGER

MAN WORKING ON LINE

DO NOT CLOSE THIS SWITCH WHILE THIS TAG IS DISPLAYED

SIGNATURE: ______________________

This is the ONLY person authorized to remove this tag.

INDUSTRIAL INDEMNITY/INDUSTRIAL UNDERWRITERS/
INSURANCE COMPANIES

4E210—R66

Fig. 12.3--Typical Warning Tag (Con't).

Source: Industrial Indemnity/Industrial Underwriters/Insurance Cos.

3. Pump Rooms. The same basic precautions apply here as they do to any type of enclosed room or pit where wastewater or gases may enter and accumulate.

Always provide adequate ventilation to remove gases and supply oxygen. If the room is below ground level and provided with only forced air ventilation, be certain the fan is on before entering the area. Wear a harness with a safety line (as for manhole work) when entering pits, wet wells, tanks, and below-ground pump rooms.

The tops of all stairwells or ladders should be protected by a removable safety chain. Keep this chain in place when the stairwell or ladder is not being used.

Never remove guards from pumps, motors, or other equipment without first locking out or turning off equipment at main breaker and properly tagging. Always replace all guards before starting units.

Guards should be installed around all rotating shaft couplings, belt drives, or other moving parts normally accessible.

Maintain good housekeeping in pump room. Remove all oil and grease, and clean up spills immediately.

If you have a multi-level pump building, never remove and leave off equipment removal hatches unless you are actually removing or replacing equipment. Be sure to provide barricades or ropes around the opening to prevent falls. Be extremely cautious when working around openings that have raised edges. These are hazardous because you can stumble over them easily.

Never start a positive displacement pump against a closed valve. On piston pumps, the yoke over the ball check could break and endanger personnel in the vicinity.

All emergency lights used in these areas should be explosion proof. Be sure to keep light shields in place and replace immediately when broken. Permanent lights should be of an approved explosion-proof type. Until the area has been checked for an explosive atmosphere, NO OPEN FLAMES (such as a welding torch) OR SMOKING SHOULD BE ALLOWED.

CAUTION

UNLESS YOU ARE A QUALIFIED ELECTRICIAN, STAY OUT OF THE INSIDE OF ALL ELECTRICAL PANELS. IF YOU DO NOT KNOW OR ARE NOT FAMILIAR WITH THE EQUIPMENT, LEAVE IT ALONE!

4. Wet Pits--Sumps. Covered wet pits or sumps are potential death traps. Never enter one by yourself. Use a safety harness and have sufficient personnel available to lift you out. Always use forced air to ventilate the area, and check for explosive gases and oxygen deficiency before entering. Also, be particularly alert for hydrogen sulfide gas. Use your nose initially, but do not continue to depend upon it as you will become insensitive to the odor. A small, reasonably priced hydrogen sulfide detection unit may be purchased. Check with your local safety equipment supplier.

   After you have determined the atmosphere is safe, use extreme care in climbing up and down access ladders to pit areas. The application of a nonslip type coating on ladder rungs is helpful. If available, a truck hoist is safer than a ladder for entering pit areas.

   Watch your footing on the floor of pits and sumps. They are very slippery.

   Never attempt to carry tools or equipment up or down ladders into pits or sumps. Always use bucket and handline or sling for this purpose.

   Only explosion-proof lights and equipment should be used in these areas.

   A good safety practice is to turn off all chlorination, whether located upstream or directly in sump, and allow ample time before entering the area. This, with forced ventilation, will give time for the area to be cleared of chlorine fumes.

Chlorination safety is discussed in Chapter 10, Disinfection and Chlorination.

QUESTIONS

12.2E Why should slimes, rags, or greases be removed from around bar screens or racks?

12.2F What precautions would you take when working on electrical or mechanical equipment?

12.2G What parts of equipment should have guards installed around them?

12.2H Why should you not depend on your nose to detect hydrogen sulfide gas over long periods of time?

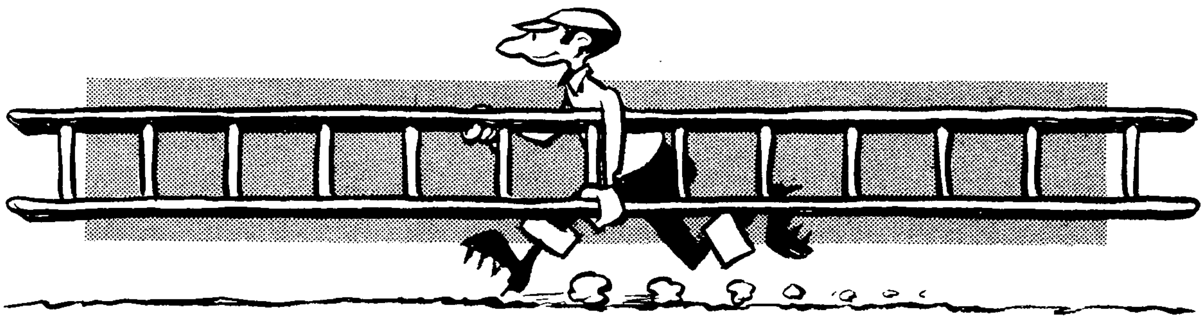
12.2I How would you transport tools or equipment into or out of pits or sumps?

12.211 Grit Chambers

Grit chambers may be of various designs, sizes, and shapes; but they all have one thing in common: they get dirty. Good housekeeping is needed! Keep walking surfaces free of grit, grease, oil, slimes, or other material that will make a slippery surface.

Before working on mechanical or electrical equipment, be certain that it is turned off and properly tagged (Figs. 12.2 and 12.3). Install and maintain guards on gears, sprockets, chains, or other moving parts that are normally accessible.

If it becomes necessary to enter the chamber, pit, or tank for cleaning or other work, do so with extreme caution. If this is a covered area, provide and maintain adequate ventilation to remove gases from the area and to supply oxygen to the workers. Use only explosion-proof lights. Always check for explosive gases and oxygen deficiency before entering.



Be sure of your footing when working in these structures. Rubber boots with a nonskid cleat type sole should be worn. Step slowly and cautiously as there is usually an accumulation of slippery material or slimes on the bottom. Use hand holds and railings; if none are available, install them now.

Use ladders, whether vertical or ships ladders, cautiously. If possible, apply nonslip material or coatings to ladder rungs. Keep handrails free of grease and other slippery substances.

If it is necessary to take tools or equipment into the bottom area, lower these in a bucket or sling by handline. Never attempt to carry items up or down a ladder.

12.212 Clarifiers or Sedimentation Basins

The greatest hazard involved in working on or in a clarifier is the danger of slipping. If possible, maintain a good nonskid surface on all stairs, ladders, and catwalks. This may be done by using nonskid strips or coating. Be extremely cautious during freezing weather. A small amount of ice can be very dangerous.

Your housekeeping program should include the brushing or cleaning of effluent weirs and launders (effluent troughs). When it is necessary to actually climb down into the launder, always wear a harness with a safety line and have someone with you. A fall may result in a very serious injury.

Be cautious when working on the bottom of a clarifier. When hosing down, always hose a clean path to walk upon. Avoid walking on the remaining sludge whenever possible.

Always turn off and lock out or turn off and tag clarifier breaker before working on drive unit. If necessary, adjustments may be made on flights or scrapers while the unit is in operation; but keep in mind that, although these are moving quite slowly, there is tremendous power behind their movement. Stay clear of any situation where your body or the tools you are using may get caught under one of the flights or scrapers.

Guards should be installed over or around all gears, chains, sprockets, belts, or other moving parts. Keep these in place whenever the unit is in operation.

Railing should be installed along the tank side of all normal walkways. If the unit is elevated above ground, railings should be installed along the outside of all walkways, also. Check with your State Safety Office for requirements on railing installation.

12.213 Digesters and Digestion Equipment[4]

Digesters and their related equipment include many hazardous areas and potential dangers.

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[4] Also see "Safe Work Procedure No. 2, Entering and Working in Digesters", Jour. Water Poll. Control Fed., Vol. 42, No. 3, Part 1, p 466 (March 1970).

No smoking and no open flames should be allowed in the vicinity of digesters, in digestion control buildings, or in any other areas or structures used in the sludge digestion system. This includes pipe galleries, compressor or heat exchanger rooms, and others. All these areas should be posted with signs in a conspicuous place which forbid smoking and open flames. Methane gas produced by anaerobic conditions is explosive when mixed with the proper proportion of air.

All enclosed rooms or galleries in this system should be well ventilated with forced air ventilation. Before entering any enclosed area or pit which is not ventilated, a check should be made for explosive gases and hydrogen sulfide. Do not depend upon your nose for hydrogen sulfide (H_2S) detection in these areas. A small amount of H_2S in the air will make your sense of smell immune to the odor in a short period of time. Use an H_2S detector.

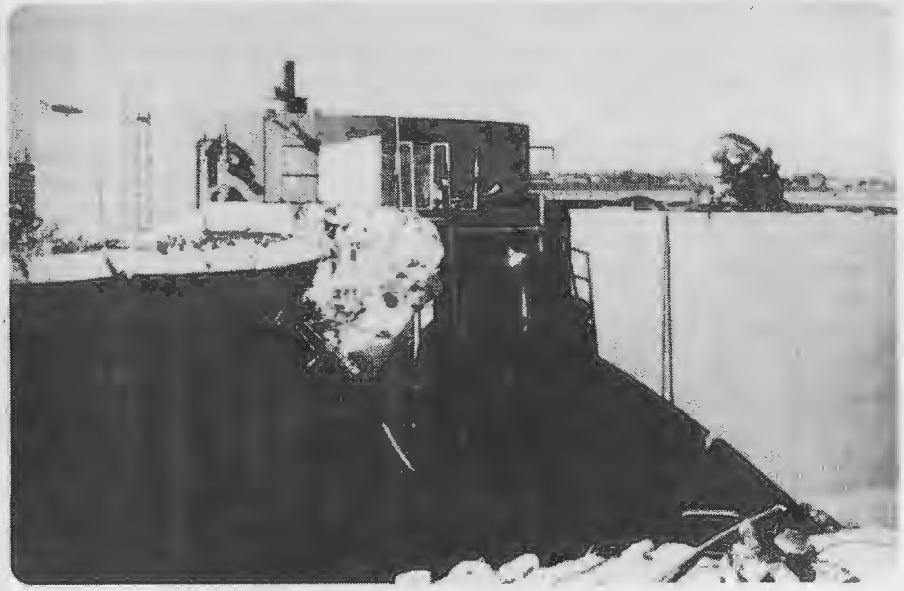
When you are working in these areas, forced air ventilation with a portable blower should be provided. Again, do not go into an area by yourself where H_2S is present. Have someone watch you.

Never enter a partially empty or completely empty digester without first thoroughly ventilating the structure and then checking for an explosive atmosphere and the presence of hydrogen sulfide gas. Explosion-proof lights and nonsparking tools[5] and shoes should always be used when working around, on top of, or in a digester unless it has been completely cleaned and emptied, continuously ventilated by a blower, and constant checks are made of the atmosphere in the tank.

A GOOD SAFETY PRACTICE IS TO:
NEVER ALLOW SMOKING OR OPEN FLAMES WITHIN AN EMPTY DIGESTER.
(FIG. 12.4).

Be certain that guardrails are installed along the edges of the digester roof or cover in areas where it is necessary to work close to the edge. A fall from the top of a digester could be fatal.

[5] Nonsparking tools are especially manufactured for use in areas where potentially explosive mixtures of gases may be present.



Explosion blew off top of digester

and landed on top of pickup truck

Fig. 12.4 Blown-up digester

When working on equipment such as draft tube mixers, compressors, diffusers, etc., be certain that the unit which operates or supplies gas to these types of equipment is properly locked out and appropriately tagged (Figs. 12.2 and 12.3).

If you have a heated digester, read and heed the manufacturer's instructions before working on the boiler or heat exchanger. Know that the gas valve is turned off before attempting to light the pilot. Be certain that the fire box has been ventilated according to the manufacturer's instructions before lighting the pilot.

CAUTION

WASTE GAS BURNERS ARE NOTED FOR BLOWING OUT IN A MODERATE WIND. BEFORE YOU ATTEMPT TO RELIGHT THE UNIT, BE CERTAIN THAT THE MAIN VALVE HAS BEEN TURNED OFF AND THE STACK ALLOWED TO VENT ITSELF FOR A FEW MINUTES. MANY OPERATORS HAVE HAD THEIR HAIR AND EYEBROWS SINGED FROM A BACKFLASH FROM THIS UNIT.

When it becomes necessary to clean tubes or coils in a heat exchanger, turn the unit supplying hot water off far enough in advance to allow the heat exchanger to cool. Never open the unit without doubly checking the water and sludge temperatures. Be certain that they have cooled down to body temperature or lower.

Before working on any sludge pump, whether it is centrifugal or positive displacement, be certain that the unit is turned off and properly tagged (Figs. 12.2 and 12.3).

Positive displacement pumps should be equipped with an air chamber and a pressure switch to shut the unit off at a preset pressure. <u>Never</u> start a positive displacement pump against a <u>closed discharge valve</u> because pressure could build up and burst a line or damage the pump. If you have closed this valve in order to inspect or clean the pump, double check to be sure that it is open before starting the unit.

Sludge pump rooms should be well ventilated to remove any gases that might accumulate from leakage, spillage, or from a normal pump cleaning. If you spill digesting sludge, clean it up immediately to prevent the possible accumulation of gases.

Provide thorough, regularly scheduled inspection and maintenance of your gas collection system. Inspect drip traps regularly. The so-called "automatic" drip trap is known to jam open frequently, allowing gas to escape.

Good maintenance of flame arrestors will ensure that they will be able to perform their job of preventing a backflash of the flame.

QUESTIONS

12.2J How can the danger of slipping be reduced on slippery surfaces?

12.2K Why should no smoking or open flames be allowed in the vicinity of digesters?

12.2L What safety precautions would you take before entering a recently emptied digester?

12.2M What would you do before relighting a waste gas burner?

12.2N Why should you never start a positive displacement pump against a closed discharge valve?

12.214 Trickling Filters

When it becomes necessary to inspect or service a rotating distributor, stop the flow of wastewater to the unit and allow it to come to rest.

NEVER STAND OR WALK ON THE FILTER MEDIA WHILE THE ROTATING DISTRIBUTOR IS IN MOTION.

Provide an approved ladder or stairway for access to the media surface. Be positive this is free from obstructions such as hose bibs, valve stems, etc.

Extreme caution should be used when walking on the filter media. The biological slimes make the media very slippery. Move cautiously and be certain of your footing.

NEVER ALLOW ANYONE TO RIDE A ROTATING DISTRIBUTOR.

Although a rotating distributor moves fairly slowly, the force behind it is powerful. An operator who has fallen off and been dragged by a distributor is fortunate if he can walk away under his own power.

WARNING

THE MERCURY IN THE SEAL OF A ROTATING DISTRIBUTOR IS EXTREMELY TOXIC.

Always wear rubber gloves when handling mercury. <u>When cleaning mercury, follow the manufacturer's recommendations.</u> Do so only in the open in a well-ventilated room. Be sure to have a tray under the working area during mercury clean-up. It is extremely difficult to recover mercury from the floor. Dry mercury vaporizes slowly, and mercury vapors also are toxic.

Refrain from smoking and eating when handling mercury. Always wash your hands thoroughly when finished.

When inspecting underdrains, check to determine that the channels or conduits are adequately ventilated. Gases are not normally a problem here, but may be if there is a build-up of solids which have become septic.

If it becomes necessary to jack up a distributor mechanism for inspection or repair, always provide a firm base off the media or drainage system for the jack plate. A firm base may be provided by wooden planks which will spread the weight over a large area. However, sometimes the only way to obtain firm support is to remove the media and use the drainage system as a firm base. Remember you are lifting a heavy weight. Do not attempt inspection or repair work until the distributor has been adequately and properly blocked in its raised position.

12.215 Aerators

Guardrails should be installed on the tank side of usual work areas or walkways. If the tank is elevated above ground, guardrails should also be installed on the ground side of the tank. An operator should never go into unguarded areas by himself.

When working on Y-walls, or other unguarded areas where work is done infrequently, at least a two-man team should do the work. Approved life preservers with permanently attached handlines should be accessible at strategic locations around the aerator. You should wear a safety harness with a life line when servicing aerator spray nozzles and other items around an aerator.

An experiment in England found that if an operator fell into a diffused aeration tank, he should be able to survive because air will collect in the clothing and tend to help keep him afloat.[6] Drownings apparently occur when a person is overcome by the initial shock or there is nothing to grab hold of to keep afloat or to pull oneself out of the aerator.

When removing or installing diffusers, be aware of the limitations of your working area. Inspect and properly position hoists and other equipment used in servicing swing diffusers.

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[6] Kershaw, M.A., "Buoyancy of Aeration Tank Liquid", Jour. Water Poll. Control Fed., Vol. 33, No. 11, p 1151 (Nov. 1961).

When it is necessary to work in an empty aerator, lower yourself into the aerator with a truck hoist if one is available. Ladders are awkward and dangerous; but if portable ladders must be used, properly position them so that they will not slip or twist. A good practice is to tie the top of the ladder so that it cannot slip. Be extremely careful when using fixed ladders as they become very slippery. The floor of the aerator also is likely to be extremely slippery.

If your plant is in an area subject to freezing weather, be aware of possible ice conditions around these units and use caution accordingly.

12.216 Ponds

Ponds of any kind present basically the same hazards. Therefore, the following safety measures will apply to ponds in general.

If it is necessary to drive a vehicle on top of the pond levees, maintain the roadway in good driving condition by surfacing it with gravel of asphalt. Do not allow chuck holes or the formation of ruts. Be extremely cautious in wet weather. The material used in the construction of most levees becomes very slippery when wet. Slippery conditions should be corrected using crushed rock or other suitable material.

Never go out on the pond for sampling or other purposes when by yourself. Someone should be standing by on the bank in case you get into trouble. Always wear an approved life jacket when working from a boat or raft on the surface of the pond. And, as in any boating activity, do not stand up in the boat while performing work.

QUESTIONS

12.2O What precautions should you take when working with mercury?

12.2P How would you stop the rotating distributor on a trickling filter?

12.2Q Why should you never work alone on the center "Y" wall of an aerator?

12.217 Chlorine

CHLORINE GAS IS A HIGHLY IRRITATING AND CORROSIVE GAS.
DANGER....HANDLE WITH CAUTION!

The most common causes of accidents involving chlorine gas are leaking pipe connections and over-chlorinating.

Chlorine bottles or cylinders should be stored in a cool, dry place, away from direct sunlight or from heating units. Some heat is needed to cause desired evaporation and to control moisture condensation on tanks. Chlorine bottles or cylinders should never be dropped or allowed to strike each other with any force. Cylinders should be stored in an upright position and secured with a chain, wire rope, or clamp. They should be moved only by hand truck and should be well secured during moving. One-ton tanks should be blocked so that they cannot roll. They should be lifted only by an approved lifting bar with hooks over the ends of the containers. Never lift a bottle or cylinder with an improvised sling.

Connections to cylinders and tanks should be made only with approved clamp adaptors or unions. Always inspect all surfaces and threads of the connector before making connection. If you are in doubt as to their conditions, do not use the connector. Always use a new approved type gasket when making a connection. The reuse of gaskets very often will result in a leak. Check for leaks as soon as the connection is completed. Never wait until you smell chlorine. If you discover even the slightest leak, correct it immediately, as leaks tend to get worse rather than better. Like accidents, chlorine leaks generally are caused by faulty procedure or carelessness.

Obtain from your chlorine supplier and post in a conspicuous place (outside the chlorination room) the name and telephone number of the nearest emergency service in case of severe leak.

Cylinder storage and chlorinator rooms should be provided with means of ventilating the room. As chlorine is approximately two and a half times heavier than air, vents or an exhaust fan should be provided at floor level. Ideal installations have a blower mounted on the roof to blow air into the room and are vented at the floor level to allow escaped chlorine to be blown out of the building.

Always enter enclosed cylinder storage or chlorinator rooms with caution. If you smell chlorine when opening the door to the area, immediately close the door, turn on ventilation, and seek assistance.

Never attempt to enter an atmosphere of chlorine when by yourself or without an approved air supply and protective clothing. Aid can usually be obtained from your local fire department, which will normally have available a self-contained breathing apparatus which will allow a person to enter safely into an atmosphere of chlorine.

An excellent booklet may be obtained from PPG Industries, Inc., *Chlorine--Safe Handling*.[7] Safety information on chlorine handling is also contained in Chapter 10, Disinfection and Chlorination. Your local chlorine supplier will probably provide you with all the information you need to handle and use chlorine safely. It is your responsibility to obtain, read, and understand safety information and to practice safety.

12.218 Applying Protective Coatings

CAUTION! When applying protective coatings in a clarifier or any other tank or pit, whether enclosed or open topped, use protective equipment to prevent skin burns from vapors from asphaltic or bitumastic coatings. This may involve the use of protective clothing as well as protective creams to be applied to exposed skin areas. An air supply must be used when painting inside closed vessels or in an open deep tank. Many paint fumes are heavier than air; therefore, ventilation must be from the bottom upward.

Check with your paint supplier for any hazards involved in using his products.

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[7] PPG Industries, Inc., Chemical Division, One Gateway Center, Pittsburgh, Pennsylvania 15222.

12.219 Housekeeping

Good housekeeping can and has prevented many accidents.

Have a place for your tools and equipment. When they are not being used, see that they are kept in their proper place.

Clean up all spills of oil, grease, wastewater, sludge, etc. Keep walkways and work areas clean.

Provide proper containers for wastes, oily rags, papers, etc. Empty these frequently.

Remove snow and melt ice with salt in areas where persons may slip and fall.

A clean plant will reduce the possibility of physical injuries and infections.

QUESTIONS

12.2R How should one-ton chlorine tanks be lifted?

12.2S Why are chlorine vents placed on floor level?

12.2T What should you do if you open a door and smell chlorine?

12.2U What factors are important in keeping a neat and safe plant?

END OF LESSON 2 OF 3 LESSONS

on

PLANT SAFETY AND GOOD HOUSEKEEPING

Please answer the discussion and review questions before continuing with Lesson 3.

DISCUSSION AND REVIEW QUESTIONS

Chapter 12. Plant Safety and Good Housekeeping

(Lesson 2 of 3 Lessons)

Write the answers to these questions in your notebook. The problem numbering continues from Lesson 1.

10. When cleaning racks or screens, on what kind of surface should the operator stand?

11. Never lean against a removable safety chain. True or False?

12. Why should only qualified electricians work on an electrical control panel?

13. Why should effluent weirs and launders on clarifiers be brushed or cleaned?

14. Why should no smoking or open flames be allowed in the vicinity of the digester or sludge digestion system?

15. Why should a tray be placed under the working area during mercury clean-up?

16. Why should you never go out on a pond for sampling or other purposes by yourself?

17. Where should the name and telephone number of the nearest emergency chlorine leak repair service be posted?

18. What safety precautions should be taken when applying protective coatings?

12.3 SAFETY IN THE LABORATORY[8]

In addition to all safety practices and procedures mentioned in the previous sections of this chapter, the collecting of samples and the performance of laboratory tests require that you be aware of the specific hazards involved in this type of work.

Laboratories use many hazardous chemicals. These chemicals should be kept in limited amounts and used with respect. Your chemical supplier may be able to supply you with a safety manual.

12.30 Collecting Samples

Whenever possible, rubber gloves should be worn when your hands may come in direct contact with wastewater or sludge. When you have finished sampling, always wash the gloves thoroughly before removing them. After removing the gloves, wash your hands thoroughly, using a disinfectant type soap.

NEVER COLLECT ANY SAMPLES WITH YOUR BARE HANDS IF YOU HAVE ANY BROKEN SKIN AREAS SUCH AS CUTS OR SCRATCHES.

Do not climb over or go beyond guardrails or chains when collecting samples. Use sample poles, ropes, etc., as necessary to collect samples.

[8] Also see "CRC Handbook of Laboratory Safety", by Norman V. Steere, Chemical Rubber Publishing Company, 18901 Cranwood Parkway, Cleveland, Ohio 44128. Price $24.50.

12.31 Equipment Set-Up and Performance of Tests

Following are some basic procedures to follow when working in the laboratory:

1. Use proper safety goggles or face shield in all tests where there is danger to the eyes.

NEVER LOOK INTO THE OPEN END OF A CONTAINER DURING A REACTION OR WHEN HEATING THE CONTAINER.

2. Use care in making rubber-to-glass connections. Lengths of glass tubing should be supported while they are being inserted into rubber. The ends of the glass should be flame polished[9] to smooth them out, and a lubricant such as water should be used. Never use grease or oil. Gloves or some other form of protection for the hands should be used when making such connections. The tubing should be held as close to the end being inserted as possible to prevent bending or breaking. Never try to force rubber tubing or stoppers from glassware. Cut the rubber as necessary to remove it.

3. Always check labels on bottles to make sure that the proper chemical is selected. Never permit unlabeled or undated containers to accumulate around or in the laboratory. Keep storage areas organized to facilitate chemical selection for use. Clean out old or excess chemicals. Separate flammable, explosive, or special hazard items for storage in an approved manner. See Section 12.9, Additional Reading, Reference 10.

ALL CHEMICAL CONTAINERS SHOULD BE CLEARLY LABELED, INDICATING CONTENTS AND DATE BOTTLE WAS OPENED OR SOLUTION PREPARED. ALL **POISONS** MUST BE LABELED WITH "**SKULL AND CROSSBONES**" AND ANTIDOTE.

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[9] Flame Polished. Sharp or broken edges of glass (such as the end of a glass tube) are flame polished by placing the edge in a flame and rotating it. By allowing the edge to melt slightly, it will become smooth.

4. Never handle chemicals with the bare hand. Use a spoon or spatula for this purpose.

5. Be sure that your laboratory is adequately ventilated.

ALWAYS WORK IN A FUME HOOD IF WORKING WITH CHEMICALS OR SAMPLES HAVING TOXIC FUMES.

Even mild concentrations of fumes or gases can be dangerous.

6. Never use laboratory glassware for a coffee cup or food dish. This is particularly dangerous when dealing with wastewaters.

7. When handling hot equipment of any kind, always use tongs, asbestos gloves, or other suitable tools. Burns can be painful and can cause more problems (encourage spills, fire, and shock).

8. When working in the lab, avoid smoking and eating except at prescribed coffee breaks or at the lunch period.

ALWAYS THOROUGHLY WASH YOUR HANDS BEFORE SMOKING OR EATING.

9. Do not pipette chemicals or wastewater samples by mouth. Always use a suction bulb on an automatic burette.

10. Handle all chemicals and reagents with care. Read and become familiar with all precautions or warnings on labels. Know and have available the antidote for all poisonous chemicals in your lab.

11. A short section of rubber tube on each water outlet is an excellent water flusher to wash away harmful

chemicals from the eyes and skin. It is easy to reach and can quickly be directed on the exposed area. Eyes and skin can be saved if dangerous materials are washed away quickly.

12. Dispose of all broken or cracked glassware immediately. Chipped glassware may still be used if it is possible to fire polish the chip in order to eliminate the sharp edges. This may be done by slowly heating the chipped area until it reaches a temperature at which the glass will begin to melt. At this point remove from flame and allow to cool.

NEVER HOLD ANY PIECE OF GLASSWARE OR EQUIPMENT IN YOUR BARE HANDS WHILE HEATING.

Always use a suitable glove or tool.

13.

REMEMBER TO ADD ACID TO WATER, BUT **NEVER** THE REVERSE.

14. Wear a protective smock or apron when working in the lab. This may save you the cost of replacing your work clothes or uniform. Protective eye shields should be worn too.

QUESTIONS

12.3A What safety precautions would you take when collecting laboratory samples from a plant influent?

12.3B Why should you always wash your hands before eating?

12.3C Why should chemicals and reagents be handled with care?

12.4 FIRE PREVENTION

Fires are a serious threat to the health and safety of the operator and to the buildings and equipment in a treatment plant. Fires may injure or even cause the death of an operator. Equipment damaged by fire may no longer function properly, and your treatment plant may have difficulty adequately treating the influent wastewater.

Good safety practices with respect to fire prevention require a knowledge of:

1. Ingredients necessary for a fire
2. Fire control methods
3. Fire prevention practices

12.40 Ingredients Necessary for a Fire

The three essential ingredients of all ordinary fires are:

1. FUEL--paper, wood, oil, solvents, and gas.

2. HEAT--the degree necessary to vaporize fuel according to its nature.

3. OXYGEN--normally at least 15 percent of oxygen in the air is necessary to sustain a fire. The greater the concentration, the brighter the blaze and more rapid the combustion.

12.41 Fire Control Methods

To extinguish a fire, it is necessary to remove only one of the essentials by:

1. Cooling (temperature and heat control)

2. Smothering (oxygen control)

3. Isolation (fuel control)

4. Interrupting the chemical chain reaction in certain types of fires

Fires are classed as A-, B-, C-, or D-type fires, according to what is burning.

Class A fires (general combustibles such as wood, cloth, paper, or rubbish) are usually controlled by cooling--as by use of water to cool the material.

Class B fires (flammable liquids such as gasoline, oil, grease, or paint) are usually smothered by oxygen control--as by use of foam, carbon dioxide, or a dry chemical.

Class C fires (electrical equipment) are usually smothered by oxygen control--use of carbon dioxide or dry-chemical extinguishers--nonconductors of electricity.

Class D fires occur in combustible metals, such as magnesium, lithium, or sodium, and require special extinguishers and techniques.

You can control and extinguish fires when they occur by knowing where fire extinguishers and hoses are kept and knowing where yard hydrants are located, what each is for, and how to use them.

12.42 Fire Prevention Practices

You can prevent fires by:

1. Maintaining a neat and clean work area, preventing accumulation of rubbish.

2. Putting oil- and paint-soaked rags in covered metal containers.

3. Observing all "no smoking" signs.

4. Keeping fire doors, exits, stairs, fire lanes, and fire-fighting equipment clear of obstructions.

5. Keeping all burnable materials away from furnaces or other sources of ignition.

6. Reporting any fire hazards you see that are beyond your control, especially electrical hazards which are the source of many fires.

Finally, here again are the things to remember:

1. Prevent fire by good housekeeping and proper handling of flammables.

2. Make sure that everyone obeys "no smoking" signs in all areas near explosive or flammable gases.

3. In case of fire, turn in the alarm immediately and make sure that the fire department is properly directed to the place of the fire.

4. Use the available portable fire-fighting equipment to control the fire until help arrives.

5. Use the proper extinguisher for that fire.

6. Learn how to operate the extinguishers.

If it is necessary to get out of the building, do not stop to get anything--just get out!

Can you prevent fires? You can if you try, so let's see what we can do to preserve our well-being and the water pollution control system.

If you guard against fires, you will be protecting your lives and your community.

12.43 Acknowledgment

Material in this section on Fire Prevention appeared in the July 1970 issue of the Journal of the Water Pollution Control Federation, on pages 1426 and 1427, as a Wastewater Wisdom talk. Originally, the information appeared as a National Safety Council "5 Minute Safety Talk", published in the Industrial Supervisor.

QUESTIONS

12.4A What are the necessary ingredients of a fire?

12.4B How should oil- and paint-soaked rags be handled?

12.5 WATER SUPPLIES

Inspect your plant to see if there are any cross-connections between your potable (drinking) water and items such as water seals on pumps, feed water to boilers, hose bibs below grade where they may be subject to flooding with wastewater or sludges, or any other location where wastewater could contaminate a domestic water supply.

If any of these or other existing or potential cross-connections are found, be certain that your drinking water supply source is properly protected by the installation of an approved back-flow prevention device.

It is a good practice to have your drinking water tested at least monthly for coliform group organisms. Sometimes the best of back-flow prevention devices do fail.

You may find in your plant that it will be more economical to use bottled drinking water. If so, be sure to tack up conspicuous signs that your water is not drinkable. This also applies to all hose bibs in the plant from which you may obtain water other than a potable source. This is a must in order to inform visitors or absent-minded or thirsty employees that the water from each marked location is not for drinking purposes.

QUESTION

12.5A Why do some wastewater treatment plants use bottled water for drinking purposes?

12.6 SAFETY EQUIPMENT AND INFORMATION

Post conspicuously on your bulletin board the location and types of safety equipment available at your plant (such as first aid kit, breathing apparatus, explosiometers, etc.). You, as the plant operator, should be thoroughly familiar with the operation and maintenance of each piece of equipment. You should review these at fixed intervals to be certain that you can safely use the piece of equipment as well as to be sure that it is in operating condition.

Contacts should be made with your local fire and police departments to acquaint them with hazards at your plant as well as to inform them of the safety equipment that is necessary to cope with problems that may arise. Quite often it is possible to arrange a joint training session with these people in the use of safety equipment and the handling of emergencies. They also should know access routes to and around the treatment plant.

If you have any specific problems of a safety nature, do not hesitate to contact officials in your state safety agency. They can be of great assistance to you. And do not forget your equipment manufacturers; their familiarity with your equipment will be of great value to you.

Also posted in conspicuous places in your plant should be such information as the phone numbers of your fire and police departments, ambulance service, chlorine supplier or repairman, and the nearest doctor who has agreed to be available on call. Having these immediately available at telephone sites may save your or a fellow worker's life. Check and make sure these numbers are listed at your plant. If they are not listed, ADD THEM NOW.

QUESTION

12.6A What emergency phone numbers should be listed in a conspicuous place in your plant?

12.7 "TAILGATE" SAFETY MEETINGS[10]

Safety is crucial. Accidents cost money. No one can afford to lose time from his job due to injury. Safety meetings provide the opportunity to explain and discuss safe procedures and safe conditions.

In some states, by law, you may be required to conduct safety meetings at fixed intervals with employees. Whether this is required or not, it certainly is a good practice. Once every 7 to 10 days is a good frequency. These meetings should usually be confined to one topic, and should be no longer than 10 to 20 minutes. It will be worthwile to review monthly any accidents during the past month at one of the meetings. Do not use this meeting to fix blame. Try to dig into the cause and to determine what can be or has been done to prevent a recurrence of the accident

To help you conduct "tailgate" safety meetings, this chapter was arranged to discuss the safety aspects of different plant operations. The material in some sections was deliberately repeated to cover the topic and to remind you of dangers. Some plants select topics for their "tailgate" safety meetings from a "safety goof box". The box is placed in a convenient location. Whenever anyone sees an unsafe situation or sees someone perform a hazardous act without proper safety precautions, he places a note in the box identifying the situation or person and the act. The box is opened at each safety meeting, and the cause of the "goof" and the steps that can be taken to correct and prevent it from happening again are discussed.

Your state safety agency, your insurance company, equipment and material suppliers, and the Water Pollution Control Federation are all excellent sources of literature and aids that may help you in conducting "tailgate" safety meetings. Some of these agencies may be able to supply you with posters, signs, and slogans that are very effective safety reminders.[11] You may wish to dream up some reminders of your own.

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[10] "Tailgate". The term "tailgate" comes from safety meetings regularly held by the construction industry around the tailgate of a truck.

[11] Chemical Laboratory Safety Posters have been prepared by the Manufacturing Chemists Association, 1825 Connecticut Avenue, N.W., Washington, D.C. 20009. Price $2.50 per set of twelve posters.

QUESTIONS

12.7A What is the purpose of "tailgate" safety meetings?

12.7B How frequently should safety meetings be held for treatment plant operators?

12.8 SUMMARY

Following is a summary of the safety precautions that have been discussed in the previous sections.

1. Good design without proper safety precautions will not prevent accidents. All personnel must be involved in a safety program and provided with frequent safety reminders.

2. Never attempt to do a job unless you have sufficient help, the proper tools, and necessary safety equipment.

3. Never use fingers to remove a manhole cover or heavy grate. Use the proper tool.

4. "Lift with your legs, not your back" to prevent back strains.

5. Use ladders of any kind with caution. Be certain that portable ladders are positioned so they will not slip or twist. Whenever possible, tie the top of a ladder used to enter below-grade structures. Do not use metal ladders near electrical boards or appliances.

6. Never enter a manhole, pit, sump, or below-grade enclosed area when by yourself.

7. Always test manholes, pits, sumps, and below-grade enclosed areas for explosive atmosphere, oxygen deficiency, and hydrogen sulfide. Before entering, thoroughly ventilate with forced air blower.

8. Wear or use safety devices such as safety harnesses, gas detectors, and rubber gloves to prevent infections and injuries.

9. Never use a tool or piece of equipment unless you are thoroughly familiar with its use or operation and know its limitations.

10. When working in traffic areas, always provide:

    a. Adequate advance warning to traffic by signs, flags, etc.

    b. For channeling the flow of traffic around your work area by use of traffic cones, barricades, or other approved items.

    c. Protection to workers by placing your vehicle between traffic and job area, and/or by use of flashing or revolving lights, or other devices.

    d. Flagmen when necessary to direct and control flow of traffic.

11. Before starting a job, be certain that work area is of adequate size. If not, make allowances for this. Keep all working surfaces free of material that may cause surface to be slippery.

12. See to it that all guardrails and chains are properly installed and maintained.

13. Provide and maintain guards on all chains, sprockets, gears, shafts, and other similar moving pieces of equipment that are normally accessible.

14. Before working on mechanical or electrical equipment, properly turn off and/or tag breakers to prevent the accidental starting of the equipment while you are working on it. Wear rubber gloves and boots wherever you may contact "live" electrical circuits.

15. Never enter a launder, channel, conduit, or other slippery area when by yourself.

16. Do not allow smoking or open flames in the area of, on top of, or in any structure in your digestion system. Post all these areas with warning signs in conspicuous places.

17. Never enter a chlorine atmosphere by yourself and without proper protective equipment. Seek the cooperation of your local fire department in supplying self-contained breathing apparatus.

18. Obtain and post in a conspicuous location the name and telephone number of the nearest chlorine emergency service. Acquaint your police and fire department with this service.

19. Inspect all chlorine connectors and lines before using. Discard any of these that appear defective.

20. Keep all chlorine containers secured to prevent falling or rolling. Use only approved methods of moving and lifting containers.

21. Maintain a good housekeeping program. This is a proven method of preventing many accidents.

22. Conduct an effective safety awareness and training program.

These are the highlights of what has been previously discussed. Whenever in doubt about the safety of any piece of equipment, structure, operation, or procedure, contact the equipment manufacturer, your city or county safety officer, or your state safety office. One of these should be able to supply you with an answer to your questions.

ACCIDENTS DON'T JUST HAPPEN... THEY ARE CAUSED!

You can be held personally liable for injuries or damages caused by an accident as a result of your negligence.

Can you afford the price of one?

Can you afford the loss of one or more men?

Can your family afford to lose you?

12.9 ADDITIONAL READING

a. MOP 11, pages 156-163.

b. New York Manual, pages 169-182.

c. Texas Manual, pages 689-706.

d. Chlorine--Safe Handling, PPG Industries, Inc., Chemical Division, One Gateway Center, Pittsburgh, Pennsylvania 15222.

e. Safety in Wastewater Works, WPCF Manual of Practice No. 1, Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016. Price: $0.75 to members, $1.50 to others. Indicate your member association when ordering.

f. Safety Program Promotional Packet, Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016.

g. Chlorine Manual, The Chlorine Institute, Inc., 342 Madison Avenue, New York, New York 10017. Price $0.75.

h. Motivating for Safety, Journal of American Water Works Association, Vol. 61, No. 2, pp 57-59 (February 1969).

i. Test Your Safety Sense, National Safety Council, 425 North Michigan Avenue, Chicago, Illinois 60611.

j. CRC Handbook of Laboratory Safety, by Norman V. Steere, Chemical Rubber Publishing Company, 18901 Cranwood Parkway, Cleveland, Ohio 44128. Price $24.50.

END OF LESSON 3 OF 3 LESSONS

on

PLANT SAFETY AND GOOD HOUSEKEEPING

DISCUSSION AND REVIEW QUESTIONS

Chapter 12. Plant Safety and Good Housekeeping

(Lesson 3 of 3 Lessons)

Write the answers to these questions in your notebook. The problem numbering continues from Lesson 2.

19. How can samples for lab tests be collected if you shouldn't go beyond guardrails or chains?

20. What should be done with the jagged ends of glass tubes?

21. How should hot lab equipment be handled?

22. How can a fire be extinguished?

23. Fires can be prevented by good housekeeping and proper handling of flammables. True or False?

24. Why should plant water supplies be checked monthly for coliform group bacteria?

25. Why should safety equipment be checked periodically?

26. Where would you look for safety posters, signs, and slogans to aid in "tailgate" safety meetings?

27. Carefully study this illustration. List the safety hazards and indicate how each one can be corrected.

SUGGESTED ANSWERS

Chapter 12. Plant Safety and Good Housekeeping

12.1A The operator can protect himself and his family from disease by thoroughly washing his hands after being in contact with wastewater and sludges and by careful cleaning of his work clothes.

12.1B Before entering an unventilated, enclosed structure you should check for oxygen deficiency and provide ventilation.

12.1C Toxic gases and vapors originate from the discharge of certain industrial wastes into the wastewater collection system. The decomposition of certain wastes will produce dangerous gases too.

12.2A Someone should always be standing near a manhole when you enter it in case you collapse from an oxygen deficiency or are overcome by a toxic gas. An additional man should be in the vicinity to help the man at the top of the manhole recover you by pulling on the safety harness if you need help.

12.2B Instruments are available to measure the concentrations of oxygen and toxic gases in manholes and other enclosed areas.

12.2C Insist that the equipment vendor provide you and your coworkers with the proper instruction regarding the use of equipment.

12.2D Traffic may be alerted by signs, flags, fluorescent cones, flagmen, and flashing lights on a truck parked in front of the manhole.

12.2E Slimes, rags, or greases should be removed from any area because they may cause people to slip and they are unsightly.

12.2F When working on a mechanical or electrical part of equipment, you should fasten a tag to the breaker handle reading "DANGER, Do Not Start, Man Working on Equipment", or some other similar notice.

12.2G Guards should be placed around moving parts of equipment such as rotating shaft couplings, belt drives, and other moving parts normally accessible.

12.2H Our noses eventually become insensitive to some odors, such as hydrogen sulfide gas. This phenomenon is known as "factory fatigue".

12.2I Tools and equipment should not be carried, but should be transported in and out of pits and sumps by the use of buckets and handline or sling.

12.2J Slippery surfaces such as stairs, ladders, and catwalks can be made less dangerous if nonskid strips or coatings are applied at proper locations.

12.2K Smoking and open flames should not be allowed in the vicinity of digesters because when methane gas is mixed with the proper portion of air it forms an explosive mixture.

12.2L Before entering a recently emptied digester, you should ventilate the digester and check for an explosive atmosphere.

12.2M Before relighting a waste gas burner, the main gas valve should be turned off and the stack allowed to vent itself for a few minutes.

12.2N If a positive displacement pump is started against a closed discharge valve, pressures could build up and break a pipe or damage the pump.

12.2O When working with mercury you should wear rubber gloves. Mercury spills should be avoided. When finished, you must wash your hands thoroughly.

12.2P The rotary distributor may be stopped by turning off the flow of water or by some other means of slowing down the distributor. Extreme care must be taken because of the force developed by the distributor.

12.2Q You should never work alone on the center "Y" wall of an aerator because you could fall into the aerator and need help getting out.

12.2R Chlorine containers should only be lifted by an approved lifting bar with hooks over the ends.

12.2S Chlorine gas is heavier than air and is best removed when leaks occur by blowing the gas out of the room at floor level.

12.2T If you open a door and smell chlorine, immediately close the door and seek help.

12.2U Good housekeeping can and has prevented many accidents. You should keep your plant clean, provide containers for wastes, and empty them regularly.

12.3A When collecting influent samples, rubber gloves should be worn to protect the operator's hands if there is any chance of direct contact with the wastewater. If possible, sample poles or other similar types of samplers should be used.

12.3B Hands should always be washed before eating to prevent the spread of disease.

12.3C Chemicals and reagents should be handled with care to protect your body from serious injuries and possible poisoning.

12.4A The necessary ingredients of a fire are fuel, heat, and oxygen.

12.4B Oil- and paint-soaked rags should be placed in covered metal containers.

12.5A Some treatment plants use bottled drinking water because it is an economical and reliable source of potable water. This practice reduces the possibility of the spread of disease from unknown cross-connections or defective devices installed to prevent contamination by back-flows.

12.6A The following phone numbers should be conspicuously listed in your plant: Fire Department, Police Department, Ambulance, Chlorine Supplier or Repairman, and Physician. Check your list to be sure they are all listed and the numbers are correct.

12.7A The purpose of safety meetings is to remind operators of the need for safety, and to review potential hazards and how to correct or avoid dangerous situations.

12.7B Safety meetings should be held every 7 to 10 days.

OBJECTIVE TEST

Chapter 12. Plant Safety and Good Housekeeping

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to each question.

1. To prevent coming in contact with infections and infectious diseases, the operator should:
    1. Wash his hands before eating
    2. Wear protective gloves when in contact with wastewater and sludges
    3. Not wear his work clothes home
    4. Never repair equipment that comes in contact with sludge
    5. Wash his hands before going to the lavatory

2. An oxygen deficiency, or dangerous concentrations of toxic or suffocating gases, may be found in:
    1. Manholes
    2. Wet wells
    3. Empty digesters
    4. Chlorinator rooms
    5. Pump rooms

3. Manholes may be lifted with:
    1. Your fingers
    2. Your back
    3. A manhole hook

4. Traffic may be warned of a job in a street or other traffic area by:
    1. High-level signs and flags far enough ahead of the job to adequately alert drivers
    2. Leaving some manholes open so everyone can see that you are working
    3. Traffic cones arranged to guide traffic around work area
    4. Hoping autos headed toward the work area will be warned by other drivers
    5. A flagman directing traffic

5. When working on any piece of electrical equipment, the circuit breaker should be (pick only the best answer):

   1. Open
   2. Closed
   3. Tagged
   4. Locked out
   5. Locked out and tagged

6. Good housekeeping around a treatment plant means:

   1. Reading magazines
   2. Hosing down all spills immediately
   3. Keeping the coffee fresh and warm
   4. Providing a proper place for equipment and tools
   5. Keeping all walking areas clean and free of slimes, oils, and greases

7. Why should explosion-proof lights be used when working in an empty digester?

   1. If there is an explosion, the lights won't go out.
   2. Explosion-proof lights will not produce a spark which could cause an explosion.

8. The greatest hazard working in a clarifier is:

   1. Explosions
   2. Asphyxiation
   3. Slipping

9. When working in an empty digester, an operator should:

   1. Ventilate the digester
   2. Test for H_2S
   3. Test for explosive gas mixtures
   4. Use explosion-proof lights
   5. Wear nonsparking shoes

10. Gases may accumulate in sludge pump rooms from:

    1. Chlorinators
    2. Leakage
    3. Blowers
    4. Normal pump cleaning

11. When working around a trickling filter, the operator should:

    1. Never walk on the filter media while the rotating distributor is moving
    2. Ride on the distributor to get from one side to the other
    3. Wear rubber gloves when handling mercury from the seal
    4. Always provide a firm base when jacking up the distributor for repairs
    5. Never try to stop a rotating distributor by standing in front of it

12. When applying protective coatings in a tank, the operator should:

    1. Check with the manufacturer for safety precautions
    2. Provide adequate ventilation
    3. Wear protective clothing
    4. Apply protective creams to exposed skin areas
    5. Avoid breathing fumes from the protective coating

13. When working in the lab, you may:

    1. Smoke whenever you wish
    2. Use laboratory glassware for a coffee cup
    3. Add acid to water
    4. Never look into the end of a container during a reaction or when heating the container
    5. Hold a piece of glassware in your bare hands while heating it

14. The purpose of a safety meeting is to:

    1. Provide an awareness of the need for safety at all times
    2. Review potential safety hazards and outline the necessary precautions
    3. Get off work
    4. Discuss vacation plans
    5. Discuss the causes of accidents

Review Questions:

15. How many pounds of solids are under aeration in an aeration tank with a capacity of 0.4 MG when the MLSS is 2000 mg/l?

    1. 650 pounds
    2. 5000 pounds
    3. 6500 pounds
    4. 6700 pounds
    5. 7000 pounds

16. What is the food-to-organism ratio in an aeration tank if 1000 pounds of BOD are added per day and 3500 pounds of solids are under aeration?

1. 25 lbs BOD per day per 100 lbs of aeration solids
2. 28 lbs BOD per day per 100 lbs of aeration solids
3. 30 lbs BOD per day per 100 lbs of aeration solids
4. 32 lbs BOD per day per 100 lbs of aeration solids
5. 35 lbs BOD per day per 100 lbs of aeration solids

Please write on your answer sheet the total time required to work all three lessons and this Objective Test.

CHAPTER 13

SAMPLING RECEIVING WATERS

by

Bill B. Dendy

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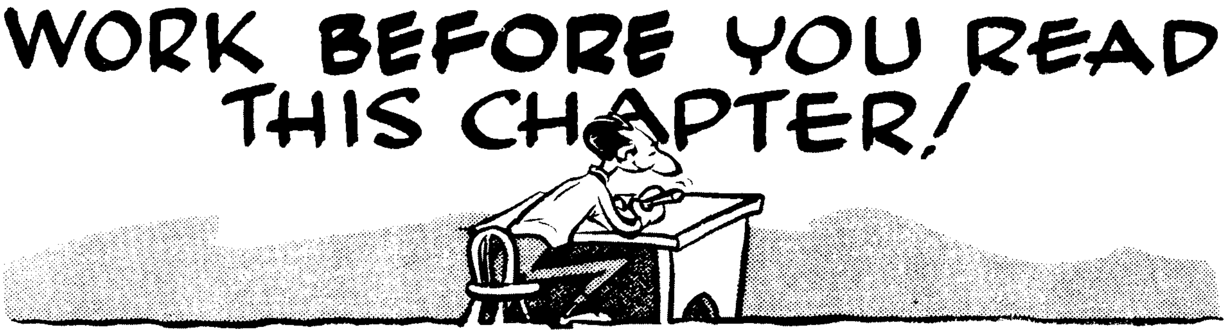
Chapter 13. Sampling Receiving Waters

PRE-TEST

Chapter 13. Sampling Receiving Waters



Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. Don't be discouraged if you don't know the answers. The Pre-Test indicates to you the important topics in this chapter.

Select the best answer (only one answer).

1. The two types of measurements required in connection with operating a treatment plant are:
   1. Temperature and dissolved oxygen
   2. Effluent and downstream
   3. Upstream and downstream
   4. In-plant and receiving water
   5. Temperature and receiving water

2. Receiving water sampling requires proper:
   1. Safety and temperature
   2. Equipment and "flailing the water"
   3. Selection of samples and collection techniques
   4. Water quality objectives and night work
   5. Snap-on belts and flags

3. To determine the location and amount of lowest dissolved oxygen downstream from a discharge it is necessary to:
   1. "Flail the water"
   2. Observe safety precautions
   3. Measure the effluent
   4. Make an "oxygen profile" of the stream
   5. Make yearly measurements

4. The average annual temperature for a stream can be measured by sampling in only one month out of the year.

   1. True
   2. False

5. Results from a sampling program should always be accepted without question or verification.

   1. True
   2. False

6. Proper sample collection techniques are specified in:

   1. <u>Standard Methods for the Examination of Water and Wastewater</u>
   2. Playboy Magazine
   3. All design manuals for concrete pipe
   4. Water quality objectives
   5. Safety precautions

7. Some receiving water characteristics which should be measured immediately after the sample is collected are:

   1. Calcium and vitamins
   2. Temperature, pH, and dissolved gases
   3. Sulfur and molasses
   4. Velocity and dissolved solids
   5. Profiles and effluents

8. A record must be made of every sample collected.

   1. True
   2. False

GLOSSARY

Chapter 13. Sampling Receiving Waters

Estuaries (ES-chew-wer-eez): Bodies of water at the lower end of a river that are subject to tidal fluctuations.

Fixed: A sample is "fixed" in the field by adding chemicals that prevent the water quality of the sample from changing before final measurements are performed later in the lab.

Representative Sample: A portion of material or water identical in content to that in the larger body of material or water being sampled.

Respiration: The physical and chemical processes by which an organism supplies its cells and tissues with oxygen needed for metabolism and relieves them of carbon dioxide formed in energy-producing reactions.

CHAPTER 13. SAMPLING RECEIVING WATERS

13.0 INTRODUCTION

The purposes of treating wastewater are to protect the health of people who may come in contact with it, to prevent nuisance due to odors or unsightliness, and to prevent the wastewater from interfering with the many uses of streams, lakes, estuaries,[1] oceans, or underground waters.

In order to find out whether or not a treatment plant is accomplishing all of these tasks, it is necessary to measure and record the effect of the plant discharge (effluent) in the receiving waters.

There are two types of measurements required in connection with operating a treatment plant. One kind is in-plant measurement for determining how well the plant operates as compared with what it is designed to do. For instance, a plant might be designed to remove 90% of the suspended solids in the raw wastewater. In-plant wastewater measurements are used to see if it is actually removing that much, by determining the amount of suspended solids in the influent (raw wastewater) and effluent and calculating the percent reduction while the wastewater flows through the plant. Results of in-plant measurements are used to regulate or control plant processes for effective waste treatment. In-plant sampling site selection and procedures are presented in Chapter 14, Section 14.3.

Receiving water measurements are used to determine the effect of the waste discharge on the receiving waters and on the beneficial uses of the receiving waters, after it leaves the plant. It is possible that a plant could be operating according to its design

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[1] Estuaries (ES-chew-wer-eez). Bodies of water at the lower end of a river that are subject to tidal fluctuations.

and be removing 90% of the suspended solids, yet still be causing a bad effect on the receiving water which receives the effluent. This could happen because the plant was not designed properly or there has been a change in the receiving water, such as a reduction in stream flow, since the plant was built. Also a 90% reduction on a very concentrated waste may not be good enough.

Receiving water measurements are as important as the in-plant measurements because the real purpose of the plant is to protect the receiving waters. However, plants should always be operated as efficiently as possible, therefore in-plant measurements must not be slighted. Also, it is absolutely necessary that the plant effluent be measured so that it can be related to effects in the receiving waters.

The usual approach in measuring the effect of a discharge on receiving waters is to take a measurement in an area which is not affected (upstream) and in an area which is affected (downstream) and compare the two. This comparison shows how much effect the discharge has on the receiving waters. It also shows whether the discharge is causing a violation of the water quality objectives or standards which have been set by the water pollution control agency or health department.

13.1 SAMPLING (Selection of Samples)

13.10 General

To plan a water quality survey, you must understand the reasons for or objectives of the survey. The overall objectives of each survey greatly influence the location of sampling stations, types of samples, frequency and time of day of collecting samples, and other factors. When developing sampling programs, survey planners also must realize that water quality characteristics vary from one body of water to another, from place to place in a given body of water, and from time to time at a fixed location in a given body of water.

A sampling program must be prepared in a manner that will produce accurate and useful results. The collection, handling, and testing of each sample should be scheduled and conducted in such a manner to assure that the results will be descriptive of the sources of the individual samples at the time and place of collection. Select locations of sampling stations and collect samples during times of the day and/or night that will provide the data needed to meet the objectives of your survey. Collect enough data over a period of time to adequately describe the condition or quality of the water at each sampling station.

To illustrate these important items, consider a simplified example of a waste discharge into a flowing river. Assume the river flows at 500 cubic feet per second (cfs) and the treatment plant discharges at 10 cfs (6.46 MGD). Assume that it is desirable to find out what is the effect on the river. To determine the effect, the following questions must be answered.

1. What are the characteristics of the river upstream from the discharge?

2. What are the river characteristics downstream?

3. If upstream and downstream river characteristics are different, does the discharge cause the difference?

4. Are the downstream river characteristics in violation of established standards or objectives?

5. If the river downstream is in violation of standards or objectives, did the discharge cause it?

Start with Question 1. Assume that you wish to measure:

a. Temperature

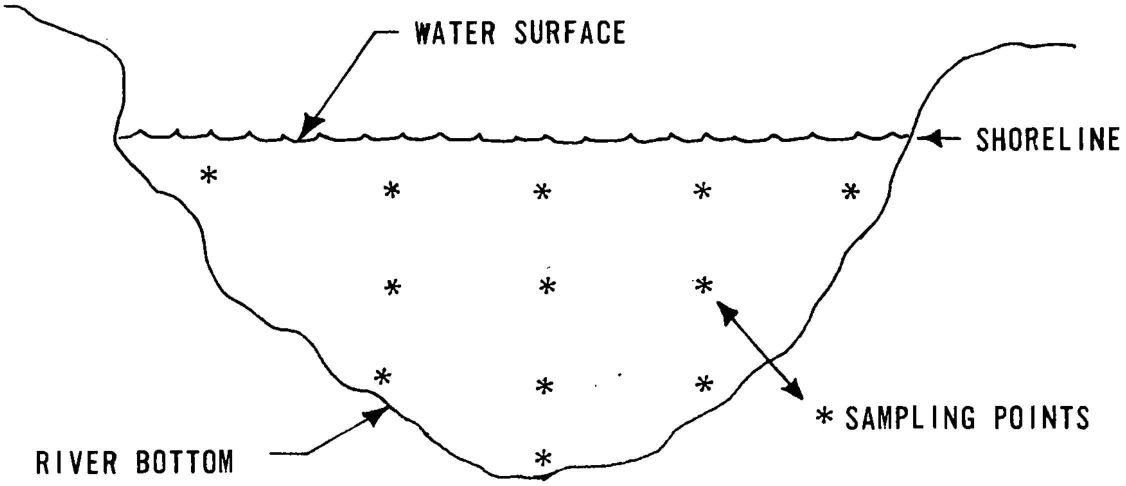
b. Dissolved Oxygen

13.11 Temperature

You must develop a temperature measurement program which will accurately describe the river temperature upstream from the discharge. How can this be done so that the changes from hour to hour during the day and from month to month during the year are known? Also, how can the temperature be measured so that the average for the river cross-section can be found, as well as the variations from the average in the cross-section? (See Fig. 13.1)

In some rivers which are deep and slow moving, the temperature may be several degrees cooler on the bottom than on the top. Thus, if the temperature measurement up-river from the discharge was taken near the bottom and the one down-river near the top, it might appear that the discharge had caused the stream to warm up when it actually had little effect.

The first thing to do is locate the river cross-section (line across the stream) to be sampled. This may be located at a bridge or near a boat dock or some other accessible place. Then measure the temperature at several points across the stream and at several depths at each point (see Fig. 13.1). Measurements also should be taken near shorelines, in backwater areas, and near



NOTE: Sampling points should be located near the shoreline and approximately one foot below the water surface and one foot above the bottom. The number of sampling points between the water surface and the bottom will depend on the depth of the water, and the number of vertical sampling sections will depend on the width of the stream.

Fig. 13.1 River cross-section showing typical sampling points the stream bottom. These are locations where problems first develop. If the temperatures are all about the same (within about 1°C or 2°F),[2] you can assume the stream is well mixed with a uniform temperature.

Next thing to consider is the time of day. Most streams will be cooler at night than during the day. Usually mid-channel temperature measurements vary less than those in shallow stretches. The minimum (lowest) temperature usually occurs about dawn and the highest in the late afternoon. The best way to measure these variations is to use a 24-hour recorder. If no recorder is available, take a measurement each hour for 24 hours (a little night work never hurt anybody!) to get an average temperature for the day, add up all the numbers, and divide by 24. Then see <u>what time of day</u> the average value and the maximum value usually <u>occur</u>. (This may vary with the season.) It is usually accurate enough for most streams to measure the temperature at those times and use the values for an average daily and maximum daily. For example, assume the following measurements on the next page were recorded:

[2] °C means "degrees centigrade" or degrees Celsius", both of which refer to a particular temperature scale; °F means "degrees Fahrenheit", a different temperature scale.

Time	Temperature °C
12 NOON	12.4
1 PM	12.8
2 PM	13.2
3 PM	13.6
4 PM	14.0
5 PM	13.8
6 PM	13.6
7 PM	13.3
8 PM	13.0
9 PM	12.7
10 PM	12.4
11 PM	12.0
12 MIDNIGHT	11.6
1 AM	11.2
2 AM	10.8
3 AM	10.5
4 AM	10.3
5 AM	10.1
6 AM	10.0
7 AM	10.2
8 AM	10.4
9 AM	10.8
10 AM	11.2
11 AM	11.8
TOTAL	= 285.7°C

$$\text{Average Temperature, °C} = \frac{\text{Sum of Measurements, °C}}{\text{Number of Measurements}}$$

$$= \frac{285.7\text{°C}}{24}$$

$$= 11.9\text{°C}$$

The average temperature of 11.9°C occurs at about 11 AM and again about 11 PM. If every day is like this, a measurement taken at 11 AM each day will give a fairly accurate record of the daily average temperature. Periodic rechecks of the hourly variation should be made. The same goes for the maximum value, which occurs at 4 PM.

The next thing to consider is the seasonal variation in temperature. Streams normally warm up in summer and cool off in winter. Obviously, if a measurement is taken daily (as explained above) this record will show all variations throughout the year. But, usually the daily average temperature does not change very much day to day.

Assume that the daily values for each month have been used to calculate monthly averages and that the following numbers have been obtained.

Month	Monthly Average Temperature, °C
January	7.0
February	6.0
March	8.0
April	10.0
May	12.0
June	14.0
July	16.0
August	19.0
September	18.0
October	14.0
November	10.0
December	8.0
TOTAL =	142.0°C

$$\text{Yearly Average, °C} = \frac{\text{Sum of Measurements, °C}}{\text{Number of Measurements}}$$

$$= \frac{142.0\text{°C}}{12}$$

$$= 11.8\text{°C}$$

Minimum Monthly Average, °C = 6.0°C

Maximum Monthly Average, °C = 19.0°C

The month-to-month changes in temperature are not very predictable because some years are colder than others, or summer lasts longer, or something else unusual can happen. The minimum and maximum monthly averages indicate the extent of the monthly changes for the observed year.

This discussion of temperature measurement does not mean that temperature is the most important characteristic to measure, although it is important from the standpoint of protecting fish. It does show how important it is for you to be careful when selecting a sample for measuring any characteristic of wastewater or the receiving waters. It is important to plan ahead so that each sample will indicate or represent the actual conditions of the river. If this is accomplished, you have obtained a representative sample.[3] Going out blindly taking measurements (sometimes known as "flailing the water") can yield a lot of numbers which don't mean very much, but only the person who takes the measurement knows that. Others who use the numbers may assume they are meaningful and act accordingly. Always plan ahead to get maximum benefit from your receiving water sampling program.

Now go back to Question 2. What are the characteristics (in this case, temperature) down-river from the discharge? The same procedure for sample selection downstream should be used as previously explained. There is an additional consideration, however. The cross-section selected for a sampling station should be far enough downstream for the waste discharge to have become well mixed.

If the stream is very sluggish and deep, the discharge may not mix thoroughly for a mile or more; so it will be necessary to sample in such a way that the unmixed condition can be described properly. (Fig. 13.2) The higher the stream velocity, shallower the water, and the sharper the bends in the stream, the greater the turbulence and thus the quicker the discharge becomes mixed with the receiving waters.

Before going out in the filed to measure water quality, obtain a range of expected values for guidance in sampling and interpreting results. Try various sampling locations to find high and low values for different times of the day and season.

Look now at the problem of measuring the temperature (or other characteristic) of the treatment plant effluent. Wastewater flow from a municipal discharge normally has a variable flow rate and variable characteristics. Fortunately, this variation follows similar patterns from day to day, week to week, year to year, so a logical sampling program can be set up to keep track of the characteristics of the plant effluent.

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[3] Representative Sample. A portion of material or water identical in content to that in the larger body of material or water being sampled.

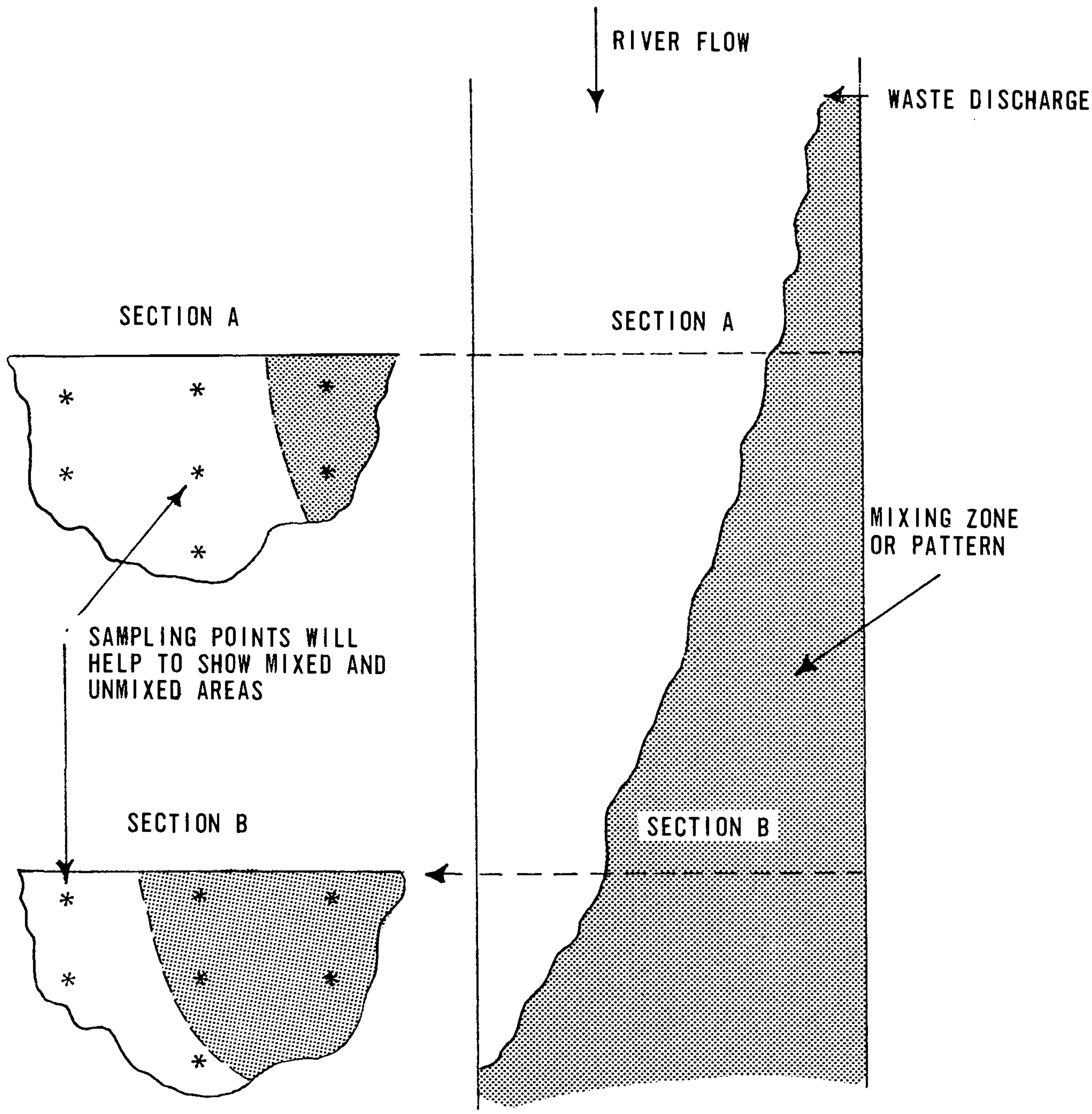

Fig. 13.2 Waste mixing in a river

REMEMBER:

The effluent measurement program must be designed to tell the operator how much volume of flow and what quality of constituents are entering the receiving waters, hourly, daily, weekly, monthly, and yearly.

It is desirable to have a convenient access where the effluent can be sampled easily. A remote sampling location or one which is difficult to reach will discourage regular sampling. Wherever the sampling station is located, it must provide meaningful samples.

13.12 Dissolved Oxygen

Another measurable characteristic of the stream is dissolved oxygen. The principles for collecting samples for measuring dissolved oxygen are the same as for measuring temperature. In fact, the amount of dissolved oxygen that can be in water depends on temperature, among other things.

Cold water will hold more dissolved oxygen than hot water. This does not mean that cold water always will contain more oxygen. Cold waters tend to slip under warmer waters because they have a greater density. In the lower layers of a body of water they are farther from the sources of oxygen from surface aeration and algal activity. Bottom waters may be close to deposits of organic materials that use oxygen. The net result could be lower oxygen concentrations in colder waters if they remain near the bottom too long.

In measuring the dissolved oxygen downstream from a treatment plant discharge, it is important to remember that a decrease in dissolved oxygen may not be noticeable immediately downstream, even if the effluent is well mixed with the stream. Many hours of flow time may be required for the oxygen to be reduced due to organic material in the discharge. So it is necessary to make an "oxygen profile" of the stream to get a good measure of the effect of the effluent.

Making a profile means merely measuring the dissolved oxygen at several different cross-sections downstream from the discharge to find out where the lowest dissolved oxygen level occurs. For this example, assume the same waste discharge and river used in the previous example.

Number the cross-sections to be sampled as follows:

Cross-Section No.	Location
1	1 mile above discharge
2	1 mile below discharge
3	3 miles below discharge
4	5 miles below discharge
5	7 miles below discharge
6	9 miles below discharge
7	11 miles below discharge

Identify the location of any additional waste discharges or points of inflow from tributary streams. Selection of the number and location of sampling cross-sections depends on stream characteristics, accessibility, and information desired. Normally locations are selected to show critical conditions and changes in the receiving waters.

At each cross-section, be sure representative samples are being selected. Always remember that a gallon of sample is supposed to be identical to the millions of gallons of water that flow past the sampling point.

Now, assume that you have checked and found that only one properly located sample was required to represent each cross-section and that the following measurements were obtained:

Cross-Section No.	Temperature, ^{o}C	Dissolved Oxygen, mg/1
1	13.5	10.5
2	13.5	10.0
3	13.5	9.0
4	13.5	7.5
5	13.5	6.0
6	13.5	7.1
7	13.5	8.9

(Note that the temperature is constant for all cross-sections. This is to simplify the example. If the temperature increased downstream from the discharge, some of the drop in dissolved oxygen would be due to the temperature increase and some would be due to the organic material. You also should be sure to notice any effects due to tributaries or other waste discharges.)

Fig. 13.3 shows a plot or graph of the measurements listed above. This is a good way to show the dissolved oxygen profile. Profiles for different days or months can be plotted on the same sheet in different colors to show how the profile changes from season to season or from year to year. The location of the low point may move up or down the stream, depending on the amount of flow in the

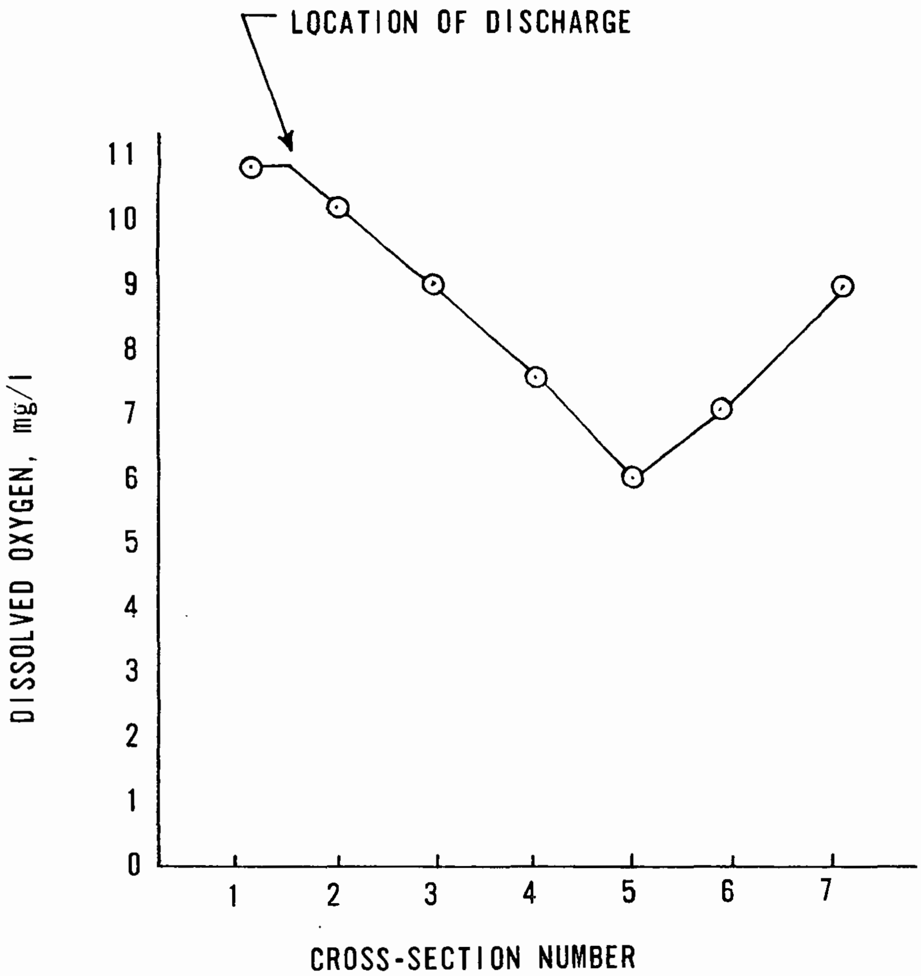

Fig. 13.3 Dissolved oxygen profile

stream and other factors. Therefore, several points must be obtained for each profile to be sure the amount and location of low point can be determined. Additional discharges will complicate the profile.

13.13 Review of Sampling Results

To determine if sampling stations are in the proper location and producing meaningful results, the results from the testing program must be carefully reviewed. If the results don't appear correct, try to determine why they appear strange. Look for sampling errors, testing errors, and recording errors. Attempt to verify each step in your sampling program. Remember that you sample because something unusual can happen. Don't reject strange results because they are unusual, but investigate and attempt to identify the reasons for the results. Establish additional sampling locations when necessary and eliminate or relocate stations that are not producing meaningful results.

QUESTIONS

13.1A An assistant plant operator collected samples and measured the temperature at one stream cross-section each hour for 24 hours. Following are the results he reported:

Time	Temperature °C	Time	Temperature °C
1 PM	13.5	1 AM	12.4
2 PM	13.4	2 AM	11.0
3 PM	14.3	3 AM	11.0
4 PM	14.7	4 AM	10.8
5 PM	14.5	5 AM	10.6
6 PM	13.8	6 AM	10.5
7 PM	14.0	7 AM	10.7
8 PM	13.7	8 AM	11.6
9 PM	13.4	9 AM	11.4
10 PM	22.7	10 AM	11.8
11 PM	12.7	11 AM	12.4
12 MIDNIGHT	12.2	12 NOON	13.0
		TOTAL =	310.1°C

$$\text{Average Temperature, °C} = \frac{\text{Sum of Measurements, °C}}{\text{Number of Measurements}}$$

$$= \frac{310.1\ \text{°C}}{24}$$

$$= 12.9\text{°C}$$

You are the supervisor. What would be your response to these results?

13.1B Which measurement would you be doubtful about?

a. 12 MIDNIGHT
b. 4 AM
c. 10 PM
d. 6 AM

13.1C Assume that you tell him to collect a new set of measurements two days later. He measures (not copies) all the same numbers except for the one you questioned earlier, and the new reading for that hour is 13.0. What are the new total and average values?

a. 296.3 and 13.2
b. 316.9 and 12.6
c. 300.4 and 12.5
d. 306.1 and 12.7
e. 298.9 and 13.0

13.1D a. What are the new maximum and minimum values?
b. At what times did they occur?
c. Which sample most nearly represented the average value?

13.2 SAMPLING (Collection Techniques)

13.20 Collection

The proper techniques to follow and precautions to observe to be sure a good sample is obtained are adequately covered in several publications. (See Section 13.6, Additional Reading.)

In all of these books the emphasis is on having the proper equipment and supplies (See Chapter 14, Section 14.3) to do a good job. Remember that behind all the instructions on techniques is the basic idea that the sample must be collected and preserved in such a manner that it does not change significantly from the time it is first obtained in the field until the final analysis is completed.

For example, if a gallon of water is selected from a stream for a dissolved oxygen measurement, be sure that the amount of dissolved oxygen in the sample does not change before it is measured. The same goes for any other characteristic.

Some characteristics change so rapidly that they should be measured immediately. This is true of temperature, pH, and dissolved oxygen. Some of the dissolved gases can be "fixed"[4] for a while to allow transporting the sample to the laboratory for measurement. Procedures for "fixing" can be found in "Standard Methods" and other publications on analysis. It is usually not a good idea to try to fix a sample containing a significant amount of organic matter, such as a plant effluent, because it tends to change anyway. Take a field kit to the sampling location and test at the site.

13.21 Frequency of Sampling

Regular sampling intervals should be developed in cooperation with the regulatory agency having authority over the plant and the receiving waters. When the treatment plant effluent is not meeting discharge requirements or the receiving waters are not meeting established water quality standards, the frequency of sampling may be increased.

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[4] Fixed. A sample is "fixed" in the field by adding chemicals that prevent the water quality indicator from changing before final measurements are performed later in the lab.

13.22 Size of Sample

When samples are tested in the field, the size of sample should be sufficient to perform the desired tests. If samples are preserved and transported to a lab for analysis, the size of sample should be at least twice the amount needed to perform the desired tests to allow for back-up or repeat tests.

13.23 Labeling of Samples

A record must be made of every sample collected. Every sample bottle must be identified and should have attached to it a label or tag indicating the exact location where the sample was collected, date, hour, air and water temperature, and name of collector. Other pertinent data such as water level or river flow and weather conditions should be recorded. Precipitation, cloud conditions and prevailing winds during the last few days should be noted when collecting samples. The weather during the three or four days before sampling may be entirely different from the weather on the day of sampling, but may significantly affect the character of the sample. Sampling points should be identified on maps, including a detailed description, and identified in the field by easily located markers or landmarks.

13.3 SAFETY

Take adequate precautions to prevent falling or slipping onto the water when sampling. Not only can this save your life, it also will prevent muddying the sample. Choose sampling cross-sections or "stations" carefully so that safe access is possible in winter and summer. Use snap-on safety belts when leaning over bridge railings or stream banks. When sampling on a bridge, be sure there is enough room for the man collecting the samples and traffic. Wear a life preserver when sampling from a boat; and be sure the boat is well marked with lights, reflectors, and flags to prevent collisions. At least two people should man a sampling boat. When the sampler's attention is focused on the job he is doing, he cannot keep an eye out for other watercraft.

13.4 OTHER TYPES OF RECEIVING WATERS

This lesson on sampling receiving waters has been limited to very simple examples of flowing streams or rivers. Some other types of receiving waters you may encounter are:

1. Oceans
2. Estuaries
3. Groundwaters
4. Lakes

These receiving waters usually require a more sophisticated approach to sampling and measurement of characteristics. The basic rules are the same, however, for sample selection and collection techniques. The best answer to sampling these types of receiving waters is to seek advice from a consultant, a regulatory agency, or other experts on where and how to sample and on how to evaluate the results.

13.5 WHAT TO MEASURE

There are hundreds, possibly thousands, of characteristics which could be measured in receiving waters and plant effluents. Many of them are not important to the operation of a treatment plant; however, it is possible to list a minimum number of characteristics which should enable the operator to measure the effect of his plant's effluent and find out if it meets water quality objectives.

Following is a listing of characteristics which should be observed or measured in the receiving waters and in the plant effluent:

	Effluent	Receiving Waters
1.	Visual Inspection (color, floating materials)	Visual Inspection (color, floating materials)
2.	Coliform Group Bacteria and Chlorine Residual	Coliform Group Bacteria
3.	Biochemical Oxygen Demand	Dissolved Oxygen
4.	Suspended Solids and Settleable Solids	Suspended Solids and Clarity
5.	Temperature	Temperature
6.	pH	pH
7.	Odor	Odor
8.	Grease	Grease

The list above is basic. Some additional characteristics which may be important in various situations are:

	Effluent	Receiving Waters
1.	Total Dissolved Solids	Total Dissolved Solids
2.	Chlorine	Chlorine
3.	Hardness	Hardness
4.	Viruses	Viruses
5.	Toxicity	Health of Aquatic Animals
6.	Biostimulants (such as nitrogen, phosphorus, etc.)	Algae and other Aquatic Plants
7.	Iron and Manganese	Iron and Manganese
8.	Chlorinated Hydrocarbons (pesticides)	Chlorinated Hydrocarbons (pesticides)
9.	Fluoride	Fluoride
10.	ABS	ABS
11.	Phenols	Phenols

Many of these effluent tests are for the record rather than for plant control purposes. The operator can do nothing in adjustment of treatment plant processes to affect the characteristics. However, he will often be asked to measure them because they are listed in the plant's waste discharge requirements or receiving water standards. Some of them, such as toxicity, can be controlled by ordinances which prevent toxic substances from being put in the wastewater collection system. Others, such as total dissolved solids, may require the city to find a new water supply.

QUESTIONS

13.2A What is a "fixed" sample?

13.3A What safety precautions should be taken when sampling?

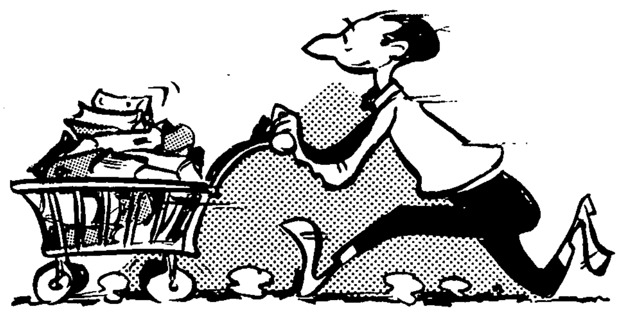
13.4A What characteristics should be observed or measured in the effluent and receiving waters of a treatment plant?

13.6 ADDITIONAL READING

a. MOP 11, pages 173-177.

b. New York Manual, pages 127-130.

c. *Standard Methods* for Examination of Water and Wastewater, produced by APHA, AWWA, and WPCF, Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016. Price: $16.50 to members, prepaid only; otherwise $22.50 plus postage. Indicate your member association when ordering. (This publication also contains instructions for building a sampler.)



DISCUSSION AND REVIEW QUESTIONS

Chapter 13. Sampling Receiving Waters

Please write the answers to these questions in your notebook.

1. Why should receiving waters be sampled?
2. Can a treatment plant operate as effectively as possible and still have a bad effect on the receiving waters? Why?
3. Why are receiving waters measured upstream from the point of discharge?
4. Where should samples be collected in the cross-section of a stream at a particular sampling location? Assume you are trying to find the point in the section which will give you a representative measurement of the entire section.
5. Why should more than one sampling station be established downstream from the point of wastewater discharge?
6. What does the term "representative sample" mean?
7. What is a major concern regarding sample water quality <u>after</u> the sample has been collected?
8. How large a sample should be collected?
9. What information should be included on a sample label?
10. What safety precautions should be taken when sampling from a bridge?

SUGGESTED ANSWERS

Chapter 13. Sampling Receiving Waters

13.1A I would contact the assistant plant operator and attempt to verify the results he recorded. Also I would ask him if he noticed anything unusual.

13.1B (c) 10 PM

13.1C (c) 300.4 and 12.5

13.1D a. Maximum 14.7°C and Minimum 10.5°C.
b. Time of maximum temperature, 4 PM; minimum temperature, 6 AM.
c. 11 AM.

13.2A A "fixed" sample is a sample which has chemicals added to prevent a particular water quality indicator from changing before the sample can be analyzed.

13.3A Adequate safety precautions should be taken when sampling to prevent falling or slipping into the water. Provisions should be made to warn other watercraft (flags). An assistand should be available to rescue anyone falling into the water and to warn other watercraft.

13.4A

	Effluent	Receiving Waters
1.	Visual Inspection (color, floating materials)	Visual Inspection (color, floating materials)
2.	Coliform Group Bacteria and Chlorine Residual	Coliform Group Bacteria
3.	BOD	DO
4.	Suspended Solids and Settleable Solids	Suspended Solids and Clarity
5.	Temperature	Temperature
6.	pH	pH
7.	Odor	Odor
8.	Grease	Grease

OBJECTIVE TEST

Chapter 13. Sampling Receiving Waters

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1.

1. The two types of measurements required in connection with operating a treatment plant are:
   1. Temperature and dissolved oxygen
   2. Effluent and downstream
   3. Upstream and downstream
   4. In-plant and receiving water
   5. Temperature and receiving water

2. Receiving water sampling requires proper:
   1. Safety and temperature
   2. Equipment and "flailing the water"
   3. Selection of samples and collection techniques
   4. Water quality objectives and night work
   5. Snap-on belts and flags

3. To determine the location and amount of lowest dissolved oxygen downstream from a discharge, it is necessary to:
   1. "Flail the water"
   2. Observe safety precautions
   3. Measure the effluent
   4. Make an "oxygen profile" of the stream
   5. Make yearly measurements

4. The average annual temperature for a stream can be measured by sampling in only one month out of the year.
   1. True
   2. False

5. Results from a sampling program should always be accepted without question or verification.
   1. True
   2. False

6. Proper sample collection techniques are specified in:
   1. Standard Methods for the Examination of Water and Wastewater
   2. Playboy Magazine
   3. All design manuals for concrete pipe
   4. Water quality objectives
   5. Safety precautions

7. Some receiving water characteristics which should be measured immediately after the sample is collected are:

   1. Calcium and vitamins
   2. Temperature, pH, and dissolved gases
   3. Sulfur and molasses
   4. Velocity and dissolved solids
   5. Profiles and effluents

8. A record must be made of every sample collected.

   1. True
   2. False

Review Questions:

9. What is the volatile acid/alkalinity relationship in a digester if the alkalinity is 1760 mg/l and the volatile acids are 140 mg/l?

   1. 0.05
   2. 0.08
   3. 0.10
   4. 0.125
   5. 0.15

10. A digester contains 1000 pounds of volatile matter under digestion. If 0.05 pounds of new volatile solids can be added per day per pound of volatile matter under digestion, how many pounds of sludge solids can be added per day with a volatile content of 70%?

   1. 20 pounds per day
   2. 50 pounds per day
   3. 70 pounds per day
   4. 100 pounds per day
   5. 200 pounds per day

Please write on your IBM answer sheet the total time required to work this chapter.

CHAPTER 14

LABORATORY PROCEDURES AND CHEMISTRY

by

James Paterson

(with a special section by Joe Nagano)

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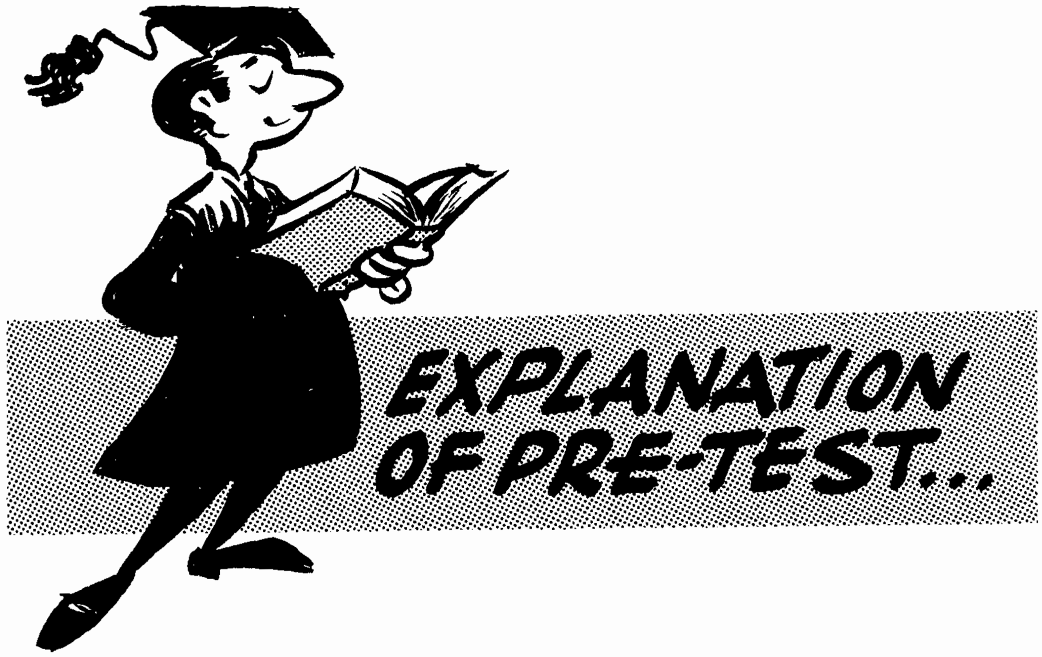
CHAPTER 14 LABORATORY PROCEDURES AND CHEMISTRY



The objective of the Pre-Test is to indicate to you the important topics in this chapter. You are not expected to know the answers to the questions, and your improvement in the Objective Test is an indication of how effective your efforts were in learning the material.

PRE-TEST

Chapter 14. Laboratory Procedures and Chemistry

Name _______________________________________ Date _______________

Please write your name and mark the correct answers on the IBM answer sheet. There may be more than one correct answer to each question.

TRUE OR FALSE (1-10):

1. A rubber bulb should be used to pipette wastewater or polluted water.

    1. True
    2. False

2. Acid may be added to water, but not the reverse.

    1. True
    2. False

3. Always wear safety goggles when conducting any experiment in which there may be danger to the eyes.

    1. True
    2. False

4. Smoking and eating should be avoided when working with infectious material such as wastewater and sludge.

    1. True
    2. False

5. In the washing of hands after working with wastewater, the kind of soap is less important than the thorough use of soap.

    1. True
    2. False

6. The pH scale may range from 0 to 14, with 7 being a neutral solution.

    1. True
    2. False

7. If at all possible, samples for the BOD test should be collected before chlorination

    1. True
    2. False

8. The COD test is a measure of the chemical oxygen demand of wastewater.

    1. True
    2. False

9. The BOD test is a measure of the organic content of wastewater.

    1. True
    2. False

10. The answers from the total solids and suspended solids tests are always the same.

    1. True
    2. False

Possible definitions of the words listed below are given on the right. If the definition of a word is after the number 2, mark column 2 on your answer sheet.

Word	Definition
	1. Surrounding
11. Aliquot	2. Capacity to resist pH change
12. Ambient	3. Portion of a sample
13. Blank	4. Inside
14. Buffer	5. Test run without sample

15. Large errors in laboratory tests may be caused by:

    1. Improper sampling
    2. Large samples
    3. Poor preservation
    4. Poor quality effluent
    5. Lack of mixing during compositing

16. The most critical factor in controlling digester operation is the:

    1. CO_2
    2. Gas production
    3. Volatile solids
    4. Volatile acids/alkalinity relationship
    5. pH

17. The COD test:

    1. Measures the biochemical oxygen demand
    2. Estimates the first-stage oxygen demand
    3. Measures the carbon oxygen demand
    4. Estimates the total oxygen consumed
    5. Provides results quicker than the BOD test

18. A clarity test on plant effluent:

    1. Tells if the effluent is safe to drink
    2. Is measured by an amperometer
    3. Should always be measured at the same time
    4. Should always be measured under the same light conditions
    5. Is measured by a Secchi Disc

19. Coliform group bacteria are:

    1. Measured by the membrane filter method
    2. Measured by the multiple fermentation technique
    3. Measured by the modified Winkler procedure
    4. Harmful to humans
    5. Indicative of the potential presence of bacteria originating in the intestines of warm-blooded animals

20. The saturation concentration of dissolved oxygen in water does not vary with temperature.

    1. True
    2. False

21. DO probes are commonly used to measure dissolved oxygen in water in:

    1. Aeration tanks
    2. Sludge digesters
    3. Manholes
    4. Streams
    5. BOD bottles

22. Hydrogen sulfide:

    1. Reacts with moisture and oxygen to form a substance corrosive to concrete
    2. Is sometimes written as H_2S
    3. Smells like rotten eggs
    4. Is formed under aerobic conditions
    5. Should not be controlled in the collection system

23. Results from the settleability test of activated sludge solids may be used to:

    1. Calculate SVI
    2. Calculate SDI
    3. Calculate sludge age
    4. Determine ability of solids to separate from liquid in final clarifier
    5. Calculate mixed liquor suspended solids

24. Results of the settleable solids test run using Imhoff cones may be used to:

    1. Calculate the Imhoff Settling Index
    2. Calculate the efficiency of a plant
    3. Calculate the pounds of solids pumped to the digester
    4. Indicate the quality of the influent
    5. Indicate the quality of the effluent

25. Precautions that must be observed in running the suspended solids-Gooch crucible test include:

    1. Collecting and testing a representative sample
    2. Proper temperature level in oven at all times
    3. Lack of leaks around and through the glass fiber
    4. Thoroughly mixing sample before testing
    5. Discarding any large chunks of material in sample

26. A chlorine residual should be maintained in a plant effluent:

    1. To keep the chlorinator working
    2. For disinfection purposes
    3. For testing purposes
    4. To protect the bacteriological quality of the receiving waters
    5. None of these

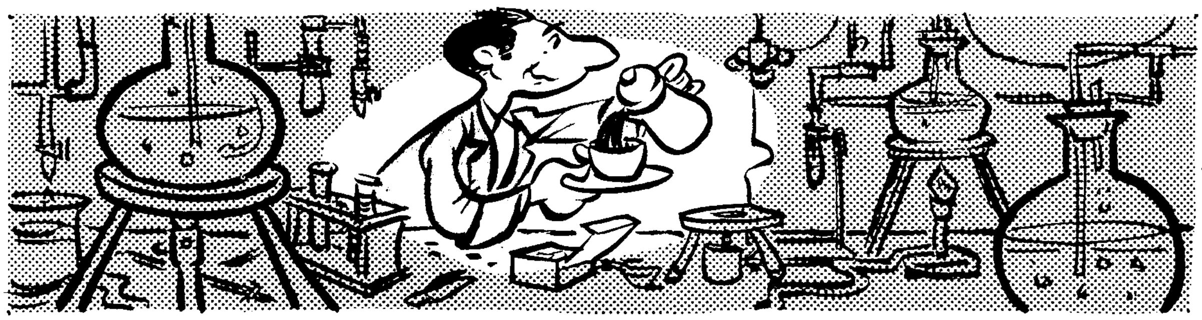
CHAPTER 14. LABORATORY PROCEDURES AND CHEMISTRY

14.0 INTRODUCTION

14.00 Should You Start This Lesson Now?

Laboratory procedures and results are the means by which we control the efficiency of our treatment processes and measure the effectiveness of the processes. To operate your plant as efficiently as possible, you must understand the laboratory procedures and relate them to the actual operation of your plant.

This lesson has been given to you at this time mainly for reference purposes. When you read the lessons on the treatment processes you should begin to wonder how certain tests are performed that are essential for proper plant operation. At this time you should refer to this lesson for a general discussion and a description of the laboratory procedure.



It might seem logical to you to complete this lesson first in order to better understand the operational aspects of the treatment process lessons. Many operators and potential operators who were interested in this profession have taken this course. Most of them have said that they wanted to learn about the treatment processes first and then learn how to apply the lab procedures to plant operation. Many potential operators experienced difficulty with the terminology when they tried to work this chapter before completing the lessons on the treatment processes. If you are an experienced operator and are anxious to learn more chemistry and to obtain a better understanding of lab procedures, you may decide to try this lesson first.

Past experience has indicated that most operators prefer to use this section as a reference while studying the lessons on treatment processes. You are the operator who wants to learn more about treatment plant operation, and you are encouraged to use this material in any manner that you feel best fits your particular situation and professional goals. Now is the time for you to decide whether you are going to:

1. Thumb through this lesson, proceed through the chapters on treatment processes, and then complete this lesson;

2. Complete the lessons on treatment processes, referring to this lesson when interested, and then complete this lesson;

3. Complete this lesson and then the lessons on treatment processes; or

4. Follow your own plan.

14.01 Material in This Lesson

A few of the lab procedures outlined in this chapter are not "Standard Methods" (4),[1] but are used by many operators because they are simple and easy to perform. Some of these procedures are not accurate enough for scientific investigations, but are satisfactory for successful plant control and operation. When lab data must be submitted to regulatory agencies for monitoring and enforcement purposes, you should request the agency to provide you with a list of approved test procedures.

Each test section contains the following information:

1. Discussion of test.
2. What is tested?
3. Apparatus.
4. Reagents.
5. Procedures.
6. Precautions.
7. Examples.
8. Calculations.

---

[1] Numbers in parentheses refer to references in Section 14.02.

If you would like to read an introductory discussion on laboratory equipment and analysis, the Water Pollution Control Federation has a good publication entitled "Simplified Laboratory Procedures" (3). Good discussions on the use of the analytical balance may be found in "Laboratory Procedures" (1) or "Simplified Procedures" (3).

14.02 References

1. "Laboratory Procedures for Operators of Water Pollution Control Plants" by Joe Nagano. Obtain from Secretary-Treasurer, California Water Pollution Control Association, P.O. Box 61, Lemon Grove, California 92045. Price $3.25 to members of CWPCA; $4.25 to others.

2. "FWPCA Methods for Chemical Analysis of Water and Wastes," Environmental Protection Agency, Water Quality Office, Analytical Quality Control Laboratory, 1014 Broadway, Cincinnati, Ohio 45202. (November 1969)

3. "Simplified Laboratory Procedures for Wastewater Examination," WPCF Publication No. 18, 1968, 60 pages. $2 to WPCF members; $3 to others.

4. "Standard Methods for Examination of Water and Wastewater," 13th Edition , 1971, 874 pages. $16.50 to WPCF members; $22.50 plus postage to others.

Both References 3 and 4 may be obtained by writing:

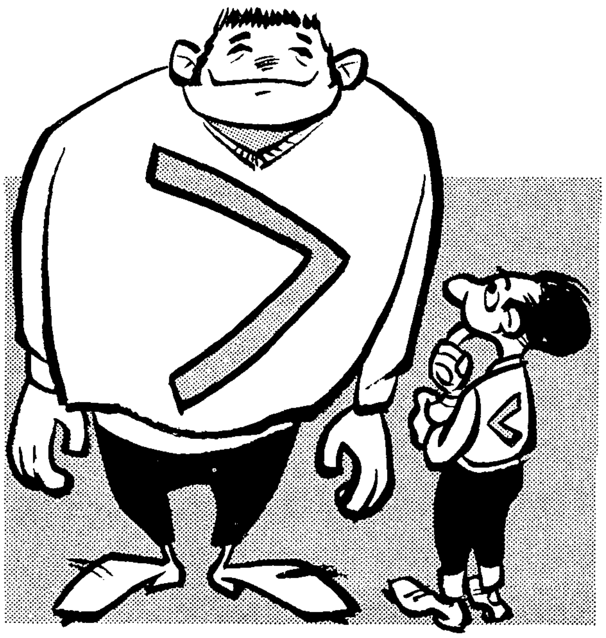
Water Pollution Control Federation
3900 Wisconsin Avenue
Washington, D.C. 20016

Order forms may be found in the Journal of the Water Pollution Control Federation.

14.03 Acknowledgments

Many of the illustrated laboratory procedures were provided by Mr. Joe Nagano, Laboratory Director, Hyperion Treatment Plant, City of Los Angeles, California. These procedures originally appeared in Laboratory Procedures for Operators of Water Pollution Control Plants, prepared by Mr. Nagano and published by the California Water Pollution Control Association. The lists of equipment, reagents, and procedures outlined in this chapter are similar to those listed in the references in Section 14.02. Use of information from these references is gratefully acknowledged.

14.1 GLOSSARY OF TERMS AND EQUIPMENT



14.10 Terminology

$>$ Greater than.

DO $>$ 5 mg/l, would be read as DO greater than 5 mg/l.

$<$ Less than.

DO $<$ 5 mg/l, would be read as DO less than 5 mg/l.

Aliquot (AL-li-kwot). Portion of a sample.

Ambient Temperature (AM-bee-ent). Temperature of the surroundings.

Amperometric (am-PURR-o-MET-rick). A method of measurement that records electric current flowing or generated, rather than recording voltage. Amperometric titration is an electrometric means of measuring concentrations of substances in water.

Anaerobic Environment (AN-air-O-bick). A condition in which "free" or dissolved oxygen is not present.

Blank. A bottle containing dilution water or distilled water, but the sample being tested is not added. Identical tests are frequently run on a sample and a blank and the differences compared.

Buffer. A measure of the ability or capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water or wastewater for offering a resistance to changes in the pH.

Composite (proportional) Samples (com-POZ-it). Samples collected at regular intervals in proportion to the existing flow and then combined to form a sample representative of the entire period of flow over a given period of time.

Distillate. In the distillation of a sample, a portion is evaporated; the part that is condensed afterwards is the distillate.

End Point. Samples are titrated to the end point. This means that a chemical is added, drop by drop, to a sample until a certain color change (blue to clear, for example) occurs which is called the end point of the titration. In addition to a color change, an end point may be reached by the formation of a precipitate or the reaching of a specified pH. An end point may be detected by the use of an electronic device such as a pH meter.

Flame Polished. Sharp or broken edges of glass (such as the end of a glass tube) are flame polished by placing the edge in a flame and rotating it. By allowing the edge to melt slightly, it will become smooth.

M or Molar. A molar solution consists of one gram molecular weight of a compound dissolved in enough water to make one liter of solution. A gram molecular weight is the molecular weight of a compound in grams. For example, the molecular weight of sulfuric acid (H_2SO_4) is 98. A 1M solution of sulfuric acid would consist of 98 grams of H_2SO_4 dissolved in enough distilled water to make one liter of solution.

Molecular Weight. The molecular weight of a compound in grams is the sum of the atomic weights of the elements in the compound. The molecular weight of sulfuric acid (H_2SO_4) in grams is 98.

Element	Atomic Weight	Number of Atoms	Molecular Weight
H	1	2	2
S	32	1	32
O	16	4	64
			98

N or Normal. A normal solution contains one gram equivalent weight of a reactant (compound) per liter of solution. The equivalent weight of an acid is that weight of a compound which contains one gram atom of ionizable hydrogen or its chemical equivalent. For example, the equivalent weight of sulfuric acid (H_2SO_4) is 49 (98 divided by 2 because there are two replaceable hydrogen ions). A 1N solution of sulfuric acid would consist of 49 grams of H_2SO_4 dissolved in enough water to make one liter.

Oxidation (ox-i-DAY-shun). Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In wastewater treatment, organic matter is oxidized to more stable substances.

Percent Saturation. Liquids can contain in solution limited amounts of compounds and elements. 100% saturation is the maximum theoretical amount that can be dissolved in the solution. If more than the maximum theoretical amount is present, the solution is supersaturated.

$$\text{\% Saturation} = \frac{\text{Amount in Solution}}{\text{Maximum Theoretical Amount in Solution}} \times 100\%$$

Reagent (re-A-gent). A substance which takes part in a chemical reaction that is used to measure, detect, or examine other substances.

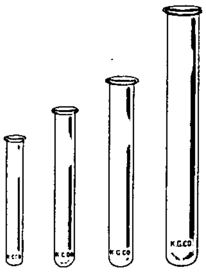
Representative Sample. A portion of material or water identical in content to that in the larger body of material or water being sampled.

Titrate. To titrate a sample, a chemical solution of known strength is added on a drop-by-drop basis until a color change, precipitate, or pH in the sample is observed (end point). Titration is the process of adding the chemical solution to completion of the reaction as signaled by the end point.

14.11 Equipment

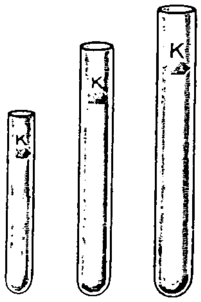
Equipment can be better described by a photo or a sketch than a written description; consequently, this portion of the glossary will describe equipment in this manner. Photos of equipment shown were provided by Van Waters & Rogers.

ILLUSTRATIONS OF LABORATORY APPARATUS



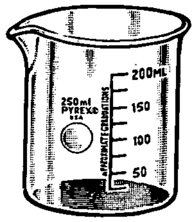
60809-021 Series

Test Tube



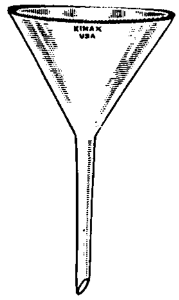
60824-116 Series

Culture Tube
Without Lip



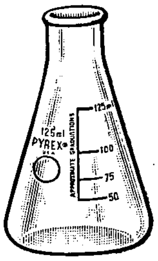
13912-207

Beaker



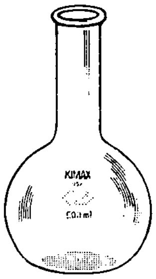
30209-025

Funnel



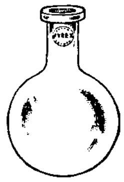
29140-023

Flask,
Erlenmeyer
(ER-len-MY-er)
Wide Mouth



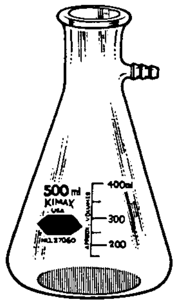
29110-102

Flask,
Boiling
Flat Bottom



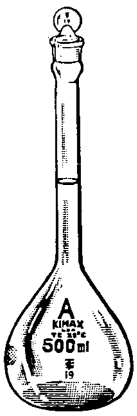
29126-022

Flask,
Boiling
Round Bottom
Short Neck



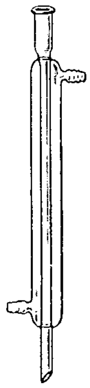
29415-100

Flask,
Filtering



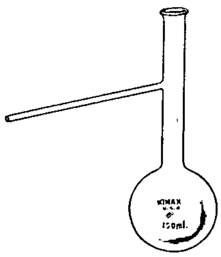
29619-642

Flask,
Volumetric



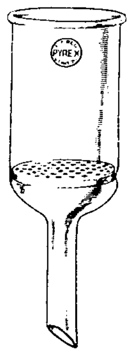
23130-049
23131-020

Condenser



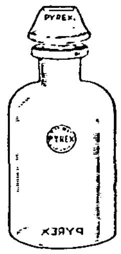
29209-083

Flask,
Distilling



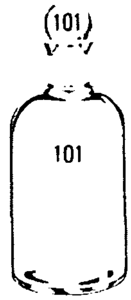
30294-024

Funnel,
Buchner
With
Perforated Plate



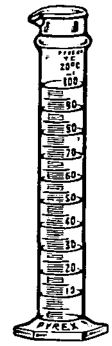
16269-027

Bottle,
Reagent



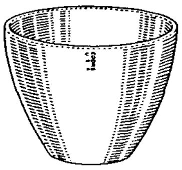
16285-114

Bottle,
BOD



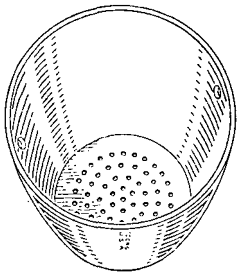
24707-265

Cylinder,
Graduated



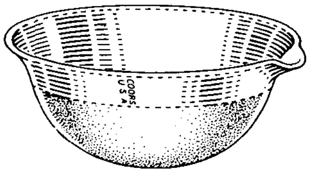
23810-021

Crucible
Porcelain



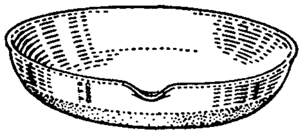
23835-000

Crucible
Gooch
(GOO-ch)
Porcelain



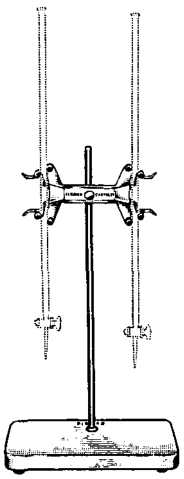
25310-019

Dish,
Evaporating



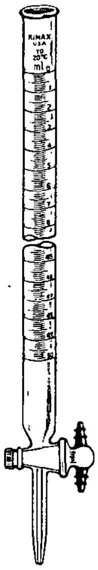
25313-017

Dish,
Evaporating
Shallow Form



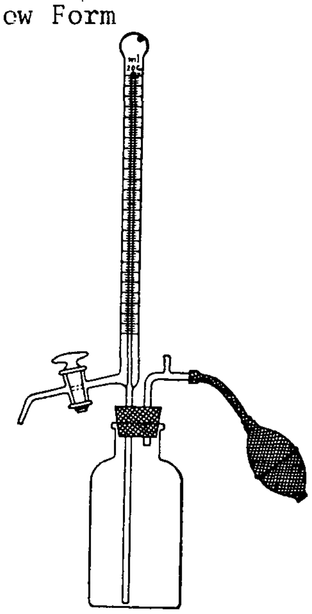
17685-005

Support, Buret
& Buret Clamp



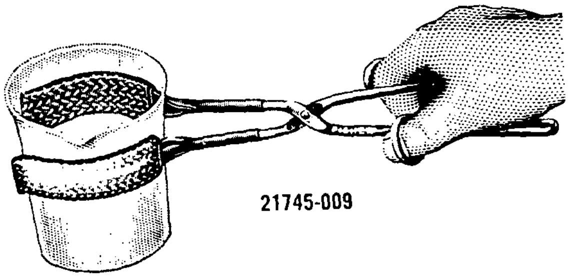
17454-443

Buret
(bur-RET)



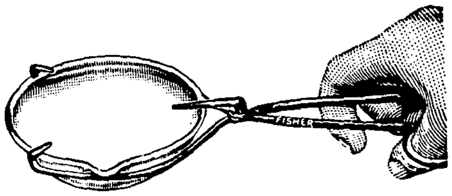
17590-044

Buret
Automatic



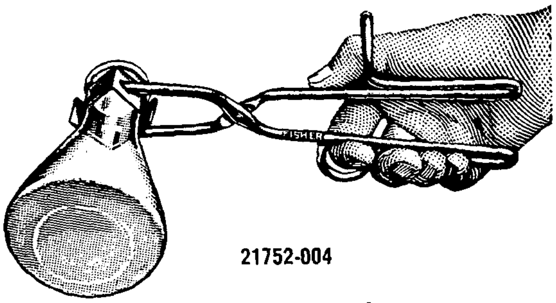
21745-009

Clamp, Beaker,
Safety Tongs



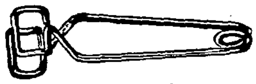
21750-009

Clamp, Dish,
Safety Tongs



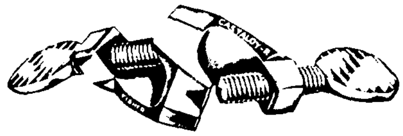
21752-004

Clamp, Flask,
Safety Tongs



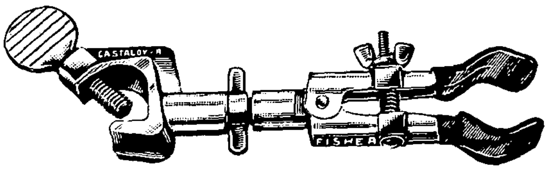
21770-028

Clamp, Test Tube



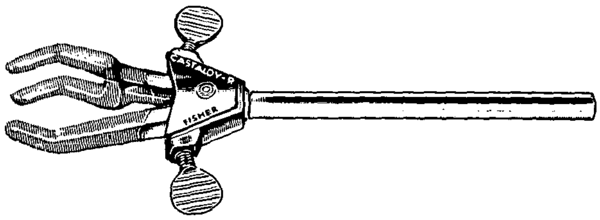
21677-000

Clamp Holder



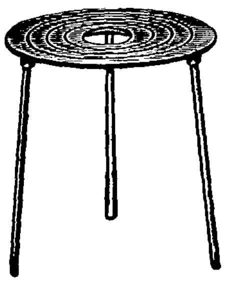
21611-046

Clamp, Utility



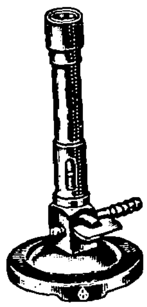
21633-049

Clamp



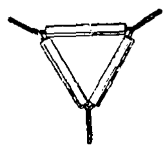
62765-029 Series

Tripod, Concentric
Ring



17951-029

Burner, Bunsen

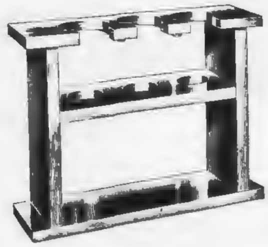


62730-024 Series

Triangle
Fused

66187-004

Cone,
Imhoff
(IM-hoff)



66190-009

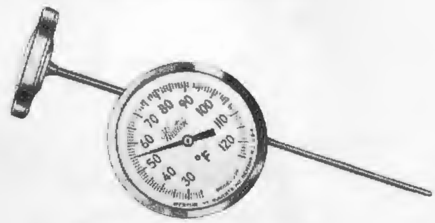
Cone Support

53047-024 Series

Pipette
(PIE-pet)
Volumetric

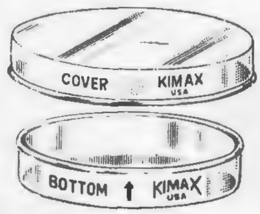
53224-028 Series

Pipet, Serological



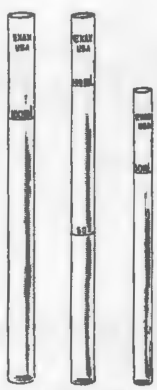
61048-033 Series

Thermometer, Dial



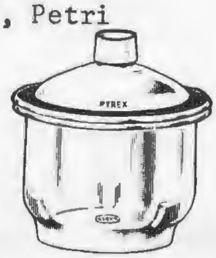
25353-248

Dish, Petri



66176-325

Color Comparison
Tubes, Nessler

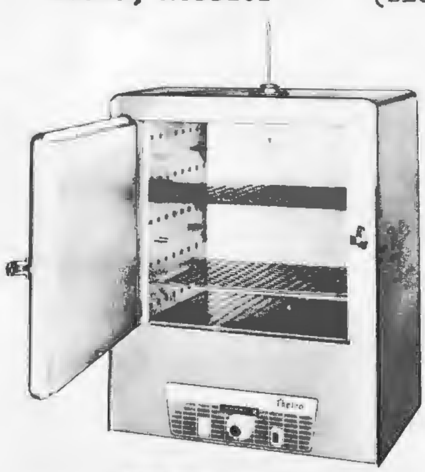


25026-026

Desiccator
(DES-ick-kay-tor)

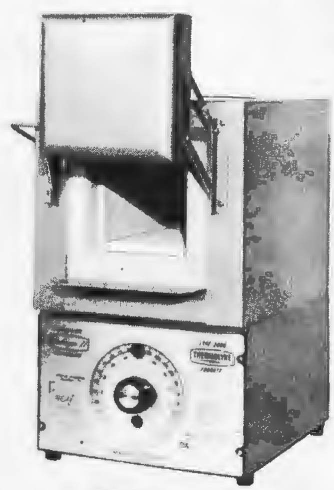
33976-009

Hot Plate



52368-022 Series

Oven, Mechanical Convection



30632-003

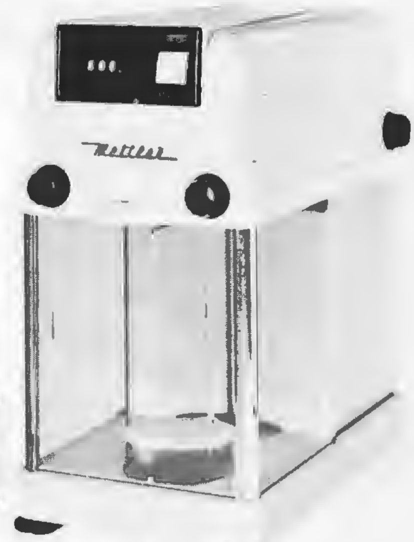
Muffle Furnace, Electric

35960-000

BOD Cabinet

Weight = 95.5580 gm.

11274-008 Reading Scale

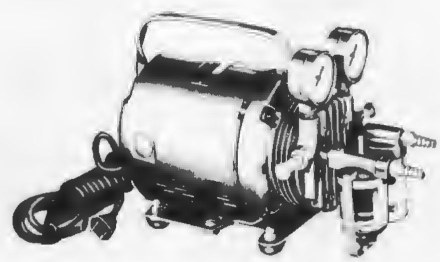


11274-008

Balance, Analytical

34114-055

pH Meter

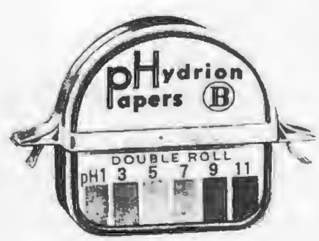


54906-001

Pump, Air Pressure & Vacuum

57980-000

Spectrophotometer



60776-002

Test Paper, pH 1-11

14.2 SAFETY AND HYGIENE, by A.E. Greenberg from California Water Pollution Control Association Operators Laboratory Manual

14.20 Laboratory Safety

Safety is important in the laboratory as well as in the rest of the treatment plant. Therefore, each employee working in a laboratory should be thoroughly familiar with this section.

On questions of safety, consult your state's General Industrial Safety Orders or similar document and Sax's "Dangerous Chemicals".[2]

Personnel working in a wastewater treatment plant laboratory must realize that a number of hazardous materials and conditions exist. PREVENT ACCIDENTS. Be alert and careful. Be aware of potential dangers at all times. The major threats to you are listed for your safety.

1. Infectious Materials

   Wastewater and sludge contain millions of bacteria, some of which are infectious and dangerous, and can cause diseases such as tetanus, typhoid, dysentery, poliomelytis, and hepatitis. Personnel handling these materials should thoroughly wash their hands with soap and water, particularly before handling food. Do not pipette wastewater or polluted samples by mouth. Use a rubber bulb. Though not mandatory, inoculations by your County Health Department are recommended for each employee.

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[2] See Sax, N.I., Dangerous Properties of Industrial Materials, Third Edition, Reinhold, New York, 1968, price $35.

2. Corrosive Chemicals

A. Acids

(1) Examples: Sulfuric, hydrochloric, nitric, glacial acetic, Pomeroy solutions Nos. 1 and 2, and chromic acid cleaning solutions.

(2) Acids are extremely corrosive to human tissue, metals, clothing, wood, cement, stone, and concrete. Use glassware or polyethylene containers.

(3) In case of accidental spills, immediately dilute with large portions of water and neutralize the acid with sodium carbonate or bicarbonate until bubbling and foaming stops. Clean up neutralized material. If spills occur on bench tops, dilute, neutralize, and squeeze into sink. If spills occur on person, immediately wash off with water. If spills occur on face (spills of concentrated acid), immediately flood with large quantities of cold water. Notify supervisor. Remember to add acid to water, but not reverse. Pour and pipette carefully to prevent spilling and dropping. Prevent contact with metals, particularly equipment.

B. Bases

(1) Examples: Sodium hydroxide, potassium hydroxide, ammonium hydroxide, alkaline iodide---sodium azide solution.

(2) Handle with extra care and respect. They are extremely corrosive to skin, clothing, and leather. Use glassware and polyethylene containers.

Ammonium hydroxide is extremely irritating to the eyes and respiratory system. Pour ammonium hydroxide under a laboratory hood with fan in operation.

(3) In case of accident, wash with large quantities of water and use saturated boric acid solution to neutralize.

C. Miscellaneous

(1) Chlorine gas solution---avoid inhalation. Handle in hood. Secure cover to prevent escape of vapors.

(2) Ferric salts, Ferric chloride---very corrosive to metals. Avoid body contact and wash off immediately.

(3) Strong oxidants---avoid body contact. Wash off immediately. Use of perchloric acid by untrained personnel must be prohibited.

3. Toxic Materials

Avoid ingesting or inhaling.

A. Solids: Cyanides, chromium, cadmium, and other heavy metal compounds.

B. Liquids: Use in vented hood. Carbon tetrachloride, ammonium hydroxide, nitric acid, bromine, chlorine water, aniline dyes, formaldehyde, chloroform, and carbon disulfide. Carbon tetrachloride is absorbed into skin on contact; its vapors will damage the lungs; and it will build up in your body to a dangerous level.

C. Gases: Use in vented hood. Hydrogen sulfide, chlorine, ammonia, nitric, hydrochloric acid.

D. Most laboratory chemicals have toxicity warnings and antidotes on their labels. Learn about the materials you use. Don't breathe, eat, or drink them; and if they come in contact with your body, quickly apply large quantities of water to wash the substance away.

4. Explosive or Inflammable Materials

   A. Gases: Acetylene, hydrogen.

   B. Liquids: Carbon disulfide, benzene, ethyl ether, petroleum ether, acetone, gasoline.

   Store these materials according to fire regulations to prevent fire hazards. If large quantities must be stored, they should be located in a separate storage building.

   Do not use near open flame or exposed heating elements. Use under a vented laboratory hood. Do not distill to dryness or explosive mixtures may result. Use face mask. Do not throw flammable liquids into sinks. Cigarette discard may cause fire. Do not let gas cylinders fall.

5. Broken Equipment

   A. Inexpensive Items--Beakers and flasks should be discarded, except for minor chips which can be flame polished[3] easily.

   B. Expensive Items--Should be set aside for salvage if possible. Discard if damaged beyond repair.

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[3] Flame Polished. Sharp or broken edges of glass (such as the end of a glass tube) are flame polished by placing the edge in a flame and rotating it. By allowing the edge to melt slightly, it will become smooth.

6. Miscellaneous

A. Use safety goggles or face mask in any experiment in which there is danger to the eyes. Never look into the end of the test tube during reaction or heating.

Use care in making rubber-to-glass connections. Lengths of glass tubing should be supported while they are being inserted into rubber. The ends of the glass should be flame polished, and either wetted or covered with a lubricating jelly for ease in joining connections. Never use grease or oil. Gloves or grippers should be worn when making such connections, and the tubing should be held as close to the end being inserted as possible to prevent bending or breaking.

Never try to force rubber tubing or stoppers from glassware. Cut the rubber or material off.

B. Always check labels on bottles to make sure that the chemical selected is correct. All chemicals and bottles should be clearly labeled. Never handle chemicals with bare hands. Use spatula, spoon, or tongs.

C. Never work in a poorly ventilated area. Toxic fumes even in mild concentrations can knock you out. Be sure you have adequate ventilation before you start work in the laboratory.

D. Smoking and eating should be avoided when working with infectious materials such as wastewater and sludge. Never use laboratory glassware for serving the food.

E. Always use the proper type of equipment for handling hot containers, such as protective gloves, tongs, clothing, glasses, etc.

F. Where cylinders of oxygen or other compressed gases are used in the laboratory, they should be stored in separated and ventilated sections. They should be chained or clamped in an upright position while being used. The protective caps should never be removed until the cylinder is set and clamped in place, ready for attachment of valve gage and connections. Always use fittings approved for the cylinder being used and carefully follow instructions.

G. In working in the plant, be careful around:

(1) Digesters--Do not smoke.

(2) Chlorinators--Be aware of chlorine leaks. Chlorine may be detected by its odor, or a white mist will form near a rag soaked in ammonia.

(3) Power and Blower--Wear ear plugs or ear covers if working over one hour in engine room.

(4) Open Wastewater Tanks--Be careful; don't fall in.

(5) Closed Wastewater Tanks--Avoid running over tank covers by foot or vehicle.

(6) In Tanks or Near Construction--Wear hard hats.

14.21 Personal Hygiene for Wastewater Treatment Plant Personnel

Although it is highly unlikely that personnel can contract diseases by working in wastewater treatment plants, such a possibility does exist with certain diseases.

1. Some diseases are contracted through breaks in the skin, cuts, or puncture wounds. In such cases the bacteria causing the disease may be covered over and trapped by flesh, creating a suitable anaerobic environment[4] in which the bacteria may thrive and spread throughout the body.

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[4] Anaerobic Environment (AN-air-O-bick). A condition in which "free" or dissolved oxygen is <u>not</u> present.

For protection against diseases contracted through breaks in the skin, cuts, or puncture wounds, everyone working in or around wastewater must receive immunization from tetanus. Immunization must be received before the infection occurs. To prevent diseases from entering open wounds, care must be taken to keep wounds protected either with band aids or, if necessary, with rubber gloves or waterproof protective clothing.

2. Diseases that may be contracted through the gastrointestinal system or through the mouth are typhoid, cholera, dysentery, amebiases, worms, salmonella, enfectious hepatitis, and polio virus. These diseases are transmitted by the infected wastewater materials being ingested or swallowed by careless persons. The best protection against these diseases is furnished by thorough cleansing. Hands, face, and body should be thoroughly washed with soap and water, particularly the hands, in order to prevent the transfer of any unsanitary materials or germs to the mouth while eating. A change of working clothes into street clothes before leaving work is highly recommended to prevent carrying unsanitary materials to the employee's home. Personal hygiene, thorough cleansing, and washing of the hands are effective means of protection.

   Immunization is provided for typhoid and polio. Little is known about infectious hepatitis except that it can be transmitted by wastewater. It is frequently associated with gross wastewater pollution.

3. Diseases that may be contracted by breathing contaminated air include (1) tuberculosis, (2) infectious hepatitis, and (3) San Joaquin fever. There has been no past evidence to indicate the transmission of tuberculosis through the air at wastewater treatment plants. However, there was one case of tuberculosis being contracted by an employee who fell into wastewater and, while swimming, inhaled wastewater into his lungs. San Joaquin fever is caused by a fungus which may be present in wastewater. However, there is no record of operators contracting the disease while on the job.

The best insurance against these diseases is proper personal hygiene and immunization. Your plant should have an immunization program against (1) tetanus, (2) typhoid, (3) polio, and (4) smallpox (although smallpox is not related to wastewater). The immunizations should be provided to protect you. Check with your local or state health department for recommendations regarding immunization.

In the washing of hands, the kind of soap is less important than the thorough use of the soap. (Special disinfectant soaps are not essential.)

The use of protective clothing is very important, particularly gloves and boots. The protection of wounds and cuts is also important. Report injuries and take care of them.

The responsibility rests upon <u>you</u>.

There is no absolute insurance against contraction of disease in a wastewater treatment plant. However, the likelihood of transmission is practically negligible. There appears to be no special risk in working at treatment plants. In fact, operators may receive a natural immunization by working in this environment.

QUESTIONS

14.2A Why should you always use a rubber bulb to pipette wastewater or polluted water?

14.2B Why are inoculations against disease recommended for people working around wastewater?

14.2C What would you do if you spilled a concentrated acid on your hand?

14.2D True or False: You may add acid to water, but never water to acid.

14.2E If you are working in a wastewater treatment plant, why should you change your clothes before going home at night?

14.3 SAMPLING, by Joe Nagano, from California Water Pollution Control Association Operators Laboratory Manual

14.30 Importance

Before any laboratory tests are performed, it is highly important to obtain a proper, representative sample. Without a representative sample, a test should not even be attempted because the test result will be incorrect and meaningless. A laboratory test without a good sample will most likely lead to erroneous conclusions and confusion. The largest errors produced in laboratory tests are usually caused by improper sampling, poor preservation, or lack of enough mixing during compositing[5] and testing.

14.31 Accuracy of Laboratory Equipment

Laboratory equipment, in itself, is generally quite accurate. Analytical balances weigh to 0.1 milligram. Graduated cylinders, pipettes, and burettes usually measure to 1% accuracy, so that the errors introduced by these items should total less than 5%, and under the worst possible conditions only 10%. Under ideal conditions let us assume that a test of raw wastewater for suspended solids should run about 300 mg/l. Because of the previously mentioned equipment or apparatus variables, the value may actually range from 270 to 330 mg/l. Results in this range are reasonable for operation. Other less obvious factors are usually present which make it quite possible to obtain results which are 25, 50, or even 100% in error, unless certain precautions are taken. Some examples will illustrate how these errors are produced.

The City of Los Angeles Terminal Island Treatment Plant is a primary treatment facility with a flow of 8 million gallons per day. It has an aerated grit chamber, two circular 85-foot clarifiers of 750,000 gallon capacity, and two digesters 100 and 75 feet in diameter.

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[5] Composite (Proportional) Samples (com-POZ-it). Samples collected at regular intervals in proportion to the existing flow and then combined to form a sample representative of the entire period of flow over a given period of time.

Monthly summary calculations based upon the suspended solids test showed that about 8,000 pounds of suspended solids were being captured per day during sedimentation assuming 200 mg/l for the influent and 100 mg/l for the effluent. However, it also appeared that 12,000 pounds per day of raw sludge solids were being pumped out of the clarifier and to the digester. Obviously, if sampling and analyses had been perfect, these weights would have balanced. The capture should equal the removal of solids. A study was made to determine why the variance in these values was so great. It would seem logical to expect that the problem could be due to (1) incorrect testing procedures, (2) poor sampling, (3) incorrect metering of the wastewater or sludge flow, or (4) any combination of the three or all of them.

In the first case, the equipment was in excellent condition. The operator was a conscientious and able employee who was found to have carried out the laboratory procedures carefully and who had previously run successful tests on comparative samples. It was concluded that the equipment and test procedures were completely satisfactory.

14.32 Selection of a Good Sampling Point to Obtain a Representative Sample

A survey was then made to determine if sampling stations were in need of relocation. By using Imhoff cones and running settleable solids tests along the influent channel and the aerated grit chamber, one could quickly recognize that the best mixed and most representative samples were to be taken from the aerated grit chamber rather than the influent channel.

The settleable solids ran 13 ml/l in the aerated grit chamber against 10 ml/l in the channel. By the simple process of determining the best sampling station, the suspended solids value in the influent was corrected from 200 mg/l to the more representative 300 mg/l. Calculations, using the correct figures, changed the solids capture from 8,000 pounds to 12,000 pounds per day and a balance was obtained.

This study clearly illustrates the importance of selecting a good sampling point in securing a truly representative sample. It emphasizes the point that even though a test is accurately performed, the result may be entirely erroneous and meaningless insofar as use for process control is concerned, unless a good representative sample is taken. Furthermore, a good sample is highly dependent upon the sampling station. Whenever possible, select a place where mixing is thorough and the wastewater quality is uniform. As the solids concentration increases, above about 200 mg/l, mixing becomes even more significant because the wastewater solids will tend to separate rapidly with the heavier solids settling toward the bottom, the lighter solids in the middle, and the floatables rising toward the surface. If, as is usual, a one-gallon portion is taken as representative of a million-gallon flow, the job of sample location and sampling must be taken seriously.

14.33 Time of Sampling

Let us consider next the time and frequency of sampling. In carrying out a testing program, particularly where personnel and time are limited due to the press of operational responsibilities, testing may necessarily be restricted to about one test day per week. If the operator should decide to start his tests early in the week, by taking samples early on Monday morning he may wind up with some very odd results.

One such incident will be cited. During a test for ABS (alkyl benzene sulfonate), samples were taken early on Monday morning and rushed into the laboratory for testing. Due to the detention time in the sewers, these wastewater samples actually represented Sunday flow on the graveyard shift, the weakest wastewater obtainable. The ABS content was only 1 mg/l, whereas it would normally run 8 to 10 mg/l. So the time and day of sampling is quite important, and the samples should be taken to represent typical weekdays or even varied from day to day within the week for a good cross-section of the characteristics of the wastewater.

14.34 Compositing and Preservation of Samples

Since the wastewater quality changes from moment to moment and hour to hour, the best results would be obtained by using some sort of continuous sampler-analyzer. However, since operators are usually the sampler-analyzer, continuous analysis would leave little time for anything but sampling and testing. Except for tests which cannot wait due to rapid chemical or biological change of the sample, such as tests for dissolved oxygen and sulfides, a fair compromise may be reached by taking samples throughout the day at hourly or two-hour intervals.

When the samples are taken, they should be immediately refrigerated to preserve them from continued bacterial decomposition. When all of the samples have been collected for a 24-hour period, the samples from a specific location should be combined or composited together according to flow to form a single 24-hour composite sample.

To prepare a composite sample, (1) the rate of wastewater flow must be metered and (2) each grab sample must then be taken and measured out in direct proportion to the volume of flow at that time. For example, Table I illustrates the hourly flow and sample volume to be measured out for a 12-hour proportional composite sample.

TABLE I

DATA COLLECTED TO PREPARE PROPORTIONAL COMPOSITE SAMPLE

Time	Flow MGD	Factor	Sample Vol	Time	Flow MGD	Factor	Sample Vol
6 AM	0.2	100	20	12 N	1.5	100	150
7 AM	0.4	100	40	1 PM	1.2	100	120
8 AM	0.6	100	60	2 PM	1.0	100	100
9 AM	1.0	100	100	3 PM	1.0	100	100
10 AM	1.2	100	120	4 PM	1.0	100	100
11 AM	1.4	100	140	5 PM	0.9	100	90
							1140

A sample composited in this manner would total 1140 ml.

Large wastewater solids should be excluded from a sample, particularly those greater than one-quarter inch in diameter.

A very important point should be emphasized. <u>During compositing and at the exact moment of testing, the samples must be vigorously remixed so that they will be of the same composition and as well mixed as when they were originally sampled.</u> Sometimes such remixing may become lax, so that all the solids are not uniformly suspended. Lack of mixing can cause low results in samples of solids that settle out rapidly, such as those in activated sludge or raw wastewater. Samples must therefore be mixed thoroughly and poured quickly before any settling occurs. If this is not done, errors of 25 to 50% may easily occur. For example, on the same mixed liquor sample, one person may find 3,000 mg/l suspended solids while another person may determine that there are only 2,000 mg/l due to poor mixing. When such a composite sample is tested, a reasonably accurate measurement of the quality of the day's flow can be made.

If a 24-hour sampling program is not possible, perhaps due to insufficient personnel or the absence of a night shift, single representative samples should be taken at a time when typical characteristic qualities are present in the wastewater. The samples should be taken in accordance with the detention time required for treatment. For example, this period may exist between 10 AM and 5 PM for the sampling of raw influent. If a sample is taken at 12 Noon, other samples should be taken in accordance with the detention periods of the serial processes of treatment in order to follow this slug of wastewater or plug flow. In primary settling, if the detention time in the primaries is two hours, the primary effluent should be sampled at 2 PM. If the detention time in the succeeding secondary treatment process required three hours, this sample should be taken at 5 PM.

14.35 Sludge Sampling

In sampling raw sludge and feeding a digester, a few important points should be kept in mind as shown in the following illustrative table.

For raw sludge from a primary clarifier at Los Angeles' Terminal Island Plant, the sludge solids varied considerably with pumping time as shown by samples withdrawn every one-half minute.

TABLE II

DECREASE IN PERCENT TOTAL SOLIDS DURING PUMPING

Pumping Time, In Minutes	Total Solids Percent	Cumulative Solids Average
0.5	7.0	7.0
1.0	7.1	7.1
1.5	7.4	7.2
2.0	7.3	7.2
2.5	6.7	7.1
3.0	5.3	6.8
3.5	4.0	6.4
4.0	2.3	5.9
4.5	2.0	5.5
5.0	1.5	5.1

a. Table II shows that the solids were heavy during the first 2.5 minutes, and thereafter rapidly became thinner and watery. Since sludge solids should be fed to a digester with solids as heavy as possible and a minimum of water, the pumping should probably have been stopped at about 3 minutes. After 3 minutes, the water content did become greater that desirable.

b. In sampling this sludge, the sample should be taken as a composite by mixing small equal portions taken every 0.5 minutes during pumping. If only a single portion of sludge is taken for the sample, there is a chance that the sludge sample may be too thick or too thin, depending upon the moment the sample is taken. A composite sample will prevent this possibility.

c. It should also be emphasized again that as a sludge sample stands, the solids and liquid separate due to gasification and flotation or settling of the solids, and that it is absolutely necessary to thoroughly remix the sample back into its original form as a mixture before pouring it for a test.

d. When individual samples are taken at regular intervals in this manner, they should be carefully preserved to prevent sample deterioration by bacterial action. Refrigeration is an excellent method of preservation and is generally preferable to chemicals since chemicals may interfere with tests such as BOD and COD.

14.36 Sampling Devices

Automatic sampling devices are wonderful timesavers and should be employed where possible. However, like anything automatic, problems of which the operator should be aware do arise in their use. Sample lines to auto-samplers may build up growths which may periodically slough off and contaminate the sample with a high solids content. Very regular cleanout of the intake line is required. Another problem occurred at Los Angeles' Hyperion Plant when the reservoir for the automatic sampler was attacked by sulfides. Metal sulfides flaked off and entered the sample container producing misleading high solids results. The reservoir was cleaned and coated with coal-tar epoxy and little further difficulty has been experienced.

Manual sampling equipment includes dippers, weighted bottles, hand-operated pumps, and cross-section samplers. Dippers consist of wide-mouth corrosion resistant containers (such as cans or jars) on long handles that collect a sample for testing. A weighted bottle is a collection container which is lowered to a desired depth. At this location a cord or wire removes the bottle stopper so the bottle can be filled. Sampling pumps allow the inlet to the suction hose to be lowered to the sampling depth. Cross-sectional samplers are used to sample where the wastewater and sludge may be in layers, such as in a digester or clarifier. The sampler consists of a tube, open at both ends, that is lowered at the sampling location. When the tube is at the proper depth, the ends of the tube are closed and a sample is obtained from different layers.

Many operators build their own sampler (Fig. 14.1) using the material described below:

1. Sampling Bucket. A coffee can attached to an eight-foot length of 1/2-inch electrical conduit or a wooden broom handle with a 1/4-inch diameter spring in a four-inch loop.

2. Sampling Bottle. Plastic bottle with rubber stopper equipped with two 3/8-inch glass tubes, one ending near bottom of bottle to allow sample to enter and the other ending at the bottom of the stopper to allow the air in the bottle to escape while the sample is filling the bottle.

For sample containers, wide-mouth plastic bottles are recommended. Plastic bottles, though somewhat expensive initially, not only greatly reduce the problem of breakage and metal contamination, but are much safer to use. The wide-mouth bottles ease the washing problem. For regular samples, sets of plastic bottles bearing identification labels should be used.

14.37 Summary

1. Representative samples must be taken before any tests are made.

2. Select a good sampling location.

3. Collect samples and preserve them by refrigeration.

4. If possible, prepare 24-hour composite samples. Mix samples thoroughly before compositing and at the time of the test.

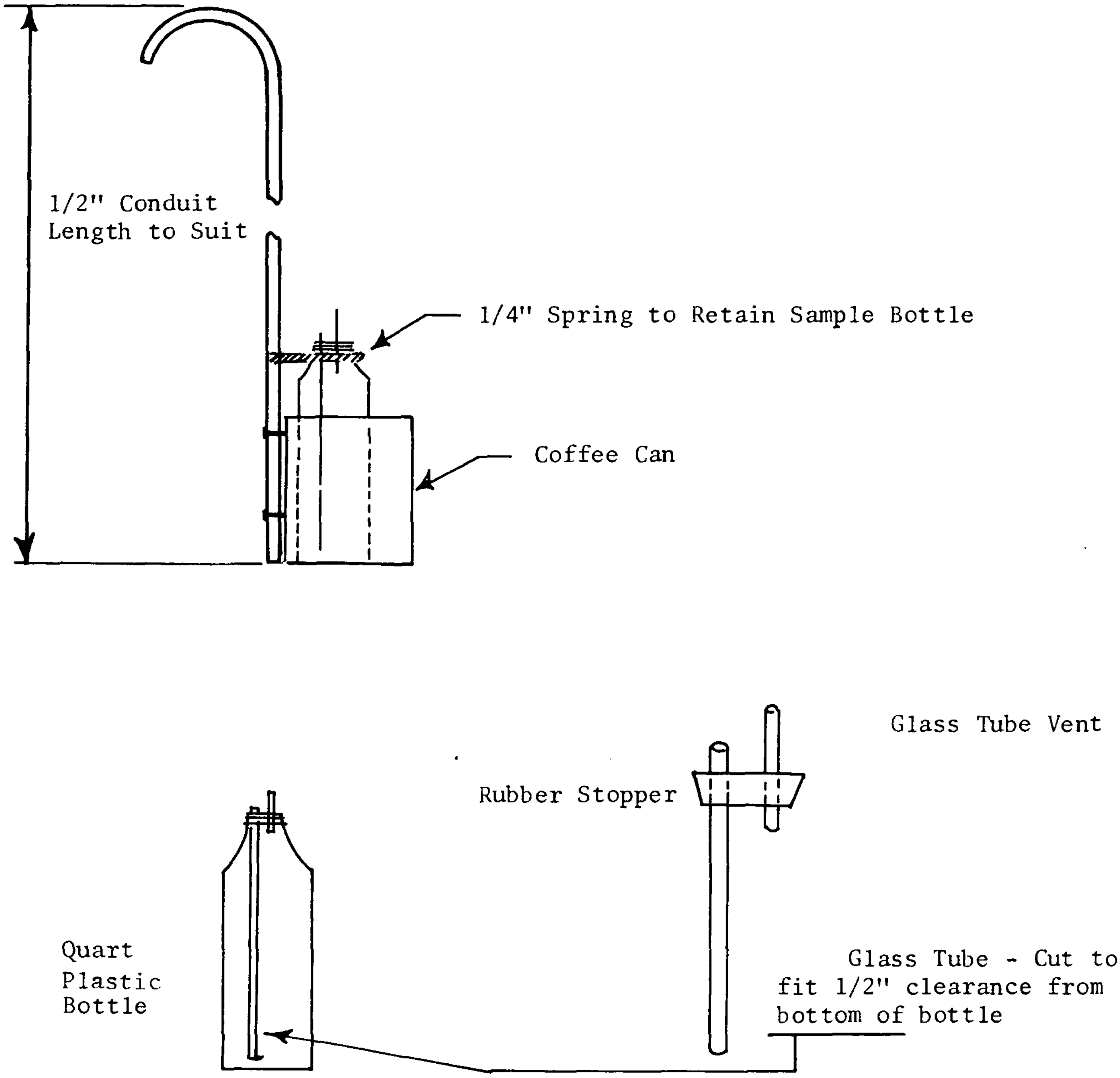


Fig. 14.1 Sampling bottle

QUESTIONS

14.3A What are the largest sources of errors found in laboratory results?

14.3B Why must a representative sample be collected?

14.3C How would you prepare a proportional composite sample?

14.4 LABORATORY WORK SHEET

All laboratory results should be recorded immediately after a sample has been measured. There is no standard laboratory form; however, your plant or the agency that regulates your discharge may have a preferred form. Figure 14.2 is a typical laboratory work sheet (sometimes called a bench sheet) and will be referred to throughout the chapter.

PLANT ______________________

DATE ______________________

SUSPENDED SOLIDS & DISSOLVED SOLIDS

SAMPLE							
Crucible							
Ml Sample							
Wt Dry & Dish							
Wt Dish							
Wt Dry							
$\text{mg/l} = \frac{\text{Wt Dry, gm} \times 1{,}000{,}000}{\text{Ml Sample}}$							
Wt Dish & Dry							
Wt Dish & Ash							
Wt Volatile							
$\% \text{ Vol} = \frac{\text{Wt Vol}}{\text{Wt Dry}} \times 100\%$							

BOD

Blank ______

SAMPLE										
DO Sample										
Bottle #										
% Sample										
Blank or adj blank										
DO after incubation										
Depletion, 5 days										
Dep %										

Nitrate NO_3

Sample ______ ______

Graph Reading ______ ______

Sett. Solids

Sample ______ ______

Direct Ml/l ______ ______

COD

Sample ______ ______ ______

Blank Titration ______ ______ ______

Sample Titration ______ ______ ______

Depletion ______ ______ ______

$\text{mg/l} = \frac{\text{Dep} \times N \text{ FAS} \times 8000}{\text{Ml Sample}}$ ______ ______ ______

Fig. 14.2 Typical laboratory work sheet

TOTAL SOLIDS

SAMPLE						
Dish No.						
Wt Dish & Wet Wt Dish						
Wt Wet						
Wt Dish + Dry Wt Dish						
Wt Dry						
% Solids = $\frac{\text{Wt Dry}}{\text{Wt Wet}}$ x 100%						
Wt Dish + Dry Wt Dish + Ash						
Wt Volatile						
% Volatile = $\frac{\text{Wt Vol}}{\text{Wt Dry}}$ x 100%						
pH						
Vol. Acid						
Alkalinity as $CaCO_3$						

Grease (Soxlet) ________________

Sample ________________

Ml Sample ________________

Wt Flask + Grease

Wt Flask ________________

Wt Grease ________________

mg/l = $\frac{\text{Wt Grease, mg x 1,000}}{\text{Ml Sample}}$ ________________

H_2S (Gas) (Starch-Iodine)

Blank __________ Ml

Sample __________ Ml

Diff __________ Ml

Diff x .68 __________ mg/l

mg/l x 43.6 __________ grain/100 cu ft

Fig. 14.2 Typical laboratory work sheet (continued)

END OF LESSON 1 OF 8 LESSONS

on

Laboratory Procedures and Chemistry

EXPLANATION OF DISCUSSION AND REVIEW QUESTIONS

Work this portion of the discussion and review questions after you have completed answering the questions in Lesson 1. At the end of each lesson in this chapter you will find some discussion and review questions that you should complete before continuing.

The purpose of these questions is to indicate to you how well you understand the material in this chapter.

<u>DISCUSSION AND REVIEW QUESTIONS</u>

(Lesson 1 of 8 Lessons)

Chapter 14. Laboratory Procedures and Chemistry

Name ______________________________ Date __________

Write the answers to these questions in your notebook before continuing.

1. What precautions should an operator take to protect himself from diseases when working in a wastewater treatment plant?

2. Why should work with certain chemicals be conducted under a ventilated laboratory hood?

3. What is meant by a representative sample?

4. How would you obtain a representative sample?

CHAPTER 14. LABORATORY PROCEDURES AND CHEMISTRY

(Lesson 2 of 8 Lessons)

14.5 PLANT CONTROL TESTS

Tests in this section are listed in alphabetical order. Many of the tests are conducted at primary, secondary, and advanced wastewater treatment plants. Certain tests are commonly used to control digester operation and activated sludge plants. Typical plant and special plant control tests are summarized below.

A. Typical Plant Control Tests

TEST NO.	TITLE
2	Biochemical Oxygen Demand or BOD, Procedure with DO
4	Chemical Oxygen Demand or COD
5	Chlorine Residual
6	Clarity
7	Coliform Group Bacteria
8	Dissolved Oxygen or DO
9	Hydrogen Sulfide
10	pH
12	Settleable Solids
16	Suspended Solids (Gooch Crucible)
17	Temperature (Wastewater)

B. Digester Control Tests

TEST NO.	TITLE
1	Alkalinity, Procedure with Volatile Acids
3	Carbon Dioxide (CO_2) in Digester Gas
14	Sludge Dewatering Characteristics
15	Supernatant Graduate Evaluation
17	Temperature (Digester Sludge)
20	Volatile Acids
21	Total and Volatile Solids (Sludge)

C. Activated Sludge Control Tests

TEST NO.	TITLE
8	Dissolved Oxygen (In Aerator)
11	Settleability
13	Sludge Age
11	Sludge Density Index (SDI)
11	Sludge Volume Index (SVI)
16	Suspended Solids (Centrifuge)

1. Total Alkalinity

   The alkalinity test is located with the volatile acid test because the volatile acid/alkalinity relationship is critical in the successful operation of sludge digesters.

2. Biochemical Oxygen Demand or BOD

   The BOD test is placed with the dissolved oxygen (DO) test because to measure the rate of oxygen uptake in the BOD test, the DO must be measured.

3. Carbon Dioxide (CO_2) in Digester Gas

A. Discussion

Changes in the anaerobic sludge digestion process will be observed in the gas quality and are usually noted after the volatile acids or volatile acid/alkalinity relationship starts to increase. The CO_2 content of a properly operating digester will range from 30% to 40% by volume. If the percent is above 44%, the gas will not burn. The easiest test procedure for determining this change is with a CO_2 analyzer.

B. What is Tested?

Sample	Preferred
CO_2 in Digester Gas	30% - 35% by Volume

METHOD A

C. Apparatus

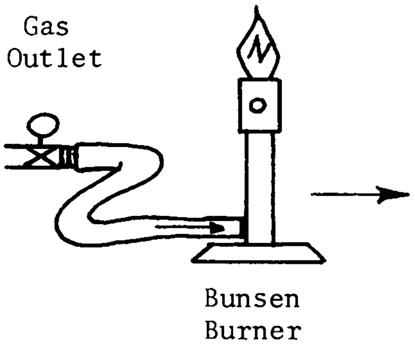
1. One Bunsen burner
2. Plastic tubing
3. 100 ml graduated cylinder
4. 250 ml beaker

D. Reagents

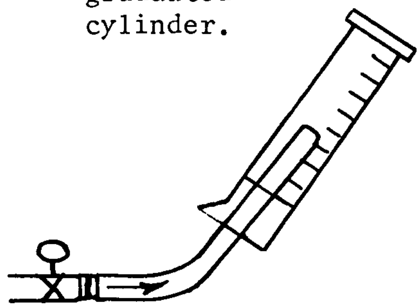
CO_2 Absorbent (KOH). Add 500 g potassium hydroxide (KOH) per liter of water.

E. Outline of Procedure

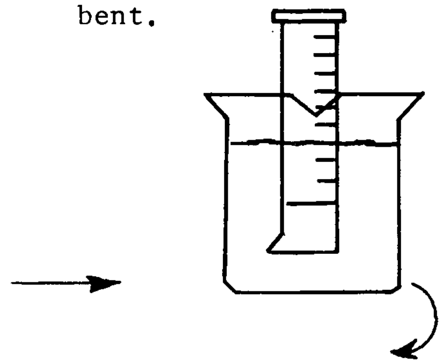
1. Clean out sampling line by allowing gas from sampling outlet to burn until line is full of gas from digester.



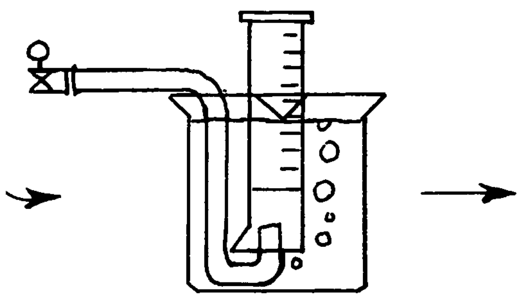
2. Displace air in graduated cylinder.



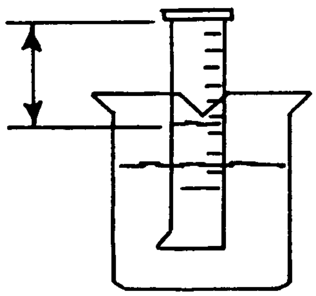
3. Place graduate upside down in beaker containing CO_2 absorbent.



4. Insert hose in graduate and run gas for 60 seconds.



5. Remove hose from graduate and then turn off gas. Wait 10 minutes.



6. Read volume of gas remaining to nearest ml.

PRECAUTIONS

1. Avoid any open flames near the digester.

2. Work in a well ventilated area to avoid the formation of explosive mixtures of methane gas.

3. If your gas sampling outlet is on top of your digester, turn on outlet and vent the gas to the atmosphere for several minutes to clear the line of old gas. Start with step 2, displace air in graduated cylinder. NEVER ALLOW ANY SMOKING OR FLAMES NEAR THE DIGESTER AT ANY TIME.

PROCEDURE

1. Measure total volume of a 100 ml graduate by filling it to the top with water (approximately 125 ml). Record this volume.

2. Pour approximately 125 ml of CO_2 absorbent in a 250 ml beaker.

   CAUTION: Do not get any of this chemical on your skin or clothes. Wash immediately with running water until slippery feeling is gone or severe burns can occur.

3. Collect a representative sample of gas from the gas dome on the digester, a hot water heater using digester gas to heat the sludge, or any other gas outlet. Before collecting the sample for the test, attach one end of a gas hose to the gas outlet and the other end to a Bunsen burner. Turn on the gas, ignite the burner, and allow it to burn digester gas for a sufficient length of time to insure collecting a representative gas sample.

4. With gas running through hose from gas sampling outlet, place hose inside inverted calibrated graduated cylinder and allow digester gas to displace air in graduate. Turn off gas.

   CAUTION: The proper mixture of digester gas and air is explosive when exposed to a flame.

5. Place graduate full of digester gas upside down in beaker containing CO_2 absorbent.

6. Insert gas hose inside upside down graduate.

7. Turn on gas, but do not blow out liquid. Run gas for at least 60 seconds.

8. Carefully remove hose from graduate with gas still running.

9. Immediately turn off gas.

10. Wait for ten minutes and shake gently. If liquid continues to rise, wait until it stops.

11. Read gas remaining in graduate to nearest ml. (Fig. 14.3)

Fig. 14.3 CO_2 measurement using inverted graduated cylinder

F. Example

Total Volume of Graduate = 126 ml

Gas Remaining in Graduate = 80 ml

G. Calculation

$$\% \; CO_2 = \frac{(\text{Total Volume, ml} - \text{Gas Remaining, ml})}{\text{Total Volume, ml}} \times 100\%$$

$$= \frac{(126 \text{ ml} - 80 \text{ ml})}{126 \text{ ml}} \times 100\%$$

$$= \frac{46}{126} \times 100\%$$

$$= 37\%$$

$$\begin{array}{r} .365 \\ 126 \,\big)\, 46.0 \\ 37\ 8 \\ \hline 8\ 20 \\ 7\ 56 \\ \hline 640 \\ 630 \end{array}$$

METHOD B

(ORSAT)

The Orsat gas analyzer can measure the concentrations of carbon dioxide, oxygen, and methane by volume in digester gas. To analyze digester gas by the Orsat method, follow equipment manufacturer's instructions. This procedure is not recommended for the inexperienced operator.

QUESTIONS

3.A What are the dangers involved in running the CO_2 in digester gas test?

3.B What is the percent CO_2 in a digester gas if the total volume of the graduated cylinder is 128 ml and the gas remaining in the cylinder after the test is 73 ml?

4. Chemical Oxygen Demand or COD

A. Discussion

COD is a good estimate of the first-stage oxygen demand for most municipal wastewaters. An advantage of the COD test over the BOD test is that you do not have to wait for five days for the results. The COD test also is used to measure the strength of wastes that are too toxic for the BOD test. COD is usually higher than the BOD, but the amount will vary from waste to waste. The method related here is a quick, effective measure of the strength of a waste.

B. What is Tested?

Sample	Common Range, mg/l
Influent	200 - 400
Effluent	40 - 80
Industrial Waste	200 - 4000

C. Apparatus

Two 50 ml graduated cylinders

10 ml pipette

50 ml burette

Boiling flask

Reflux condenser

Hot plate

D. Reagents

1. Standard potassium dichromate (K_2SO_4) 0.250 N. Dissolve 12.259 g dried $K_2Cr_2O_7$ in distilled water and make up to 1 liter.

2. Surfuric acid-silver sulfate reagent. Add 22 g of silver sulfate (Ag_2SO_4) to a 9-lb bottle of concentrated sulfuric acid (H_2SO_4). It takes one to two days to dissolve.

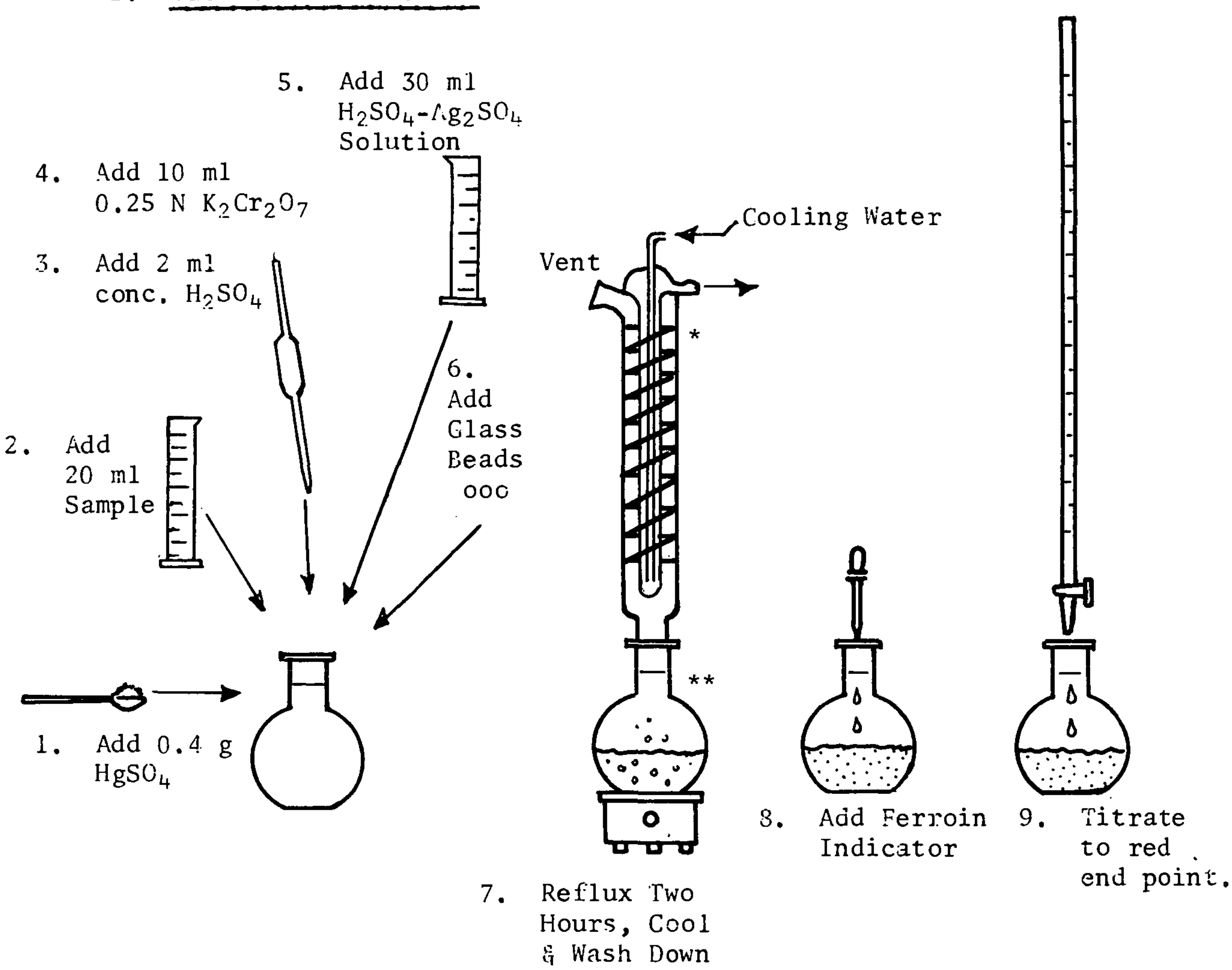
3. Standard ferrous ammonium sulfate solution, 0.25 N. Dissolve 98 g $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ in distilled water, add 20 ml concentrated H_2SO_4, cool and dilute to 1 liter. This solution is unstable and must be standardized daily.

4. Ferroin Indicator. Dissolve 1.485 g of 1,10 phenanthroline ($C_{12}H_8N_2 \cdot H_2O$), together with 0.695 g ferrous sulfate crystals ($FeSO_4 \cdot 7H_2O$), in water and make up to 100 ml.

5. Silver sulfate, reagent powder.

6. Mercuric sulfate ($HgSO_4$) analytical grade crystals.

E. Outline of Procedure



* Reflux condenser, Friedrichs, VWR - 23157-001
** Flask, boiling, flat bottom, VWR - 29113-068

PROCEDURE

1. Place 0.4 g mercuric sulfate into a 250 ml Erlenmeyer flask with a ground glass neck.

2. Measure 20.0 ml sample into the flask.

3. Add 2.0 ml concentrated sulfuric acid. Swirl until contents are well mixed.

4. Pipette 10.0 ml standard potassium dichromate solution into the flask.

5. Carefully add 30 ml sulfuric acid-silver sulfate reagent into the flask while swirling the flask. Use caution. Make sure contents of the flask are thoroughly mixed before heat is applied.

6. Add a few glass beads to reduce bumping and connect to condenser. The reflux mixture must be thoroughly mixed before heat is applied. If this is not done, local hot spots on bottom of flask may cause mixture to be blown out of flask.

7. Prepare a blank[6] by repeating above steps and by substituting distilled water for the sample.

8. Reflux samples and blank for two hours. (If sample mixture turns completely green, the sample was too strong. Dilute sample with distilled water and repeat above steps substituting diluted sample.)

9. While the samples and blank are refluxing, standardize the ferrous ammonium sulfate solution:

   a. Pipette 10.0 ml standard potassium dichromate solution into a 250 ml Erlenmeyer flask. Add about 100 ml of water.

   b. Add 30 ml concentrated H_2SO_4 with mixing. Let cool.

   c. Add 2-3 drops ferroin indicator, titrate with ferrous ammonium sulfate (FAS) solution. Color change of solution is from orange to greenish to red.

   ml FAS ________________________________

   $$\text{Concentration Ratio, } R = \frac{10 \text{ ml } K_2Cr_2O_7}{\text{ml FAS}} = \_\_\_\_\_\_\_\_$$

10. After refluxing mixture for two hours, wash down condenser. Let cool. Add distilled water to about 140 ml.

11. Titrate reflux mixtures with standard FAS.

    Blank - ml FAS __________

    Sample - ml FAS __________

---

[6] Blank. A bottle containing dilution water or distilled water, but the sample being tested is not added. Tests are frequently run on a <u>sample</u> and a <u>blank</u> and the differences compared.

F. Precautions

1. Wastewater sample should be well mixed. If large particles are present, sample should be homogenized.

2. Flasks and condensers should be clean and free from grease or other oxidizable materials, otherwise erratic results would be obtained.

3. The standard ferrous ammonium sulfate solution is unstable and should be standardized daily or each time the COD test is performed.

4. Use extreme caution in handling concentrated H_2SO_4. Spillage on skin or clothing should be immediately washed off and neutralized.

5. The solution must be well mixed before it is heated. If the acid is not completely mixed in the solution when it is heated, the mixture could spatter and some of it will pass out the vent, thus ruining the test.

6. Mercury sulfate is very toxic. Avoid skin contact and breathing of this chemical.

G. Example

1. Standardization of ferrous ammonium sulfate, FAS.

   ml 0.25 N $K_2Cr_2O_7$ = 10.0

   ml FAS = 11.0

   $$\text{Concentration Ratio, R} = \frac{\text{ml } K_2Cr_2O_7}{\text{ml FAS}}$$

   $$= \frac{10.0}{11.0}$$

2. Sample test.

   Sample Taken = 20.0 ml

   A = ml FAS used for blank = 10.0 ml

   B = ml FAS used for sample = 3.0 ml

H. Calculation for COD

Method 1

$$\text{COD, mg/l} = (A - B) \times R \times 100$$

$$= (10.0 - 3.0)\ (10/11)\ (100)$$

$$= 635 \text{ mg/l}$$

Method 2 (According to Standard Methods)

$$\text{COD, mg/l} = \frac{(A - B) \times C \times 8000}{\text{ml Sample}}$$

where

C = Normality of FAS

N = Normality of $K_2Cr_2O_7$ Standard

$$C = \frac{\text{ml } K_2Cr_2O_7}{\text{ml FAS}} \times N$$

$$= \frac{10.0}{11.0} \times 0.25$$

$$= 0.227$$

$$\text{COD, mg/l} = \frac{(10.0 - 3.0)(0.227)(8000)}{20}$$

$$= 635 \text{ mg/l}$$

QUESTIONS

4.A What does the COD test measure?

4.B What are some of the advantages of the COD test over the BOD test?

5. Chlorine Residual

A. Discussion

A chlorine residual should be maintained in a plant effluent for disinfection purposes. The amount of residual remaining in the treated wastewater after passing through a contact basin or chamber may be related to the numbers of bacteria allowed in the effluent by regulatory agencies.

Method A (Iodometric) is used for samples containing wastewater, such as plant effluents or receiving waters. Method B (Orthotolidine - Arsenite) gives best results if sample is collected and tested shortly (within 20 minutes) after chlorine has been added; however, all of the chlorine demand may not be satisfied. Method C (Amperometric[7] Titration) gives the best results, but the titrator is expensive.

B. What is Tested?

Sample	Common Range, mg/1 (After 30 Minutes)
Effluent	0.5 - 2.0 mg/1

C. Apparatus

METHOD A (Iodometric)

1. One 250 ml graduated cylinder
2. One 10 ml measuring pipette
3. One 500 ml Erlenmeyer flask
4. Two 5 ml measuring pipettes
5. One 50 ml Buret

---

[7] Amperometric (am-PURR-o-MET-rick). A method of measurement that records electric current flowing or generated, rather than recording voltage. Amperometric titration is an electrometric means of measuring concentrations of substances in water.

METHOD B (Orthotolidine-Arsenite or OTA)

One permanent glass color comparator
Three comparator cells

METHOD C (Amperometric Titration)

See Standard Methods

D. Reagents

METHOD A

1. Standard phenylarsine oxide solution, 0.00564 N. Dissolve approximately 0.8 g phenylarsine oxide powder in 150 ml 0.3 N NaOH solution. After settling, remove upper 110 ml of this solution into 800 ml distilled water and mix thoroughly. Adjust pH up to between 6 and 7 with 6 N HCl and dilute to 950 ml with distilled water. To standardize this solution accurately measure 5 to 10 ml of freshly standardized 0.0282 N iodine solution into a flask and add 1 ml KI solution. Titrate with phenylarsine oxide solution, using starch solution as an indicator. Adjust to exactly 0.00564 N and recheck against the standard iodine solution; 1.00 ml = 200 μg available chlorine. CAUTION: Toxic - avoid ingestion.

2. Potassium iodide, crystals.

3. Acetate buffer solution, pH 4.0. Dissolve 146 g anhydrous $NaC_2H_3O_2$, or 243 g $NaC_2H_3O_2 \cdot 3H_2O$, in 400 ml distilled water, add 480 g concentrated acetic acid, and dilute to 1 liter with distilled water.

4. Standard iodine titrant, 0.0282 N. Dissolve 25 g KI in a little distilled water in a 1-liter volumetric flask, add the proper amount of 0.1 N iodine solution exactly standardized to yield a 0.0282 N solution, and dilute to 1 liter. Store in amber bottles or in the dark, protecting the solution from direct sunlight at all times and keeping it from all contact with rubber.

5. Starch indicator. Make a thin paste of 6 g of potato starch in a small quantity of distilled water. Pour this paste into one liter of boiling, distilled water. Allow to boil for a few minutes, then settle overnight. Remove the clear supernatant and save; discard the rest. For preservation, add two drops of toluene ($C_6H_5CH_3$).

METHOD B

1. Orthotolidine solution for chlorine comparison. Dissolve 1.35 g orthotolidine dihydrochloride ($C_{14}H_{16}N_2 \cdot 2HCl$) in 500 ml of distilled water. Add this solution, with constant stirring, to a mixture of 350 ml distilled water and 150 ml concentrated HCl. Store at normal temperatures in amber bottles or in the dark. Protect from direct sunlight and use within six months. Avoid contact with rubber.

2. Sodium arsenite solution. Dissolve 5.0 g $NaAsO_2$ in distilled water and dilute to 1 liter. (CAUTION: Toxic; take care to avoid ingestion.)

METHOD C

See Standard Methods

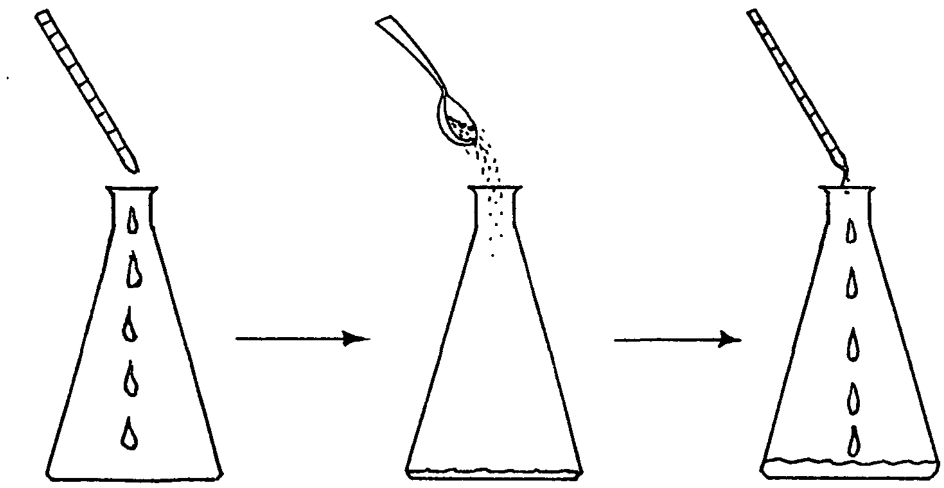
E. Procedure

METHOD A

1. Place 5.00 ml phenylarsine oxide solution to Erlenmeyer flask

2. Add excess KI (approx 1 g)

3. Add 4 ml acetate buffer solution

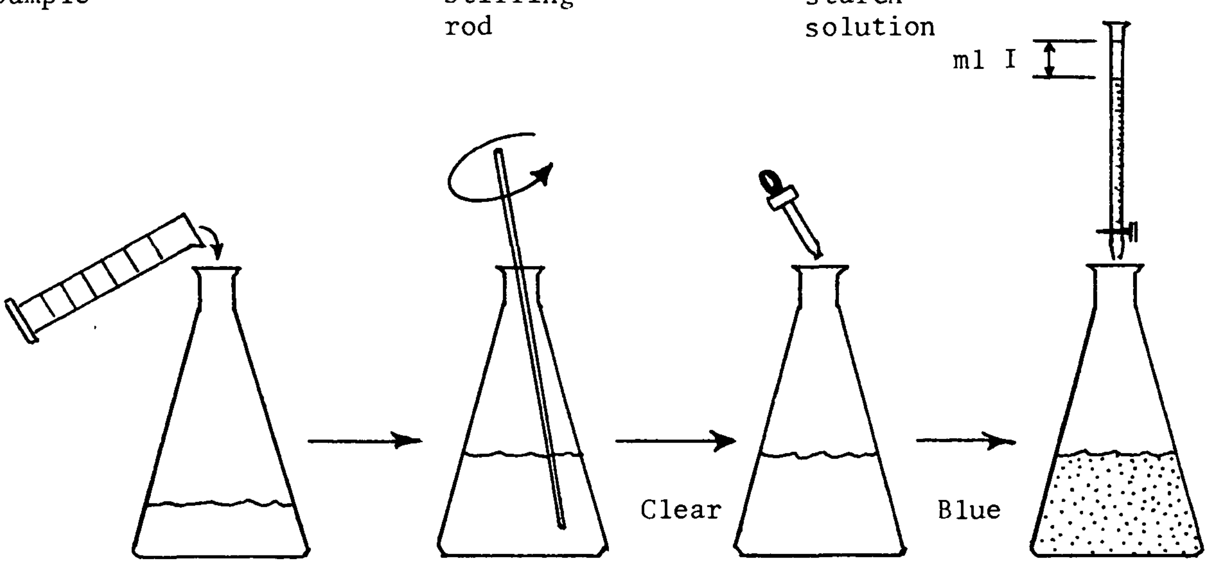


4. Add 200 ml sample

5. Mix with stirring rod

6. Add 1 ml starch solution

7. Titrate until blue color first appears and remains after mixing



METHOD A

1. Place 5.00 ml 0.00564 N phenylarsine oxide solution in an Erlenmeyer flask.

2. Add excess KI (approx. 1 g).

3. Add 4 ml acetate buffer solution, or enough to lower the pH to between 3.5 and 4.2.

4. Pour in 200 ml of sample.

5. Mix with a stirring rod.

6. Add 1 ml starch solution just before titration.

7. Titrate to the first appearance of blue color, which remains after complete mixing.

METHOD B

1. Label the three comparator cells "A," "B," and "C." Use 0.5 ml of orthotolidine reagent in 10-ml cells, 0.75 ml in 15-ml cells, and the same ratio for other volumes of sample. Use the same volume of arsenite solution as orthotolidine.

2. Add orthotolidine reagent to Cell A.

3. Add sample to mark on wall of Cell A. Mix quickly, and immediately (within 5 seconds) add arsenite solution. Mix quickly again and compare with color standards as rapidly as possible.

   Free available chlorine and interfering colors, A = ________ mg/l

4. Add arsenite solution to Cell B.

5. Add sample to mark on wall of Cell B. Mix quickly, and immediately add orthotolidine reagent. Mix quickly again and compare with color standards as rapidly as possible.

   Interfering colors present in immediate reading, B_1 = ______ mg/l

6. Compare with color standards again in exactly 5 minutes.

   Interfering colors present in 5-minute reading, B_2 = ______ mg/l

7. Add orthotolidine reagent to Cell C.

8. Add sample to mark on wall of Cell C. Mix quickly and compare with color standards in exactly 5 minutes.

   Total amount of residual chlorine and interfering colors present, C = ________ mg/l

F. Examples and Calculations

Method A

Titration of a 200 ml sample required 0.4 ml of 0.0282 N I.

$$\text{Chlorine Residual, mg/l} = \frac{(1 - \text{ml I})\ 1000}{\text{Sample Volume, ml}}$$

$$= \frac{(1 - 0.4)\ (1000)}{200}$$

$$= (0.6)\ (5)$$

$$= 3.0 \text{ mg/l}$$

NOTE: The larger the ml of I used in the titration, the smaller the (1 - ml I) term and thus the lower the chlorine residual. This is why this test is sometimes called the back titration test for chlorine residual. If 1 ml of I is used in the titration, you have titrated back to a zero chlorine residual.

Method B

Results from the OTA test on a plant effluent.

$A = 0.5$ mg/l

$B_1 = 0.2$ mg/l

$B_2 = 0.3$ mg/l

$C = 1.4$ mg/l

Total Available Residual Chlorine, mg/l $= C - B_2$

$= 1.4$ mg/l $- 0.3$ mg/l

$= 1.1$ mg/l

Free Available Residual Chlorine, mg/l $= A - B_1$

$= 0.5$ mg/l $- 0.2$ mg/l

$= 0.3$ mg/l

Combined Available Residual Chlorine, mg/l = Total Available Residual Cl, mg/l - Free Available Residual Cl, mg/l

$= 1.1$ mg/l $- 0.3$ mg/l

$= 0.8$ mg/l

Total available residual chlorine consists of free available chlorine (HOCl and OCl^-) and combined available chlorine (chloramines--compounds formed by the reaction of chlorine with ammonia).

QUESTIONS

5.A Why should plant effluents be chlorinated?

5.B Discuss the important differences between the Iodometric titration, orthotolodine, and amperometric titration methods of measuring chlorine residual.

END OF LESSON 2 OF 8 LESSONS

on

Laboratory Procedures and Chemistry

Work the next portion of the discussion and review questions before continuing with Lesson 3.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 2 of 8 Lessons)

Chapter 14. Laboratory Procedures and Chemistry

Name ______________________________ Date __________

Write the answers to these questions in your notebook. The problem numbering continues from Lesson 1.

5. How can you obtain a representative sample of digester gas?
6. Why is the COD test run?
7. Why should a chlorine residual be maintained in a plant effluent?

6. Clarity

A. Discussion

All high quality effluents should have a clarity reading taken at high noon or some other specific time. This test is based on how far you can see through your plant effluent under similar conditions at the same time every day. The objective of the test is to indicate the clearness or clarity of the plant effluent. The test can be performed either in the lab by looking down through the effluent in a graduated cylinder, or in the field by looking down through the effluent in a clarifier or chlorine contact basin. Sometimes this test is referred to as a turbidity measurement, but you are interested in the clarity of your effluent.

B. What is Tested?

Sample	Common Range (Field Test)	
Secondary Clarifiers:	Poor	Good
Trickling Filter	1 ft	3 ft
Activated Sludge	3 ft	6 ft
Activated Sludge Blanket in Secondary Clarifier	1 ft	4 ft
Chlorine Contact Basins	1 ft	5 ft

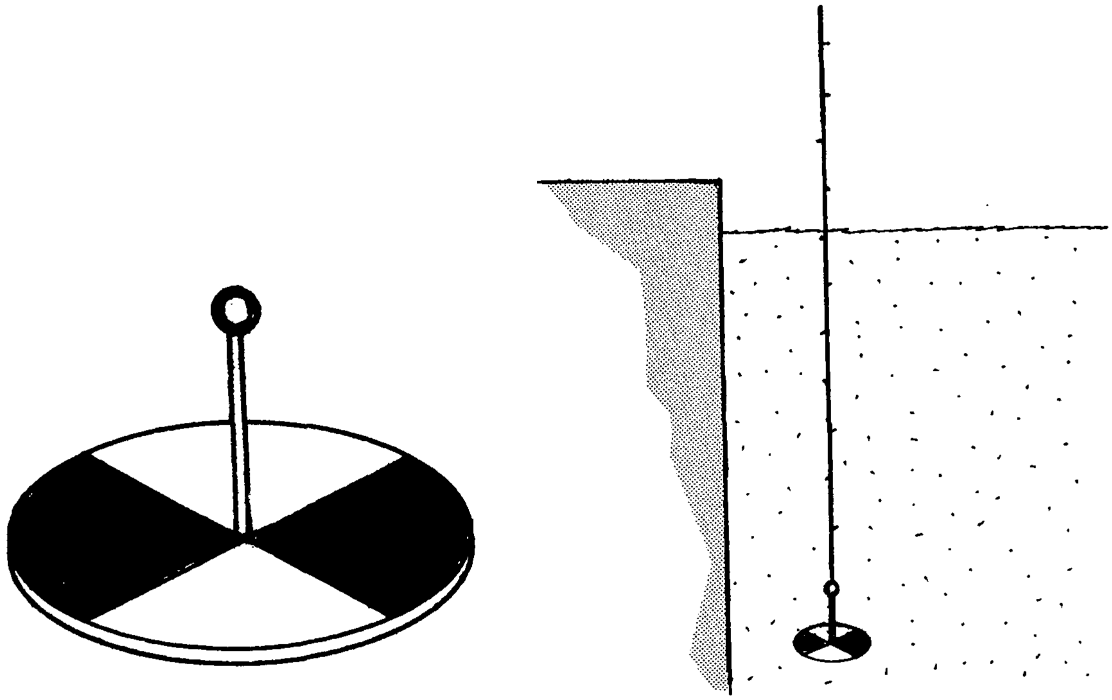
C. Apparatus

1. One clarity unit (Secchi (SECK-key) Disc) and attached cord marked in one-foot units.
2. One 1000 ml graduated cylinder
3. Hach Turbidimeter, Model 2100 A

D. Reagents

None

E. Procedures



1. Field Test. Tie end of marked nylon rope to handrail where tests will be run, for example, in final sedimentation unit. Always take tests at the same time each day for comparable results. Lower disc slowly until you just lose sight of it. Stop. Bring up slowly until just visible. Stop. Look at the marks on the rope to see the depth of water that you can see the disc through. Bring up disc and store. Record results.

2. Lab Test. Use a clean 1000 ml graduate. Fill with a well-mixed sample up to the 1000 ml mark. During every test the same lighting conditions in the lab should be maintained. Look down through the liquid in the cylinder and read the last visible number etched on the side of the graduate and record results.

3. Hach Turbidimeter. Follow manufacturer's instructions.

Whether you use one or each of these tests, you should run either test at the same time every day and under similar conditions for comparable results.

F. Example and Calculation

1. Each foot of depth is better clarity with Secchi disc.

2. Each 100 ml seen in depth is better clarity.

3. Turbidimeter reading indicates degree of clarity.

QUESTION

6.A What does the clarity test tell you about the quality of effluent?

6.B What happens when you attempt to measure clarity under different conditions, such as lighting and clarifier loadings?

7. Coliform Group Bacteria

A. Discussion

Coliform bacteria are measured to indicate the presence of bacteria originating in the intestines of warm-blooded animals. High coliform counts indicate the usefulness of water may have been impaired. Coliform bacteria are considered harmless, but their presence may be indicative of the presence of disease-producing organisms that may be found with them.

B. What is Tested?

Sample	Usual Range, MPN/100 ml
Effluent:	
Primary	5,000 to 1,000,000
Nonchlorinated Secondary	> 240,000
Chlorinated Secondary	50 to 500
Receiving Waters	1,000 to 1,000,000

C. Sampling Bottles

Wide-mouthed bottles with 200 to 400 ml capacity are used to collect samples. Before sterilization by autoclave, add sodium thiosulfate (0.1 ml of a 10% solution per 4 ounce bottle) to the bottles to neutralize any chlorine residual in the samples. When filling bottles in the field, do not flush out sodium thiosulfate or contaminate sample or bottle. Fill bottles approximately three-quarters full and start test in lab within four hours, or sooner.

D. Media Preparation

1. General Discussion

Careful media preparation is necessary to meaningful bacteriological testing. Attention must be given to the quality, mixing, and sterilization of the ingredients. The purpose of this care is to assure that if the bacteria being tested for are indeed present in a sample, every opportunity is presented for their development and ultimate identification. Much bacteriological identification is done by noting changes in the medium; consequently, the composition of the medium must be standardized. Much of the tedium of media preparation can be avoided by purchase of dehydrated media (Difco, BBL, or equivalent). The operator is advised to make use of these products; and, if only a limited amount of testing is to be done, consider using tubed, prepared media.

2. Glassware

All glassware must be thoroughly cleansed using a suitable detergent and hot water (160°F), rinsed with hot water (180°F) to remove all traces of residual detergent, and finally rinsed with distilled or deionized water.

3. Water

Only distilled water or demineralized water which has been tested and found free from traces of dissolved metals and bactericidal and inhibitory compounds may be used for preparation of culture media.

4. Buffered[8] Dilution Water

Prepare a stock solution by dissolving 34 grams of KH_2PO_4 in 500 ml distilled water, adjusting the pH to 7.2 with 1N NaOH. Prepare dilution water by adding 1.25 ml of the stock solution per liter of distilled water. This solution can be dispersed into various size dilution blanks or used as a sterile rinse water for the membrane filter test.

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[8] Buffer. A measure of the ability or capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water or wastewater for offering a resistance to changes in the pH.

5. Coliform Test--Fermentation Tube Method

a. Lactose Broth or Lauryl Tryptose Broth

For the presumptive coliform test, dissolve the recommended amount of the dehydrated medium in distilled water. Dispense solution into fermentation tubes containing an inverted glass vial. Autoclave the capped tubes at 121°C for 15 minutes.

b. Brilliant Green Bile Lactose Broth

For the confirmed coliform test, dissolve 40 grams of the dehydrated medium in one liter of distilled water. Dispense and sterilize as with Lactose Broth.

c. Compensation for Diluting Effect of Samples

Large volumes of samples can dilute the medium in the fermentation tube. Use the concentrations listed below to compensate for diluting effects when using lauryl tryptose broth.

No. ml medium in tube	Ml of sample or dilution	Nominal concentration before inoculation	No. grams dehydrated medium per liter
10	0.1 to 1.0	1x	35.6
10	10	2x	71.2
20	10	1.5x	53.4
35	100	4x	137.3

6. Coliform Test-Elevated Temperature for Fecal Coliforms

EC Broth

For the fecal coliform test, dissolve 37 grams of the dehydrated medium in one liter of distilled water. Dispense and sterilize as with Lactose Broth.

7. Coliform Test--Membrane Filter Method

M-Endo Broth

Prepare this medium by dissolving 48 grams of the dehydrated product in one liter of distilled water which contains 20 ml of ethyl alcohol per liter. Heat solution to boiling only--DO NOT AUTOCLAVE. Prepared media should be stored in a refrigerator and used within 96 hours.

8. Autoclaving

Steam autoclaves are used for the sterilization of the liquid media and associated apparatus. They sterilize (killing of all organisms) at a relatively low temperature of 121°C within 15 minutes by utilizing moist heat.

Components of the media, particularly sugars such as lactose, may decompose at higher temperatures or longer heating times. For this reason adherence to time and temperature schedules is vital.

Autoclaves operate in a manner similar to the familiar kitchen pressure cooker:

1. Water is heated in a boiler to produce steam.

2. The steam is vented to drive out air.

3. The steam vent is closed when the air is gone.

4. Continued heat raises the pressure to 15 lbs/in^2 (at this pressure, pure steam has a temperature of 121°C).

5. The pressure is maintained for the required time.

6. The steam vent is opened and the steam is slowly vented until atmospheric pressure is reached. (Fast venting will cause the liquids to boil.)

7. Sterile material is removed to cool.

In autoclaving fermentation tubes, a vacuum is formed in the inner tubes. As the tubes cool, the inner tubes are filled with sterile medium. Capture of gas in this inner tube from the culture of bacteria is the evidence of fermentation.

E. Test for Coliform Bacteria

1. General Discussion

The test for coliform bacteria is used to measure the suitability of a water for human use. The test is not only useful in determining the bacterial quality of a finished water, but it can be used by the operator in the treatment plant to guide him in achieving a desired degree of treatment.

2. Multitube Fermentation Technique

Coliform bacteria are detected in water by placing portions of a sample of the water in lactose broth. Lactose broth is a standard bacteriological medium containing lactose (milk) sugar in tryptose broth. The coliform bacteria are those which will grow in this medium at 35°C temperature and ferment and produce gas from the sugar within 48 hours. Thus to detect these bacteria the operator need only inspect fermentation tubes for gas. In practice, multiple fermentation tubes are used in a decimal dilution for each sample.

3. Materials Needed

1. Fifteen sterile tubes of lactose broth are needed for each sample.
2. Use five tubes for each dilution.
3. Dilution tubes or blanks containing 9 ml or 99 ml of sterile buffered distilled water.
4. Quantity of one and 10 ml sterile pipettes.

4. Technique for Inoculation and/or Dilution of Sample (Fig. 14.4)

All inoculations and dilutions of water specimens must be accurate and should be made so that no contaminants from the air, equipment, clothes or fingers reach the specimen, either directly or by way of the contaminated pipettes.

1. Shake the specimen bottle vigorously 20 times before removing sample volumes.

2. Into the first row of five lactose tubes pipette 1.0 ml into each tube. It is important to realize that the sample volume applied to the first row of tubes will depend upon the type of water being tested. The sample volume applied to each tube can vary from 10 ml (or more) for high quality waters to as low as 10^{-5} or 0.00001 ml (applied as 1 ml of diluted sample) for fecal specimens.

3. Make a 1:10 dilution of the sample by adding 1.0 ml of the water sample to the contents (9ml) of a sterile water tube or add 11 ml to a 99 ml blank. Mix diluted sample thoroughly by shaking.

4. Inoculate the next five tubes of lactose broth with 1.0 ml of the water sample.

5. Make a 1:100 dilution of the sample by adding 1.0 ml of the water specimen diluted 1:10 to the contents of a sterile water tube or by adding 11 ml to a 99 ml blank. Mix thoroughly by shaking.

6. Inoculate the next five tubes of lactose broth with 1.0 ml of the 1:100 dilution.

7. After measuring all portions of the sample into their respective tubes of medium, <u>gently</u> shake the rack of inoculated tubes to insure good mixing of sample with the culture medium. Avoid vigorous shaking, because air bubbles may be shaken into the fermentation tubes and thereby invalidate the test.

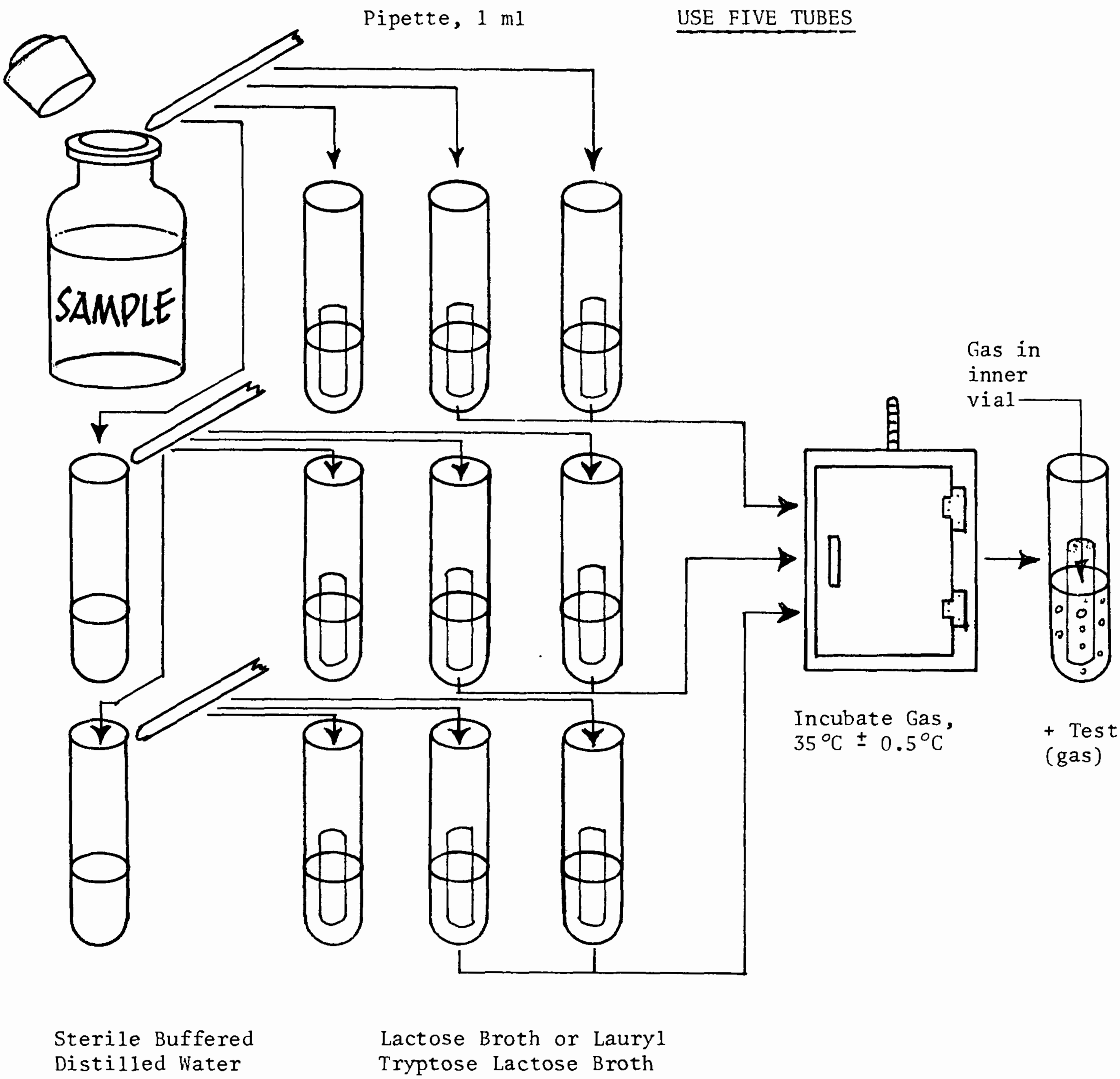


Fig. 14.4 Coliform bacteria test

5. 24-Hour Lactose Broth Presumptive Test

Place all inoculated lactose broth tubes in 35°C ± 0.5°C incubator. After 24 ± 2 hours have elapsed, examine each tube for gas formation in inverted vial (inner tube). Mark + on report form for all tubes that show presence of gas. Mark - for all tubes showing no gas formation. Save all positive tubes for confirmation test. The negative tubes must be reincubated for an additional 24 hours.

6. 48-Hour Lactose Broth Presumptive Test

Record both positive and negative tubes at the end of 48 ± 3 hours. Save all positive tubes for confirmation test.

7. 24-Hour Brilliant Green Bile Confirmation Test

Confirm all presumptive tubes that show gas at 24 or 48 hours. Transfer, with the aid of a sterile 3 mm platinum wire loop, one loop-full of the broth from the lactose tubes showing gas, and inoculate a corresponding tube of BGB (Brilliant Green Bile) broth by mixing the loop of broth in the BGB broth. "Discard" all positive lactose broth tubes after transferring is completed.

Always sterilize inoculation loops and needles in flame immediately before transfer of culture; do not lay loop down or touch it to any nonsterile object before making the transfer. After sterilization in a flame, allow sufficient time for cooling, in the air, to prevent the heat of the loop from killing the bacterial cells being transferred. Wooden sterile applicator sticks also are used to transfer cultures, especially in the field where a flame is not available for sterilization.

After 24 hours has elapsed, inspect each of the BGB tubes for gas formation. Those with any amount of gas are considered positive and are so recorded on the data sheet. Negative BGB tubes are reincubated for an additional 24 hours.

8. 48-Hour Brilliant Green Bile Confirmation Test

1. Examine tubes for gas at the end of the 48 ± 3 hour period. Record both positive and negative tubes.

2. Complete reports by decoding MPN index and recording MPN on work sheets.

9. Method of Calculation of the Most Probable Number

Select the highest dilution with all positive tubes, before a negative tube occurs, plus the next two dilutions.

Example No. 1 - Select the underlined dilutions

Dilutions	0	-1	-2	-3	-4	-5
Readings	5	5	5	2	0	0

Read MPN as 49 per 100 ml from Table III

Report results as 49,000/100 ml

We added three zeros to 49 because we started with the -2 dilution and Table III starts three dilution columns to the left (-1 or 0.1 ml, 0 or 1 ml, and 1 or 10 ml).

Example No. 2 - Select the underlined dilutions

Dilutions	0	-1	-2	-3	-4	-5
Readings	5	5	5	5	0	0

Read MPN as 23 per 100 ml from Table III

Report results as 230,000 per 100 ml

If positive tubes extend beyond three chosen dilutions, include positives beyond chosen dilutions by moving them forward.

Example No. 3

Dilutions	0	-1	-2	-3	-4	-5
Readings	5	1	0	1	0	0
This becomes	5	1	1	0	0	0

The MPN is 460 per 100 ml

If unreasonable positives occur, such as:

5 1 0 0 (2)*

*discard them.

TABLE III

MPN INDEX FOR VARIOUS COMBINATIONS OF POSITIVE AND NEGATIVE RESULTS IN A PLANTING SERIES OF FIVE 10-ml, FIVE 1-ml AND FIVE 0.1-ml PORTIONS OF SAMPLE

Number of tubes giving positive reaction out of			MPN Index
Five 10-ml portions	Five 1-ml portions	Five 0.1 ml portions	(organisms per 100 ml)
0	0	0	<2
0	0	1	2
0	0	2	4
0	1	0	2
0	1	1	4
0	1	2	6
0	2	0	4
0	2	1	6
0	3	0	6
1	0	0	2
1	0	1	4
1	0	2	6
1	0	3	8
1	1	0	4
1	1	1	6
1	1	2	8
1	2	0	6
1	2	1	8
1	2	2	10
1	3	0	8
1	3	1	10
1	4	0	11
2	0	1	5
2	0	1	7
2	0	2	9
2	0	3	12
2	1	0	7
2	1	1	9
2	1	2	12
2	2	0	9
2	2	1	12
2	2	2	14

TABLE III (cont'd.)

MPN INDEX FOR VARIOUS COMBINATIONS OF POSITIVE AND NEGATIVE RESULTS IN A PLANTING SERIES OF FIVE 10-ml, FIVE 1-ml AND FIVE 0.1-ml PORTIONS OF SAMPLE

Number of tubes giving positive reaction out of			MPN Index
Five 10-ml portions	Five 1-ml portions	Five 0.1 ml portions	(organisms per 100 ml)
2	3	0	12
2	3	1	14
2	4	0	15
3	0	0	8
3	0	1	11
3	0	2	13
3	1	0	11
3	1	1	14
3	1	2	17
3	1	3	20
3	2	0	14
3	2	1	17
3	2	2	20
3	3	0	17
3	3	1	21
3	4	0	21
3	4	1	24
3	5	0	25
4	0	0	13
4	0	1	17
4	0	2	21
4	0	3	25
4	1	0	17
4	1	1	21
4	1	2	26
4	2	0	22
4	2	1	26
4	2	2	32
4	3	0	27
4	3	1	33
4	3	2	39

TABLE III (cont'd.)

MPN INDEX FOR VARIOUS COMBINATIONS OF POSITIVE AND NEGATIVE RESULTS IN A PLANTING SERIES OF FIVE 10-ml, FIVE 1-ml AND FIVE 0.1-ml PORTIONS OF SAMPLE

Number of tubes giving positive reaction out of			MPN Index
Five 10-ml portions	Five 1-ml portions	Five 0.1 ml portions	(organisms per 100 ml)
4	4	0	34
4	4	1	40
4	5	0	41
4	5	1	48
5	0	0	23
5	0	1	31
5	0	2	43
5	0	3	58
5	0	4	76
5	1	0	33
5	1	1	46
5	1	2	63
5	1	3	84
5	2	0	49
5	2	1	70
5	2	2	94
5	2	3	120
5	2	4	148
5	2	5	177
5	3	0	79
5	3	1	109
5	3	2	141
5	3	3	175
5	3	4	212
5	3	5	253
5	4	0	130
5	4	1	172
5	4	2	221
5	4	3	278
5	4	4	345
5	4	5	426
5	5	0	240
5	5	1	348
5	5	2	542
5	5	3	920
5	5	4	1600
5	5	5	>2400

F. Test for Fecal Coliform Bacteria

1. General Discussion

Many regulatory agencies are measuring the bacteriological quality of water using the fecal coliform test because this test is a more reliable test for indicating the potential presence of pathogenic organisms than is the coliform group of organisms. The procedure described is an elevated temperature test for fecal coliform bacteria.

2. Materials Needed

Equipment required for the tests are the same as those required for the 24-Hour Lactose Broth Presumptive Test, a water bath, and EC Broth.

3. Procedure

1. Run lactose broth or lauryl tryptose broth presumptive test.

2. After 24 hours temporarily retain all gas-positive tubes.

3. Label a tube of EC broth to correspond with each gas-positive tube of broth from presumptive test.

4. Transfer one loop-full of culture from each gas-positive culture in presumptive test to the correspondingly labeled tube of EC broth.

5. Incubate EC broth tubes 24 $\pm$ 2 hours at 44.5°C $\pm$ 0.2°C in a waterbath with water depth sufficient to come up at least as high as the top of the culture medium in the tubes. Place in waterbath as soon as possible after inoculation and always within 30 minutes after inoculation.

6. After 24 hours remove the rack of EC cultures from the waterbath, shake gently, and record gas production for each tube. Gas in any quantity is a positive test.

7. As soon as results are recorded, discard all tubes. This is a 24-hour test for EC broth inoculations and not a 48-hour test.

8. Transfer any additional 48-hour gas positive tubes from the presumptive test to correspondingly labeled tubes of EC broth. Incubate for 24 ± 2 hours at 44.5°C ± 0.2°C and record results on data sheet.

9. Codify results and determine MPN of fecal coliforms per 100 ml of sample.

G. Membrane Filter Method

1. General Discussion

In addition to the fermentation tube test for coliform bacteria, another test is used for these same bacteria in water analysis. This test uses a cellulose ester filter, called a membrane filter, the pore size of which can be manufactured to close tolerances. Not only can the pore size be made to selectively trap bacteria from water filtered through the membrane, but nutrients can be diffused up through the membrane to grow these bacteria into colonies. These colonies are recognizable as coliform because the nutrients include fuchsin dye which peculiarly colors the colony. Knowing the number of colonies and the volume of water filtered, the operator can then compare the water tested with water quality standards.

2. Materials Needed

1. One sterile membrane filter having a 0.45μ pore size.

2. One sterile 47 mm Petri dish with lid.

3. One sterile funnel and support stand.

4. Two sterile pads.

5. One receiving flask (side-arm, 1000 ml).

6. Vacuum pump, trap, suction or vacuum gage, connecting sections of plastic tubing, Glass "T" hose clamp to adjust pressure by-pass.

7. Tweezers, alcohol, Bunsen Burner, grease pencil.

8. Sterile buffered distilled water for rinsing.

9. M-Endo Media.

10. Sterile pipettes--two 5 ml graduated, one 1 ml for aliquot or one 10 ml for larger aliquot. Quantity of one ml pipettes if dilution of sample is necessary. Also, quantity of dilution water blanks if dilution of sample is necessary.

11. One moist incubator at 35°C temperature. Auxiliary incubator dish with cover.

3. Illustration of Inoculation of Membrane Filter

Fig. I

1. Center membrane filter on filter holder. Handle membrane only on outer 3/16 inch with tweezers sterilized before use in ethyl or methyl alcohol and passed lightly through a flame.

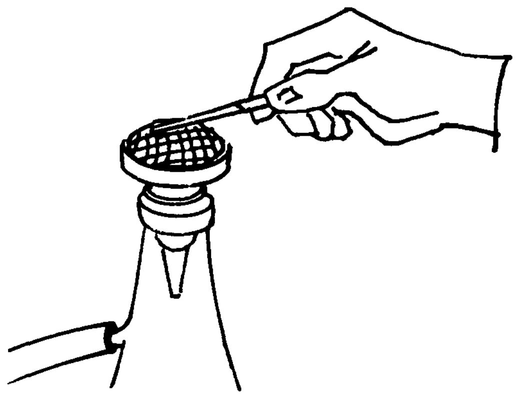


Fig. II

2. Place funnel onto filter holder.

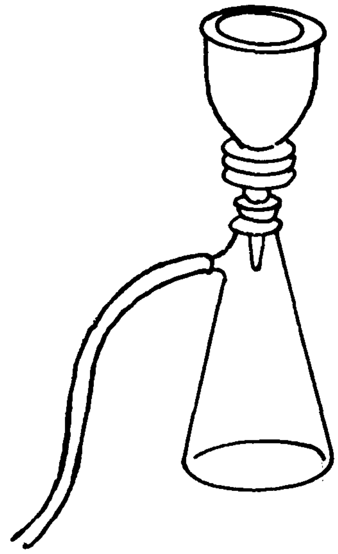
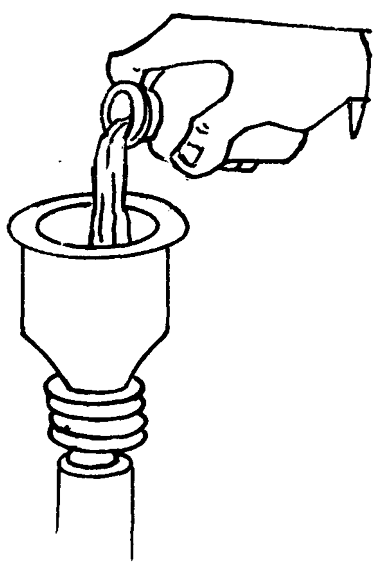
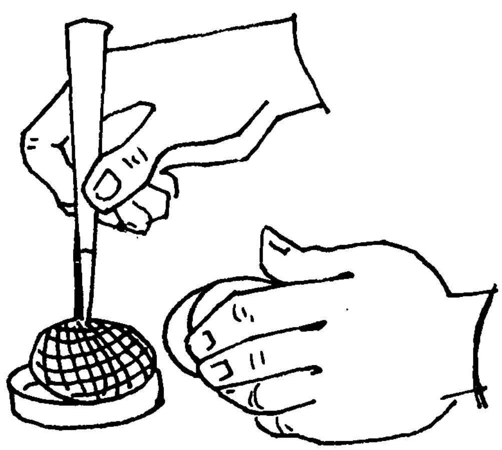


Fig. III



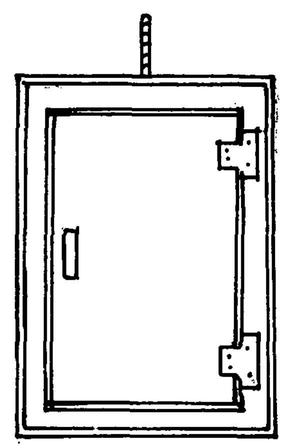
3. Pour or pipette sample aliquot into funnel. Avoid spattering. After suction is applied rinse four times with sterile buffered distilled water.

Fig. IV



4. Remove membrane filter from filter holder with sterile tweezers. Place membrane on pad. Cover with Petri top.

Fig. V



5. Incubate in inverted position for 22 ± 2 hours.

6. Count colonies on membrane.

4. Procedure for Inoculation of Membrane Filter

All filtrations and dilutions of water specimens must be accurate and should be made so that no contaminants from the air, equipment, clothes or fingers reach the specimen either directly or by way of the contaminated pipette.

1. Secure tubing from pump and bypass to receiving flask. Place palm of hand on flask opening and start pump. Adjust suction to ¼ atmosphere with hose clamp on pressure bypass. Turn pump switch to OFF.

2. Set sterile filter-support-stand and funnel on receiving flask. Loosen wrapper. Rotate funnel counter-clockwise to disengage pin. Recover with wrapper.

3. Place Petri Dish on bench with lid up. Write indentification on lid with grease pencil.

4. Unwrap sterile pad container. Light Bunsen burner.

5. Unwrap membrane filter container.

6. Sterilize tweezers by dipping in alcohol and passing quickly through Bunsen burner.

7. Center membrane filter on filter stand with tweezers after lifting funnel. Membrane filter with printed grid should show grid uppermost (Fig. I).

8. Replace funnel and lock against pin (Fig. II).

9. Shake sample or diluted sample. Measure proper aliquot[9] with sterile pipette and add to funnel.

10. Add a small amount of the sterile dilution water to funnel. This will help check for leakage and also aid in dispersing small volumes (Fig. III).

11. Now start vacuum pump.

---

[9] Aliquot (AL-li-kwot). Portion of sample.

12. After filtration of entire sample is finished, add rinse water from four consecutive dilution water tubes at each 90° of funnel quadrant, pouring just below inner lip of funnel. Allow each rinse to completely pass through funnel before proceeding to next rinse.

13. When membrane filter appears barely moist, switch pump to OFF.

14. Sterilize tweezers as before.

15. Remove membrane filter with tweezers after first removing funnel as before (Fig. I).

16. Center membrane filter on pad containing M-Endo medium with a rolling motion to insure water seal. Inspect membrane to insure no captured air bubbles are present. (Fig. IV).

17. Place inverted Petri Dish in incubator for 22 ± 2 hours.

5. Procedure for Counting Membrane Filter Colonies

1. Remove Petri Dish from incubator.

2. Remove lid from Petri Dish.

3. Turn so that your back is to window.

4. Tilt membrane filter in base of Petri Dish so that green and yellow-green colonies are most apparent. Direct sunlight has too much red to facilitate counting.

5. Count individual colonies utilizing an overhead fluorescent light. The coliform colony is characterized by a "metallic sheen" and only those colonies showing ANY amount of this sheen are considered to be coliforms.

6. Report total number of "coliform colonies" on work sheet. Use the membranes that show from 20 to 80 colonies and do not have more than 200 colonies of all types (including non-sheen or, in other words, non-coliforms).

Example:

A total of 42 colonies grew after filtering a 10 ml sample.

$$\text{Bacteria/100 ml} = \frac{\text{No. of colonies counted x 100 ml}}{\text{Sample volume filtered, ml x 100 ml}}$$

$$= \frac{(42 \text{ colonies})\ (100 \text{ ml})}{(10 \text{ ml})\ (100 \text{ ml})}$$

$$= \frac{(4.2)\ (100 \text{ ml})}{100 \text{ ml}}$$

$$= 420 \text{ per } 100 \text{ ml}$$

QUESTIONS

7.A Why should sodium thiosulfate crystals be added to sample bottles for coliform tests before sterilization?

7.B Steam autoclaves effect sterilization (killing of all organisms) at a relatively low temperature (______ °C) within ________ minutes by utilizing moist heat.

7.C Calculate the Most Probable Number (MPN) of coliform group bacteria from the following test results:

Dilutions	0	-1	-2	-3	-4	-5
Readings	5	5	5	1	2	0

7.D How is the number of coliforms estimated by the membrane for filter method?

END OF LESSON 3 OF 8 LESSONS

on

Laboratory Procedures and Chemistry

Work the next portion of the discussion and review questions before continuing with Lesson 4.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 3 of 8 Lessons)

Chapter 14. Laboratory Procedures and Chemistry

Name ______________________________ Date ____________

Write the answers to these questions in your notebook. The problem numbering continues from Lesson 2.

8. Why must the clarity test always be run under the same conditions?

9. What is the purpose of the coliform group bacteria test?

10. What does MPN mean?

3. Dissolved Oxygen or DO and Biochemical Oxygen Demand or BOD

I. IN WATER

A. Discussion

The dissolved oxygen (DO) test is, as the name implies, the testing procedure to determine the amount of oxygen dissolved in samples of water or wastewater. There are various types of tests that can be run to obtain the amount of dissolved oxygen. This procedure is the Sodium Azide Modification of the Winkler Method and is best suited for relatively clean waters. Interfering substances include color, organics, suspended solids, sulfides, chlorine, and ferrous and ferric ioon. Nitrites will not interefere with the test if fresh azide is used.

The generalized principle is that iodine will be released in proportion to the amount of dissolved oxygen present in the sample. By using sodium thiosulfate with starch as the indicator, one can titrate the sample and determine the amount of dissolved oxygen.

B. What is Tested?

Sample	Common Range, mg/l
Influent	Usually 0,>1 is very good.
Primary Clar. Effluent	Usually 0, Recirculated from filters > 2 is good.
Secondary Effluent	50% to 95% Saturation, 3 to >8 is good.
Oxidation Ponds	1 to 25+*
Activated Sludge--Aeration Tank Outlet	>2 desirable

(> means greater than)
(* supersaturated with oxygen)

C. Apparatus

METHOD A (Sodium Azide Modification of Winkler Method)

1. Buret, graduated to 0.1 ml.
2. Three 300 ml glass-stoppered BOD bottles
3. Wide-mouth Erlenmeyer flask, 500 ml.
4. One 10 ml measuring pipette.
5. One 1-liter reagent bottle to collect activated sludge.

METHOD B (DO Probe)

Follow manufacturer's instructions. See Section H for Discussion, Calibration, and Precautions.

D. Reagents

1. Manganous sulfate solution. Dissolve 480 g manganous sulfate crystals ($MnSO_4 \cdot 4H_2O$) in 400 to 600 ml distilled water. Filter through filter paper, then add distilled water to the filtered liquid to make a 1-liter volume.

2. Alkaline iodide-sodium azide solution. Dissolve 500 g sodium hydroxide (NaOH) in 500 to 600 ml distilled water; dissolve 150 g potassium iodide (KI) in 200 to 300 ml distilled water in a separate container. Exercise caution. Mix chemicals in pyrex glass bottles using a magnetic stirrer. Add the chemicals to the distilled water slowly and cautiously. Avoid breathing the fumes and body contact with the solution. Heat is produced when the water is added, and the solution is very caustic. Place an inverted beaker over the top of the mixing container and allow the container to cool at room temperature.

   Mix both solutions when they are cool.

   Dissolve 10 g sodium azide (NaN_3) in 40 ml of distilled water. Exercise caution again. This solution is poisonous.

   Add the sodium azide solution with constant stirring to the cooled solution of alkaline iodide; then add distilled water to the mixture to make a 1-liter volume. Sodium azide will decompose in time and is no good after three months.

3. Sulfuric acid. Use concentrated reagent-grade acid (H_2SO_4). Handle carefully, since this material will burn hands and clothes. Rinse affected parts with tap water to prevent injury.

   CAUTION: When working with alkaline azide and sulfuric acid, keep a nearby water faucet running for frequent hand rinsing.

4. 0.0375 N sodium thiosulfate solution. Dissolve exactly 9.308 g sodium thiosulfate crystals ($Na_2S_2O_3 \cdot 5H_2O$) in freshly boiled and cooled water and make up to 1 liter. For preservation, add 0.4 g or 1 pellet of sodium hydroxide (NaOH). Solutions of "thio" should be used within two weeks to avoid loss of accuracy due to decomposition of solution.

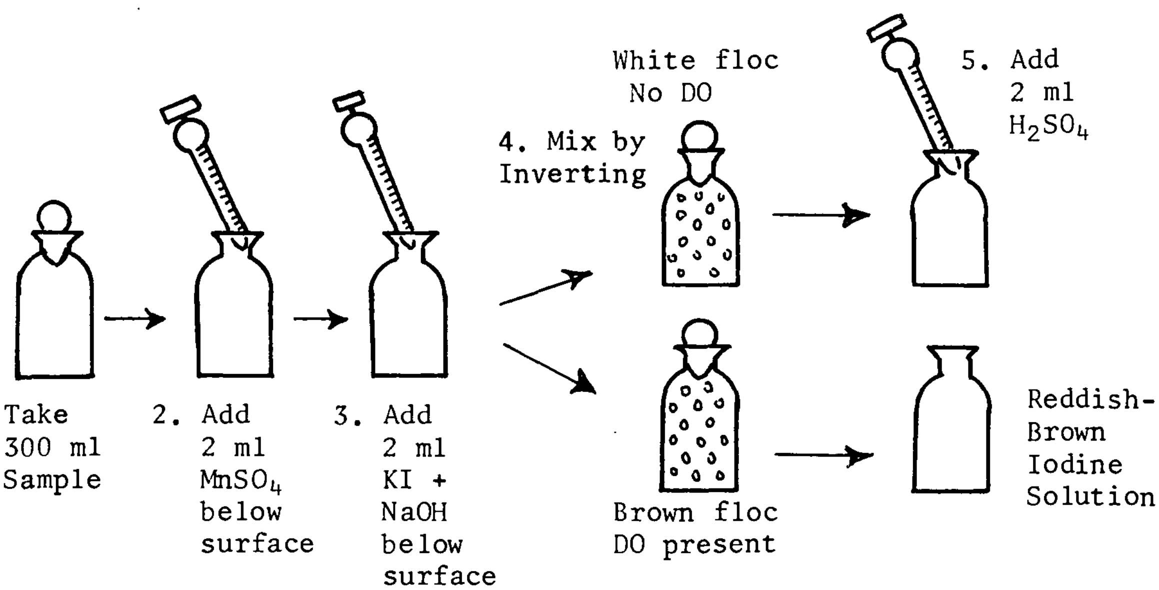
5. Starch solution. Make a thin paste of 6 g of potato starch in a small quantity of distilled water. Pour this paste into one liter of boiling, distilled water, allow to boil for a few minutes, then settle overnight. Remove the clear supernatant and save; discard the rest. For preservation, add two drops toluene ($C_6H_5CH_3$).

6. Copper sulfate solution. Make a 10 percent solution by dissolving 10 grams of copper sulfate in 100 ml of water.

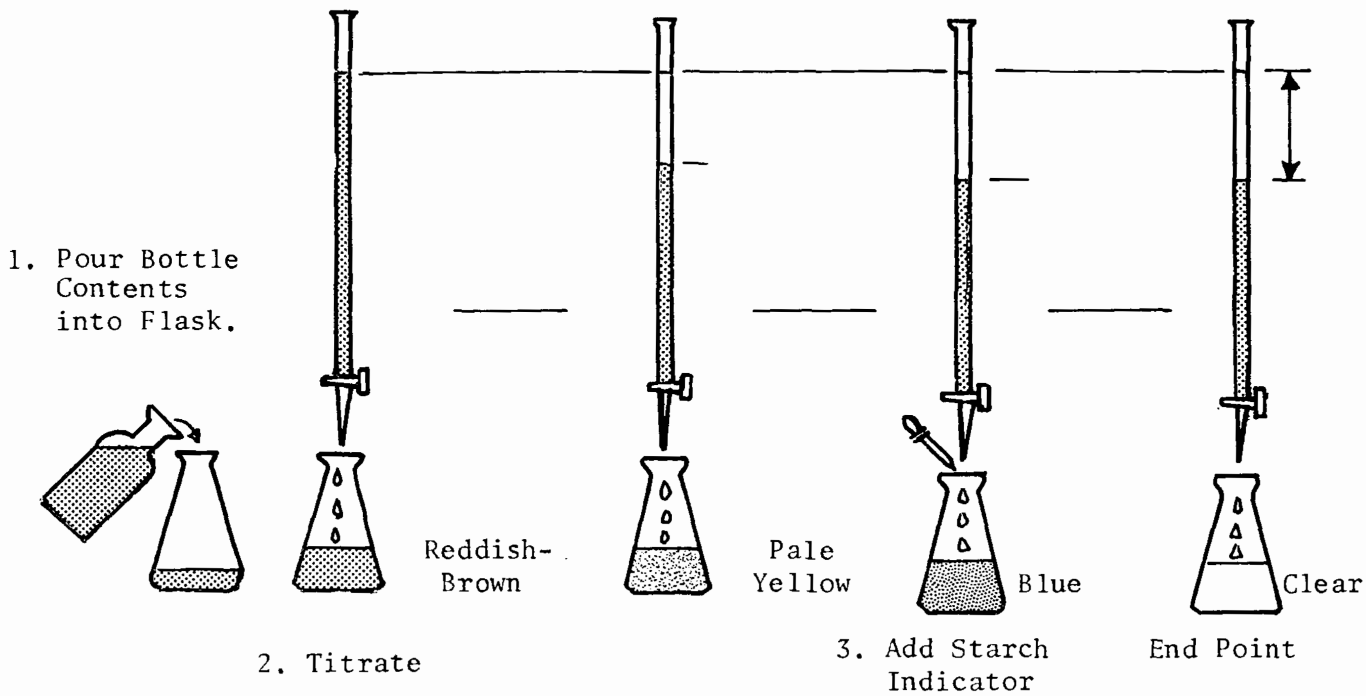
Sodium Azide Modification of the Winkler Method

NOTE: The sodium azide destroys nitrates which will interfere with this test.

E. Outline of Procedure



Titration of Iodine Solution:



PROCEDURE

The reagents are to be added in the quantities, order, and methods as follows:

1. Collect a sample to be tested in 300 ml (BOD) bottle taking special care to avoid aeration of the liquid being collected. Fill bottle completely and add cap.

2. Remove cap and add 2 ml of manganous sulfate solution below surface of the liquid.

3. Add 2 ml of alkaline-iodide-sodium azide solution below the surface of the liquid.

4. Replace the stopper, avoid trapping air bubbles, and shake well by inverting the bottle several times. Repeat this shaking after the floc has settled halfway. Allow the floc to settle halfway a second time.

5. Acidify with 2 ml of concentrated sulfuric acid by allowing the acid to run down the neck of the bottle above the surface of the liquid.

6. Restopper and shake well until the precipitate has dissolved. The solution will then be ready to titrate. Handle the bottle carefully to avoid acid burns.

7. Pour contents of bottle into an Erlenmeyer flask.

8. If the solution is brown in color, titrate with 0.0375 N sodium thiosulfate until the solution is pale yellow color. Add a small quantity of starch indicator and proceed to step 10.

9. If the solution has no brown color, or is only slightly colored, add a small quantity of starch indicator. If no blue color develops, there is zero Dissolved Oxygen. If a blue color does develop, proceed to step 10.

10. Titrate to the first disappearance of the blue color. Record the number of ml of sodium thiosulfate used.

11. The amount of oxygen dissolved in the original solution will be equal to the number of ml of sodium thiosulfate used in the titration provided significant interfering substances are not present.

    mg/l DO = ml sodium thiosulfate

F. Example

The DO titration of a 300 ml sample requires 5.0 ml of 0.0375 N Sodium Thiosulfate. Therefore, the dissolved oxygen concentration in the sample is 5 mg/l.

G. Calculation

You will want to find the percent saturation of DO in the effluent of your secondary plant. The DO is 5.0 mg/l and the temperature is 20°C. At 20°C, 100% DO saturation is 9.2 mg/l.

The dissolved oxygen saturation values are given in Table IV. Note that as the temperature of water increases, the DO saturation value (100% Saturation Column) decreases. Table IV gives 100% DO saturation values for temperatures in °C and °F.

$$\text{DO Saturation, \%} = \frac{\text{DO of Sample, mg/l} \times 100\%}{\text{DO at 100\% Saturation, mg/l}}$$

$$= \frac{5.0 \text{ mg/l}}{9.2 \text{ mg/l}} \times 100\%$$

$$= .54 \times 100\%$$

$$= 54\%$$

```
        .54
9.2 / 5.0 0
      4 6 0
        4 00
        3 68
          32
```

H. DO Probe

1. Discussion

Measurement of the dissolved oxygen (DO) concentration with a probe and electronic readout meter is a satisfactory substitute for the Sodium Azide Modification of the Winkler Method under many circumstances. The probe is recommended when samples contain substances which interfere with the modified Winkler procedure, such as sulfite, thiosulfate, polythionate, mercaptans, free chlorine or hypochlorite, organic substances readily hydrolyzed in alkaline solutions, free iodine, intense color or turbidity, and biological flocs. A continuous record of the dissolved

TABLE IV

EFFECT OF TEMPERATURE ON OXYGEN SATURATION FOR A CHLORIDE CONCENTRATION OF ZERO Mg/1

°C	°F	mg/1 DO at Saturation
0	32.0	14.6
1	33.8	14.2
2	35.6	13.8
3	37.4	13.5
4	39.2	13.1
5	41.0	12.8
6	42.8	12.5
7	44.6	12.2
8	46.4	11.9
9	48.2	11.6
10	50.0	11.3
11	51.8	11.1
12	53.6	10.8
13	55.4	10.6
14	57.2	10.4
15	60.0	10.2
16	61.8	10.0
17	63.6	9.7
18	65.4	9.5
19	67.2	9.4
20	68.0	9.2
21	69.8	9.0
22	71.6	8.8
23	73.4	8.7
24	75.2	8.5
25	77.0	8.4

oxygen content of aeration tanks and receiving waters may be obtained using a probe. In determining the BOD of samples, a probe may be used to determine the DO initially and after the five-day incubation period of the blanks and sample dilutions.

2. Procedure

Follow manufacturer's instructions.

3. Calibration

To be assured that the DO probe reading provides the dissolved oxygen content of the sample, the probe must be calibrated. Take a sample that does not contain substances that interfere with either the probe reading or the modified Winkler procedure. Split the sample. Measure the DO in one portion of the sample using the modified Winkler procedure and compare this result with the DO probe reading on the other portion of the sample. Adjust the probe reading to agree with the results from the modified Winkler procedure.

When calibrating the probe in an aeration tank of the activated sludge process, do not attempt to measure the dissolved oxygen in the aerator and then adjust the probe. The biological flocs in the aerator will interfere with the modified Winkler procedure, and the copper sulfate-sulfamic acid procedure is not sufficiently accurate to calibrate the probe. An aeration tank probe may be calibrated by splitting an effluent sample, measuring the DO by the modified Winkler procedure, and comparing results with the probe readings. Always keep the membrane in the tip of the probe from drying because the probe can lose its accuracy until reconditioned.

4. Precautions

1. Periodically check the calibration of the probe.

2. Keep the membrane in the tip of the probe from drying out.

3. Dissolved inorganic salts, such as found in sea water, can influence the readings from a probe.

4. Reactive compounds, such as reactive gases and sulfur compounds, can interfere with the output of a probe.

5. Don't place the probe directly over a diffuser because you want to measure the dissolved oxygen in the water being treated, not the oxygen in the air supply to the aerator.

8. Dissolved Oxygen

II. IN AERATOR

Copper Sulfate-Sulfamic Acid Flocculation, page 413, 12th Edition, 1965, "Standard Methods".

A. Discussion

This modification is used for biological flocs that have high oxygen utilization rates in the activated sludge process, and when a DO probe is not available. It is very important that some oxygen be present in aeration tanks at all times to maintain aerobic conditions.

This test is similar to the regular DO test except that copper sulfate is added to kill oxygen-consuming organisms, and sulfamic acid is added to combat nitrites before the regular DO test is run.

NOTE: If the results indicate a DO of less than 1 mg/l, it is possible that the DO in the aeration tank is ZERO! When the DO in the aeration tank is near zero, considerable DO from the surrounding atmosphere can mix with the sample when it is collected, when the inhibitor is added, while the solids are settling, and when the sample is transferred to a BOD bottle for the DO test. If you use this test, use a deep container and avoid stirring. See article by Hughes and Reynolds JWPCF, Vol. 41, pg. 184, January 1969, for a discussion of the shortcomings of this test.

B. What is Tested?

Sample	Common DO Range, mg/l
Aerator Mixed Liquor	0.1 - 3.0

C. Apparatus

1. One tall bottle, approximately 1000 ml.

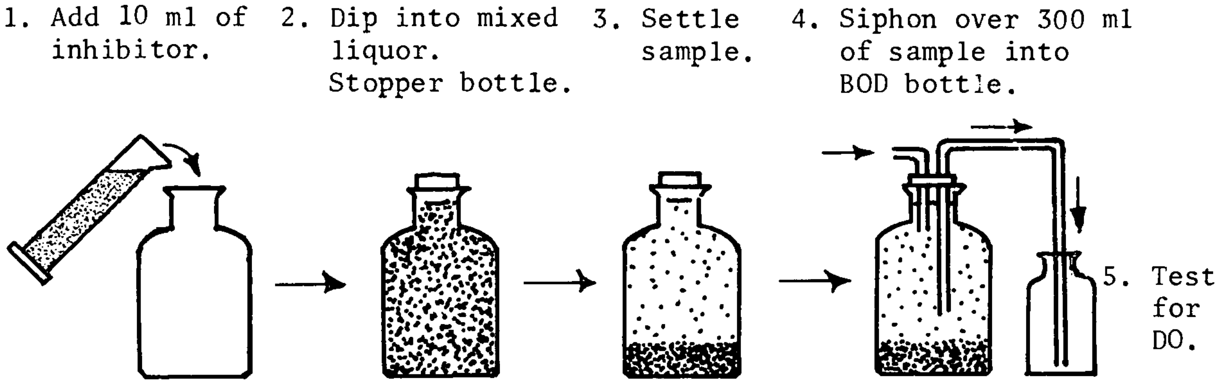
2. Regular DO apparatus.

D. Reagents

1. Copper sulfate-sulfamic acid inhibitor solution. Dissolve 32 g technical grade sulfamic acid (NH_2SO_2OH) without heat in 475 ml distilled water. Dissolve 50 g copper sulfate, $CuSO_4 \cdot 5H_2O$, in 500 ml water. Mix the two solutions together and add 25 ml concentrated acetic acid.

2. Regular DO reagents.

E. Outline of Procedure



1. Add at least 10 ml of inhibitor (5 ml copper sulfate and 5 ml sulfamic acid) to any TALL bottle (1-quart milk bottle) with an approximate volume of 1000 ml. Place filling tube near the bottom. An emptying tube is placed approximately 1/4 inch from the top of the bottle cork. Attach bottle to rod or aluminum conduit and lower into aeration tank.

2. Allow bottle to fill and then withdraw.

3. Let stand until clear supernatant liquor can be siphoned into a 300 ml BOD bottle. Do not aerate in transfer.

4. Then run regular DO.

F. and G. Example and Calculations

Same as regular DO test.

QUESTIONS

8.A Calculate the percent dissolved oxygen saturation if the receiving water DO is 7.9 mg/l and the temperature is 10°C.

8.B How would you calibrate the DO probe in an aeration tank?

8.C What are the limitations of the copper sulfate-sulfamic acid procedure for measuring DO in an aeration tank when the DO in the tank is very low?

Biochemical Oxygen Demand or BOD

A. Discussion

The BOD test gives the amount of oxygen used by microorganisms to utilize the substrate (food) in wastewater when placed in a controlled temperature for five days. The DO (dissolved oxygen) is measured at the beginning and recorded. After the 5-day incubation period the DO is again determined. The BOD is then calculated on the basis of the reduction of DO and the size of sample. This test is an estimate of the availability of food in the sample (food for organisms that take up oxygen) expressed in terms of oxygen use. Results of a BOD test indicate the rate of oxidation and provide an indirect estimate of the availability to organisms or concentration of the waste.

Samples are incubated for a standard period of five days because a fraction of the total BOD will be exerted during this period. The ultimate or total BOD is normally never run for plant control. A disadvantage of the BOD test is that the results are not available until five days after the sample was collected.

B. What is Tested?

Sample	Common Range, mg/l
Influent	150 - 400
Primary Effluent	60 - 160
Secondary Effluent	10 - 60
Digester Supernatant	1000 - 4000+
Industrial Wastes	100 - 3000+

C. Apparatus

1. 300 ml BOD bottles with ground glass stoppers
2. Incubator, 20°C
3. Pipettes, 10 ml graduated, 1/32 to 1/16-inch diameter tip
4. Burette and stand
5. Erlenmeyer flask, 500 ml

D. Reagents

See Section D, page 14-94 under DO portion of this procedure for the preparation of manganous sulfate, alkaline iodide-sodium azide, sulfuric acid, sodium thiosulfate, and starch solutions.

1. Distilled water. Water used for solutions and for preparation of the solution water must be of highest quality. It must contain no copper or decomposable organic matter. Ordinary distilled water for your car's battery is not good enough.

2. Phosphate buffer solution. Dissolve 8.5 g monobasic potassium phosphate (KH_2PO_4), 21.75 g dibasic potassium phosphate (K_2HPO_4), 33.4 g dibasic sodium phosphate crystals ($Na_2HPO_4 \cdot 7H_2O$), and 1.7 g ammonium chloride (NH_4Cl) in distilled water and make up to 1 liter. The pH of this buffer should be 7.3 and should be checked with a pH meter.

3. Magnesium sulfate solution. Dissolve 22.5 g magnesium sulfate crystals ($MgSO_4 \cdot 7H_2O$) in distilled water and make up to 1 liter.

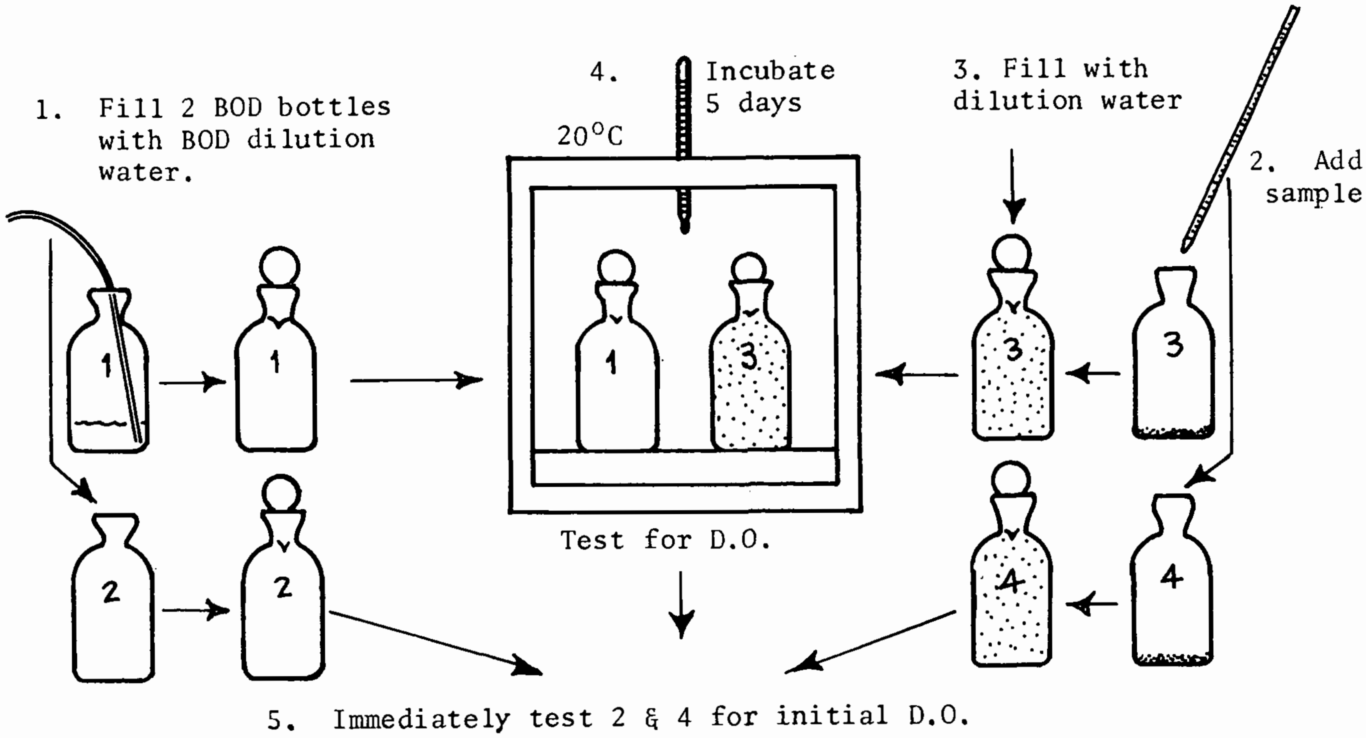
4. Calcium chloride solution. Dissolve 27.5 g anhydrous calcium chloride ($CaCl_2$) in distilled water and make up to 1 liter.

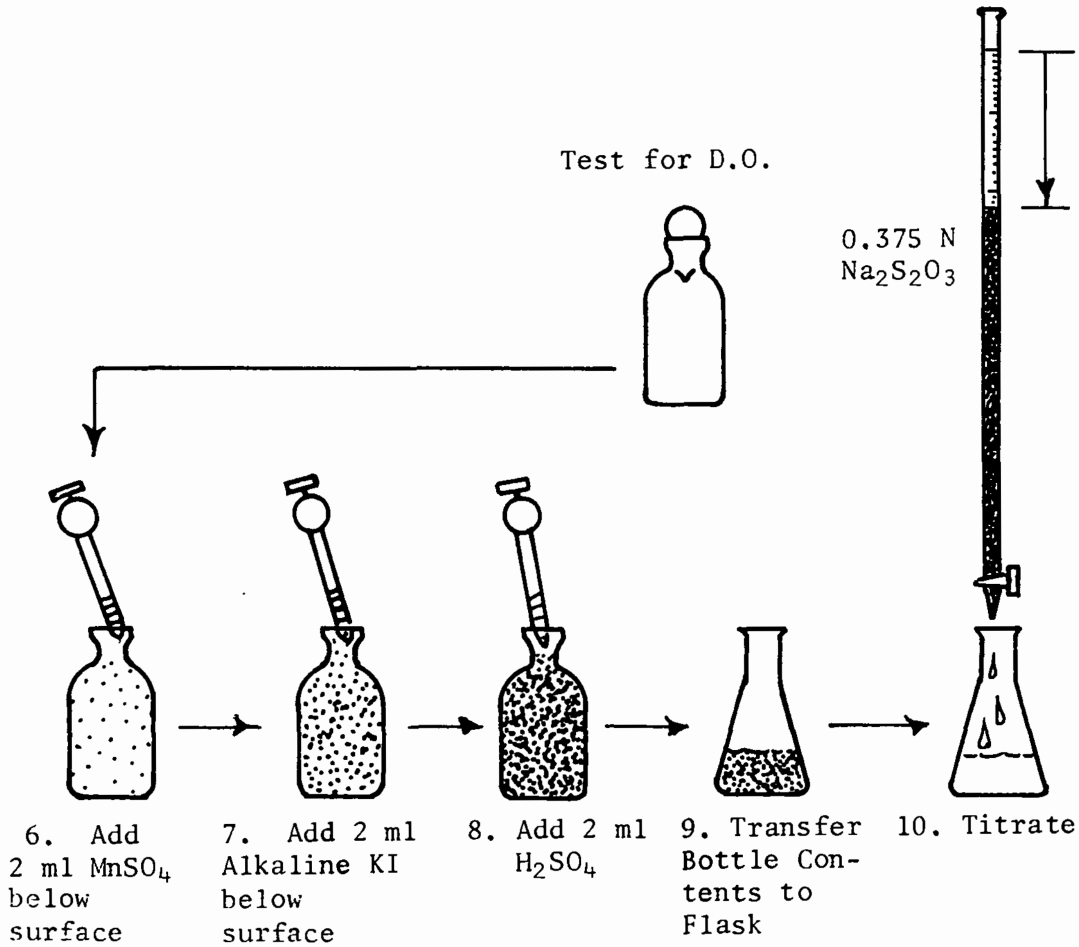
5. Ferric chloride solution. Dissolve 0.25 g ferric chloride ($FeCl_3 \cdot 6H_2O$) in distilled water and make up to 1 liter.

6. Dilution water. Add 1 ml each of phosphate buffer (step 7), magnesium sulfate (step 3), calcium chloride (step 4), and ferric chloride solutions (step 5) for each liter of distilled water. Store at a temperature as close to 20°C as possible for at least 24 hours to allow the water to become stabilized. This water should not show a drop in DO of more than 0.2 mg/l on incubation for five days.

Many plants do not prepare reagents. Small plants and plants that do not run many tests find it quicker and easier to purchase commercially prepared reagents. These reagents may be available in the desired strength or they may consist of dry pillows which are added to the sample, rather than the liquid reagent. Check with your chemical supplier for these reagents.

OUTLINE OF PROCEDURE





E. Outline of Procedure

The test is made by measuring the oxygen used or depleted during a 5-day period at 20°C by a measured quantity of wastewater sample seeded into a reservoir of dilution water saturated with oxygen. This is compared to an unseeded or blank reservoir of dilution water by subtracting the difference and multiplying by a factor for dilution. See outline on Page 14-107.

PROCEDURE

1. BOD bottles should be of 300 ml capacity with ground glass stoppers and numbers. To clean the bottles, carefully rinse with tap water followed by distilled water.

2. Fill two bottles completely with dilution water and insert the stopper tightly so that no air is trapped beneath the stopper. Siphon dilution water from its container when filling BOD bottles.

3. Set up one or more dilutions of the sample to cover the estimated range of BOD values. From the estimated BOD, calculate the volume of raw sample to be added to the BOD bottle based on the fact that:

   The most valid DO depletion is 4 mg/l. Therefore,

   $$\text{ml of sample added per 300 ml} = \frac{(4\ \text{mg/l})\ (300\ \text{ml})}{\text{Estimated BOD, mg/l}} = \frac{1200}{\text{Estimated BOD, mg/l}}$$

   Examples:

   a. Estimated BOD = 400 mg/l

   $$\text{ml of sample added to BOD bottle} = \frac{1200}{400} = 3\ \text{ml}$$

b. Estimated BOD = 200 mg/1: use 6 ml
100 mg/1: use 12 ml
20 mg/1: use 60 ml

When the BOD is unknown, select more than one sample size. For example, place several samples--1 ml, 3 ml, 6 ml, and 12 ml--into four BOD bottles.

For samples with very high BOD values, it may be difficult to accurately measure small volumes or to get a truly representative sample. In such a case, initial dilution should first be made on the sample. A dilution of 1:10 is convenient.

4. To perform the BOD test, first fill two BOD bottles with BOD dilution water. Nos. (1) and (2) in illustration, Page 14-107

5. Next, for each sample to be tested, carefully measure out the two portions of sample and place them into two new BOD bottles, Nos. (3) and (4). Add dilution water until the bottles are completely filled. Insert the stoppers. Avoid entrapping air bubbles. Be sure that there are water seals on the stoppers.

6. On bottles (2) and (4) immediately determine the initial dissolved oxygen.

7. Incubate the remaining dilution water blank and diluted sample at 20°C for five days. These are bottles (1) and (3).

8. At the end of exactly five days (± 3 hours), test bottles (1) and (3) for their dissolved oxygen by using the sodium azide modification of the Winkler method or a DO probe. At the end of five days, the oxygen content should be at least 1 mg/1. Also, a depletion of 2 mg/1 or more is desirable. Bottles (1) and (2) are only used to check the dilution water quality. Their difference should be less than 0.2 mg/1 if the quality is good and free of impurities.

F. Precautions

Since this is a bioassay (BUY-o-ass-SAY), that is, living organisms are used for the test, environmental conditions must be quite exact.

1. The temperature of the incubator must be at 20°C. Other temperatures will change the rate of oxygen used.

2. The dilution water should be made according to Standard Methods for the most favorable growth rate of the bacteria. This water must be free of copper which is often present when copper stills are used by commercial dealers. Use all glass or stainless steel stills.

3. The wastewater must also be free of toxic wastes, such as hexavalent chromium.

4. Don't use cleaning solutions to wash BOD bottles.

5. Wastewater normally contains an ample supply of seed bacteria; therefore seeding is usually not necessary.

G. Chlorinated Samples

It is very difficult to obtain reliable and reproducible results from the BOD test, and a chlorinated sample is even more difficult. For this reason, samples for BOD tests should be collected before chlorination.

H. Example

BOD Bottle Volume	=	300 ml
Sample Volume	=	15 ml
Initial DO of Diluted Sample	=	8.0 mg/l
DO of Sample and Dilution After 5-day Incubation	=	4.0 mg/l

I. Calculations

$$\text{BOD, mg/l} = \left(\begin{array}{l}\text{Initial DO of} \\ \text{Diluted Sam-} \\ \text{ple, mg/l}\end{array} - \begin{array}{l}\text{DO of Diluted} \\ \text{Sample After} \\ \text{5-Day Incuba-} \\ \text{tion, mg/l}\end{array}\right)\left(\frac{\text{BOD Bottle Vol., ml}}{\text{Sample Volume, ml}}\right)$$

$$= (8.0 \text{ mg/l} - 4.0 \text{ mg/l}) \left(\frac{300 \text{ ml}}{15 \text{ ml}}\right)$$

$$= \frac{(4.0)\ (300)}{15}$$

$$= 80 \text{ mg/l}$$

For acceptable results, the percent depletion of oxygen in the BOD test should range from 30% to 80% depletion.

$$\text{\% Depletion} = \frac{\left(\begin{array}{l}\text{DO of Diluted Sample, mg/l} \\ \quad - \text{ DO After 5 Days, mg/l}\end{array}\right)}{\text{DO of Diluted Sample, mg/l}} \times 100\%$$

$$= \frac{(8.0 \text{ mg/l} - 4.0 \text{ mg/l})}{8.0 \text{ mg/l}} \times 100\%$$

$$= \frac{4}{8} \times 100\%$$

$$= 50\%$$

When a sample requires a large volume in the BOD test and a small amount of dilution water, or if a sample has a high DO (plant or pond effluent), the initial DO of the mixture may be determined as follows.

Example:	BOD Bottle Volume	=	300 ml
	Sample Volume	=	60 ml
	Sample DO	=	2.0 mg/l
	DO of Dilution Water	=	8.0 mg/l
	DO of Sample and Dilution After 5-Day Incubation	=	4.0 mg/l

$$\text{DO of Initial Mixture of Dilution Water and Sample, mg/l} = \frac{\text{ml of Sample} \times \text{DO of Sample} + \text{ml of Dilution } H_2O \times \text{DO of Dilution } H_2O}{\text{BOD Bottle Volume}}$$

$$\text{BOD, mg/l} = \frac{60 \text{ ml} \times 2.0 \text{ mg/l} + 240 \text{ ml} \times 8.0 \text{ mg/l}}{300 \text{ ml}}$$

$$= \frac{120 + 1920}{300}$$

$$\begin{array}{r} 6.8 \\ 300 \overline{)\,2040.0} \\ \underline{1800} \\ 240.0 \\ 240.0 \end{array}$$

$$= 6.8 \text{ mg/l}$$

$$= \left(\begin{array}{l}\text{DO of} \\ \text{Diluted} \\ \text{Sample,} \\ \text{mg/l}\end{array} - \begin{array}{l}\text{DO After} \\ \text{5 Days,} \\ \text{mg/l}\end{array}\right) \left(\frac{\text{BOD Bottle Vol., ml}}{\text{Sample Vol., ml}}\right)$$

$$= (6.8 \text{ mg/l} - 4.0 \text{ mg/l}) \left(\frac{300 \text{ ml}}{60 \text{ ml}}\right)$$

$$= (2.8) \left(\frac{300}{60}\right)$$

$$\begin{array}{r} 5 \\ 60 \overline{)\,300} \end{array} \qquad \begin{array}{r} 2.8 \\ \underline{5} \\ 14.0 \end{array}$$

$$= 14.0 \text{ mg/l}$$

NOTES

1. On effluent samples where the DO is run on the sample and the blue bounces back on the end point titration, this indicates nitrite interference and can cause the BOD to be higher than actual by as much as 10% to 15% of the answer. This fact should be considered in interpreting your results. The end point also may waver because of decomposition of azide in an old reagent or resuspension of sample solids. To correct a wavering end point, try preparing a new alkaline-azide solution or more of the old solution should be used because it may be decomposing.

2. Researchers and equipment manufacturers are continually striving to develop quicker and easier tests to measure BOD. If you find a test procedure that provides you with an effective operational control test, use it. Be sure to check with your regulatory agencies for the procedures they require you to use in your effluent monitoring program.

QUESTIONS

8.D How would you determine the amount of organic material in wastewater?

8.E How would you prepare dilutions to measure the BOD of cannery waste having an expected BOD of 2000 mg/l?

8.F What is the BOD of a sample of wastewater if a 2 ml sample in a 300 ml BOD bottle had an initial DO of 7.5 mg/l and a final DO of 3.9 mg/l?

8.G Why should samples for the BOD be collected before chlorination?

8.H Why should opened bottles of "Thio" be used or restandardized within two weeks?

END OF LESSON 4 OF 8 LESSONS

on

Laboratory Procedures and Chemistry

Work the next portion of the discussion and review questions before continuing with Lesson 5.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 4 of 8 Lessons)

Chapter 14. Laboratory Procedures and Chemistry

Name ______________________________ Date ____________

Write the answers to these questions in your notebook. The problem numbering continues from Lesson 3.

11. What is the formula for calculating the percent saturation of DO?

12. What precautions should be exercised when using a DO probe?

13. What is a blank, as referred to in laboratory procedures?

14. What are some of the disadvantages of the BOD test?

15. What precautions should be taken when running a BOD test?

16. Calculate the BOD of a 5 ml sample if the initial DO of the diluted sample was 7.5 mg/l and the DO of diluted sample after 5-day incubation was 3.0 mg/l?

9. Hydrogen Sulfide (H_2S)

I. IN ATMOSPHERE

A. Discussion

The rate of concrete corrosion is often directly related to the rate of H_2S production or amount of H_2S in the atmosphere. This test deals with the time it takes a paper tape or unglazed tile to turn black. It is a qualitative measurement of the H_2S present in the sewer atmosphere. H_2S is recognized by its characteristic odor of rotten eggs.

B. What is Tested?

Sample	Common Range		
Atmosphere in sewers, outlets from force mains, wet pits, pumping stations, and influent areas to treatment plants.	Not black in 24 hours	=	Good, 24+ hr
	Black in less than 1 hour	=	Bad, < 1 hr

C. Apparatus

Lead acetate paper or unglazed tile soaked in lead acetate.

D. Reagents

Saturated lead acetate solution.

E. Procedure

1. Obtain pieces of unglazed tile or use lead acetate paper. Cut tile with hacksaw into ½ inch strips.

2. Soak strips in tile in lead acetate solution.

3. Dry tile in drying oven or air dry.

4. An open manhole or any point where wastewater is exposed to the atmosphere is a good test site. Drive a nail between metal crown

ring of manhole, concrete, or other convenient place. Tie paper or tile with cotton string to nail and then replace it and return in half an hour or less. If tile is not black or substantially colored, return periodically until black. If H_2S is present as indicated by a color change, then measure flow, temperature, pH, and BOD for further evaluation of problem.

II. IN WASTEWATER

A. Discussion

In sewers, when there is no longer any dissolved oxygen, H_2S tests are run to determine the rate of H_2S increase as the wastewater travels to a pumping station or treatment plant. If the wastewater is exposed to the atmosphere, H_2S will be released and a typical rotten egg odor will be detected. Anaerobic bacteria found in wastewater can liberate H_2S from the solids. When the gas leaves the wastewater stream and comes in contact with moisture and oxygen, sulfuric acid is formed which is very corrosive to concrete. Not all odors in wastewater are from H_2S, and there is no correlation between H_2S and other odors. The total H_2S procedure is good up to 18 mg/l, and higher concentrations must be diluted before testing. H_2S production can be controlled by up-sewer aeration which reduces H_2S formation and also stabilizes the wastewater in the collection system.

B. What is Tested?

Sample Wastewater From the Following Locations	Possible Results, mg/l Good	Bad
Sewers	.1	1
Outlets from force mains	.1	1
Wet pits, pumping stations	.1	.5
Influents to treatment plants	Preferably 0	.5

All of the above locations should be sampled, if pertinent, when using up-stream aeration to control H_2S.

C. Apparatus

1. One LaMotte-Pomeroy Sulfide Testing Kit to test:

   a. Total Sulfides

   b. Dissolved Sulfides

   c. Hydrogen Sulfide in solution

   Obtain from LaMotte Chemical Products Company. Order by Code #4630, $27.50, FOB, Chestertown, Maryland 21620.

2. One LaMotte-Pomeroy Accessory Hydrogen Sulfide Kit for testing H_2S in air and gases (not essential). Obtain from LaMotte Chemical Products Company. Order by Code #4632, $22.00, FOB, Chestertown, Maryland 21620.

D. Reagents

The instructions are in the kit.

E. Procedure

The instructions are in the kit.

F. Example

The instructions are in the kit.

G. Calculations

The instructions are in the kit.

QUESTION

9.A Why would you measure the H_2S concentration:

1. In wastewater?
2. In the atmosphere?

10. pH

A. Discussion

The intensity of the alkaline or acid strength of water is expressed by its pH.

Mathematically, pH is the logarithm of the reciprocal of the hydrogen ion concentration, or the negative logarithm of the hydrogen ion concentration.

$$pH = \log \frac{1}{(H^+)} = -\log (H^+)$$

For Example

If a wastewater has a pH of 1, then the hydrogen ion concentration $(H^+) = 10^{-1} = 0.1$.

If pH = 7, then $(H^+) = 10^{-7} = 0.0000001$.

pH Scale

0 increasing acidity -- 7 -- increasing alkalinity 14

1 ← 2 ← 3 ← 4 ← 5 ← 6 8 → 9 → 10 → 11 → 12 → 13

Neutral

6 through 8

In a solution, both hydrogen ions (H^+) and the hydroxyl ions (OH^-) are always present. At a pH of 7, the concentration of both hydrogen and hydroxyl ions equals 10^{-7} moles per liter. When the pH is less than 7, the concentration of hydrogen ions is greater than the hydroxyl ions. The hydroxyl ion concentration is greater than the hydrogen ions in solutions with a pH greater than 7.

The pH test indicates whether a treatment process may continue to function properly at the pH measured. Each process in the plant has its own favorable range of pH which must be checked routinely. Generally a pH value from 6 to 8 is acceptable for best organism activity.

The paper tape colorimetric comparison method is explained in this section. This is not considered a "Standard Method" but will give a rough indication of the pH. Most wastewater contains many dissolved solids and buffers which tend to minimize pH changes.

There are many ranges of pH tapes available. Normally a range of 5 to 8 will cover the inplant control testing.

B. What is Tested?

Wastewater	Common Range
Influent or Raw Wastewater (domestic)	6.8 to 8.0
Raw Sludge (domestic)	5.6 to 7.0
Digester Recirculated Sludge or Supernatant	6.8 to 7.2
Plant Effluent Depending on Type of Treatment	6.0 to 8.0

C. Minimum Apparatus List

1. pH Meter.

or 2. Three rolls of paper tapes (range 5 to 8).

or 3. Colorimetric set (range 6.8 to 8.4)--permanent glass which can be used with chlorine comparator or liquid color tubes that are less stable.

D. Reagents

(to be used with corresponding apparatus listed under Section C)

1. Buffer tablets of various pH values. Distilled water.
2. None.
3. Brom thyml blue (for pH 6.2 to 7.6).
   Phenol red (for 6.4 to 8.0).

E. Procedures

Use the same samples used for the other tests.

METHOD A (pH Meter)

Procedure

1. Due to the differences between the various makes and models of pH meters commercially available, specific instructions cannot be provided for the correct operation of all instruments. In each case, follow the manufacturer's instructions for preparing the electrodes and operating the instrument.

2. Standardize the instrument against a buffer solution with a pH approaching that of the sample.

3. Rinse electrodes thoroughly with distilled water after removal from buffer solution.

4. Place electrodes in sample and measure pH.

5. Remove electrodes from sample, rinse thoroughly with distilled water.

6. Immerse electrode ends in beaker of pH 7 buffer solution.

7. Shut off meter.

Precautions

1. To avoid faulty instrument calibration, prepare fresh buffer solutions as needed, once per week, from commercially available buffer tablets.

2. pH meter, buffer solution, and samples should all be at the same temperature (constant) because temperature variations will give erroneous results.

3. Watch for erratic results arising from electrodes, faulty connections, or fouling of electrodes with oily or precipitated matter.

METHOD B (Paper Tape)

Procedure

1. Measure pH directly in tank or immediately after collecting sample.

2. Tear off tape 1½ to 2" long. Dip half of tape in tank or sample and quickly read results.

3. Remove tape and compare color with colors on package, and record pH on Laboratory Work Sheet in proper column from which the sample came. For example, if the sample came from the plant influent and the color of the portion of the tape wetted by the sample matches a color on the package indicating a pH of 7.2, then record 7.2 on Laboratory Work Sheet in the influent column on the pH row. (See Fig. 14.2 second page of work sheet).

This procedure applies to liquids that have solids which separate (settle or float) easily.

METHOD B (Paper Tape-High Solids Conc. in Sample)

Procedure

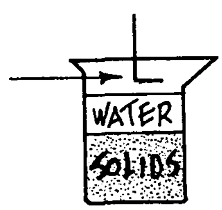
The following procedure is for samples containing higher solid concentrations such as found in the raw sludge, digester recirculated sludge, digester supernatant, and digested sludge samples.

1. Obtain representative samples and identify them.

2. Allow samples to stand until some of the solids have settled and water is visible above the solids. Sufficient water should be above the solids to allow the tape to be dipped in the sample and not discolored by the solids.

3. Bend the tape by making a sharp crease ½" from end. Very carefully allow tape to touch liquid surface.

End of bent tape



4. Remove tape from liquid surface and compare the color with pH color standard on the package. Record on Laboratory Work Sheet.

METHOD C (Colorimetric Comparitor)

Procedure

1. Fill the three tubes or two rectangular bottles provided with the comparitor unit to the indicator line with a portion of the sample being tested.

2. Add the recommended amount of indicator solution.

3. Place the tubes in the comparitor in such a way that the color standards are opposite the tubes not containing the indicator solution.

4. Compare the colors by rotating the comparitor disk or changing the standard color solution vials. Read the pH of the indicator having the color closest to the color of the sample. Record results on Laboratory Work Sheet.

5. Thoroughly wash and dry sample tubes when test is completed and before returning tubes to comparitor unit for storage.

F. Precautions

1. Collect fresh samples and test immediately. The pH of a sample can change rapidly due to loss of CO_2 and biological activity. A fresh effluent sample could have a pH of 6.5 and after standing overnight the pH could be 8.0.

2. Always measure aerator pH directly in the aerator.

3. The pH of a composite sample will not accurately describe pH conditions in your plant. A ten-minute slug of a highly acid waste can upset plant performance for a day or longer, but you may not notice it in a composite sample. Measure pH in place, frequently and quickly, for best description of environment encountered by organisms in treatment processes.

QUESTIONS

10.A How would you measure the pH by the paper tape colorimetric comparison method for:

1. Plant influent?

2. Raw sludge?

10.B What precautions should be exercised when using a pH meter?

11. Settleability of Activated Sludge Solids

I. SETTLEABILITY

A. Discussion

This test is run on mixed liquor or return sludge and plotted on attached graph (Fig. 14.5). All pertinent information is filled in for process control of aerators.

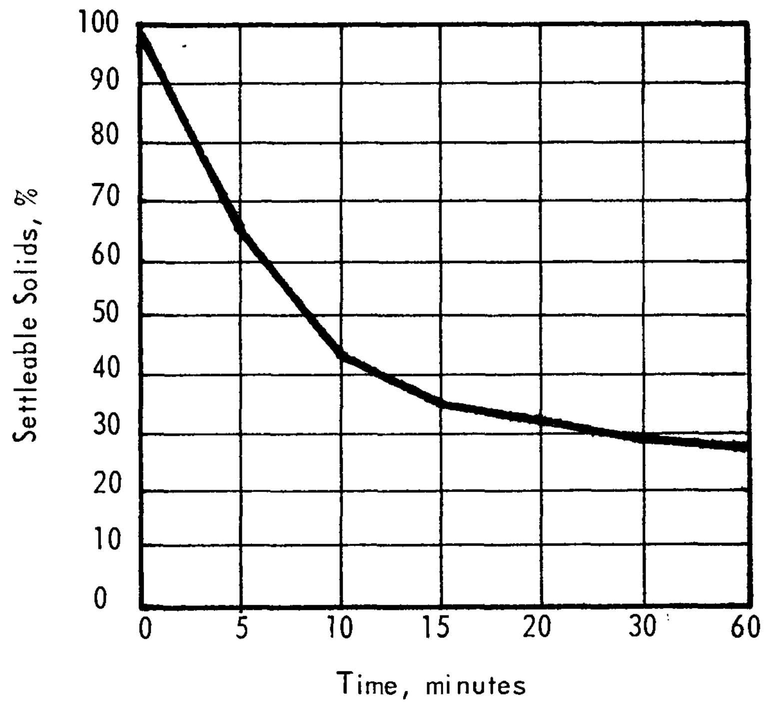


Fig. 14.5 Settleability of activated sludge solids

Settleability is important in determining the ability of the solids to separate from the liquid in the final clarifier. The activated sludge solids should be returned to the aeration tank, and the quality of the effluent is dependent upon the absence of solids flowing over the effluent weir.

The suspended solids should be run on the same sample of mixed liquor that the settleability test is run. This will allow you to calculate the Sludge Volume Index (SVI) or the Sludge Density Index (SDI) which are explained in other sections.

The 2000 ml graduate that is filled with mixed liquor in the settleability test is supposed to indicate what will happen to the mixed liquor in the final clarifier--the rate of sludge settling, turbidity, color, and volume of sludge at the end of 60 minutes.

B. What is Tested?

Sample	Working Range
Mixed Liquor or Return Sludge	Depends on desirable mixed liquor concentration

C. Apparatus

2000 ml graduated cylinder.[10]

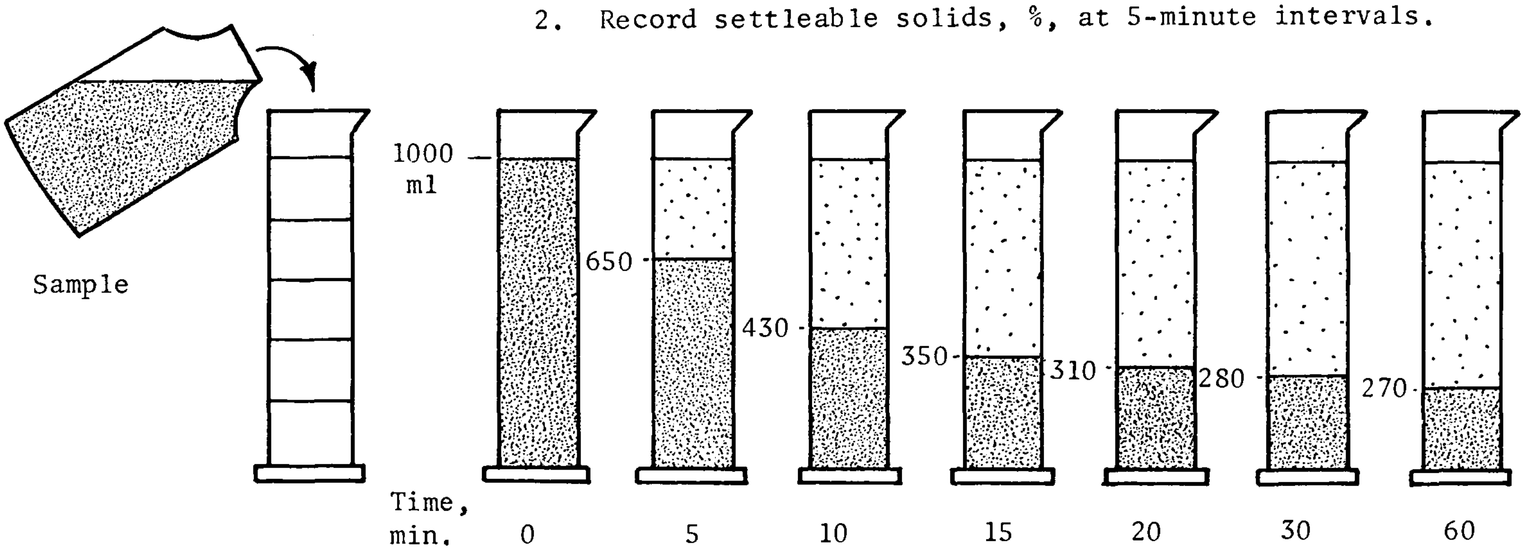
D. Reagents

None.

E. Procedure

1. Mix sample and pour into 2000 ml graduate.

2. Record settleable solids, %, at 5-minute intervals.



[10] Mallory Direct Reading Settleometer (a 2 liter graduated cylinder approximately 5 inches in diameter and 7 inches high). Obtain from Scientific Glass Apparatus Co., Inc., 735 Broad Street, Bloomfield, New Jersey. Catalog No. JS-1035. Price $16.50 each.

1. Collect a sample of mixed liquor or return sludge.
2. Carefully mix sample and pour into 2000 ml graduate. Vigorous shaking or mixing tends to break up floc and produces slower settling or poorer separation.
3. Record settleable solids, %, at regular intervals.

F. Example and Calculation

The percent settling rate can be compared for the various days of the week and with other measurements--suspended solids, SVI, percent sludge solids returned, aeration rate, and plant inflow. A very slow settling mixed liquor usually requires air and solids adjustment to encourage increased stabilization during aeration. A very rapidly settling mixed liquor usually gives poor effluent clarification.

II. SLUDGE VOLUME INDEX (SVI)

A. Discussion

The Sludge Volume Index (SVI) is used to indicate the condition of sludge (aeration solids or suspended solids) for settleability in a secondary or final clarifier. The SVI is the volume in ml occupied by one gram of mixed liquor suspended solids after 30 minutes of settling. It is a useful test to indicate changes in sludge characteristics. The proper SVI range for your plant is determined at the time your final effluent is in the best condition regarding solids and BOD removals and clarity.

B. What is Tested?

Sample	Preferable Range, SVI
Aerator Solids or Suspended Solids	100 - 250

C. Apparatus

See 11. Settleability of Activated Sludge Solids, Part I, Settleability, and 16. Suspended Solids.

D. Reagents

None.

E. Procedure

See Section 11, I, on Settleability, and 16, Suspended Solids.

F. Example

30-minute settleable solids test = 360 ml or 18%.

Mixed liquor suspended solids = 1500 mg/l.

G. Calculations

$$\text{Sludge Volume Index, SVI} = \frac{\text{\% Settleable Solids x 10,000}}{\text{Mixed Liquor Suspended Solids, mg/l}}$$

$$= \frac{18 \times 10{,}0\cancel{0}\cancel{0}}{15\cancel{0}\cancel{0}}$$

$$= \frac{1800}{15}$$

$$= 120$$

$$\begin{array}{r} 120 \\ 15\,\overline{)\,1800} \\ \underline{15} \\ 30 \\ \underline{30} \\ 0 \end{array}$$

III. SLUDGE DENSITY INDEX (SDI)

A. Discussion

The Sludge Density Index (SDI) is used in a way similar to the SVI to indicate the settleability of a sludge in a secondary clarifier or effluent. The calculation of the SDI requires the same information as the SVI test.

$$\text{SDI} = \frac{\text{mg/l of suspended solids in mixed liquor}}{\text{ml/l of settled mixed liquor solids x 10}}$$

or

$$\text{SDI} = 100/\text{SVI}$$

B. What is Tested?

Sample	Preferable Range, SDI
Aerator Solids or Suspended Solids	0.4 - 1.0

C. through G.

These items are not included because of their similarity to the SVI test.

QUESTIONS

11.A Why should you run settleability tests on mixed liquor?

11.B What is the Sludge Volume Index (SVI)?

11.C Why is the SVI test run?

11.D What is the relationship between the Sludge Density Index (SDI) and SVI?

END OF LESSON 5 OF 8 LESSONS

on

Laboratory Procedures and Chemistry

Work the next portion of the discussion and review questions before continuing with Lesson 6.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 5 of 8 Lessons)

Chapter 14. Laboratory Procedures and Chemistry

Name ______________________________ Date ____________

Write the answers to these questions in your notebook. The problem numbering continues from Lesson 4.

17. Hydrogen sulfide is measured because it causes ____________

    ____.

18. What factors promote H_2S production in sewers?

19. The pH scale runs from _____ to _____, with 7 being neutral.

20. Calculate the SVI if the mixed liquor suspended solids are 2000 mg/l and the 30-minute settleable solids test is 500 ml or 25%.

21. Calculate the SDI if the SVI is 125.

12. Settleable Solids

A. Discussion

The settleable solids test is the volume of settleable solids in one liter of sample that will settle to the bottom of an Imhoff cone during a specific time period. The test is an indication of the volume of solids removed by sedimentation in sedimentation tanks, clarifiers, or ponds. The results are read directly in milliliters from the Imhoff cone.

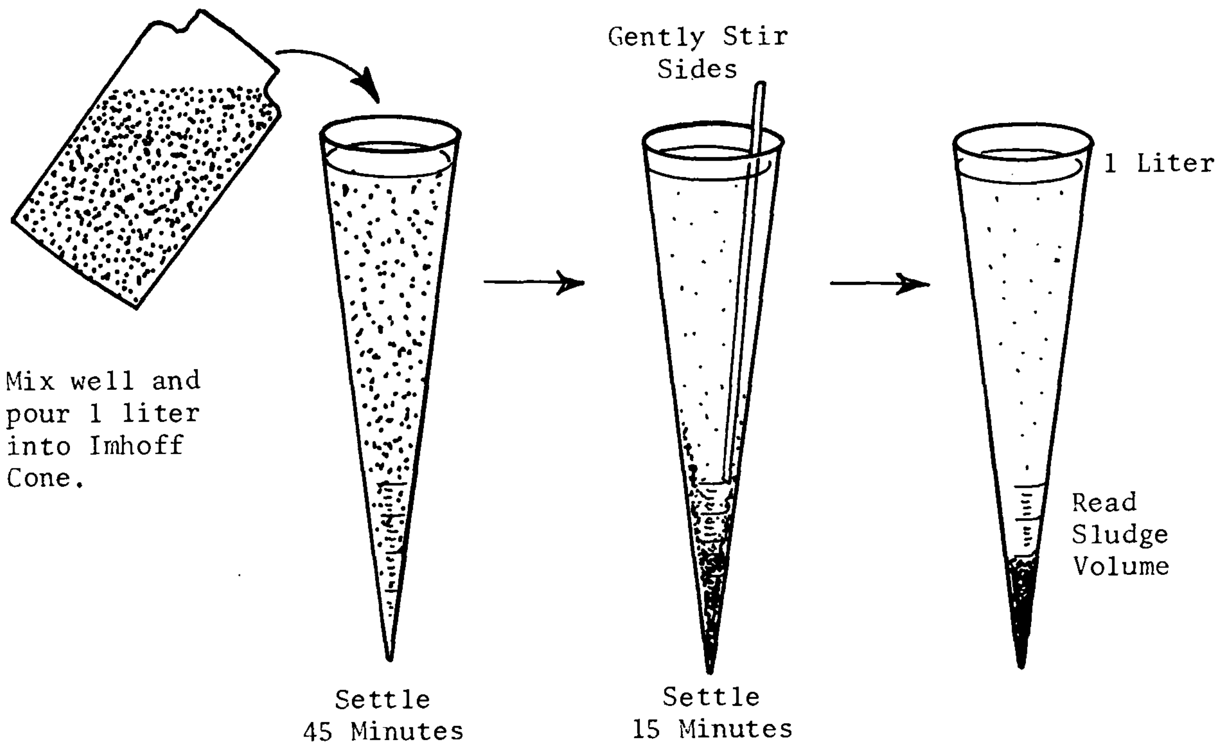
B. What is Tested?

Sample	Common Ranges Found
Influent	12 ml/l medium wastewater 20 ml/l strong wastewater 8 ml/l weak wastewater
Primary Effluent	0.1 ml/l - 3 ml/l
Secondary Effluent	Trace --0.5 ml/l Over .5 ml/l poor

C. Apparatus

1. Imhoff Cones.
2. Rack for holding Imhoff Cones.
3. Glass stirring rod, or wire.

D. Outline of Procedure



PROCEDURE

1. Thoroughly mix the wastewater sample by shaking and immediately fill an Imhoff cone to the liter mark.

2. Record the time of day that the cone was filled. T = ________.

3. Allow the waste sample to settle for 45 minutes.

4. Gently spin the cone to facilitate settling of material adhering to the side of the cone.

5. After one hour, record the number of milliliters of settleable solids in the Imhoff cone. Make allowance for voids among the settled material.

6. Record the settleable solids as ml/l or milliliters per liter.

Settleable Solids, Influent = _______ ml/l

Settleable Solids, Effluent = _______ ml/l

Settleable Solids, Removal = _______ ml/l

E. Example

Samples were collected from the influent and effluent of a primary clarifier. After one hour, the following results were recorded:

	Settleable Solids, ml/l
Influent	12.0
Effluent	0.2

F. Calculations

1. Calculate the efficiency or percent removal of the above primary clarifier in removing settleable solids.

$$\text{\% Removal of Set Sol} = \frac{(\text{Infl. Set Sol, ml/l} - \text{Effl. Set Sol, ml/l})}{\text{Influent Set Sol, ml/l}} \times 100\%$$

$$= \frac{12 \text{ ml/l} - 0.2 \text{ ml/l}}{12 \text{ ml/l}} \times 100\% \qquad \begin{array}{r} 12.0 \\ \underline{-0.2} \\ 11.8 \end{array}$$

$$= \frac{11.8}{12} \times 100\% \qquad \begin{array}{r} .983 \\ 12 \overline{)\,11.8} \\ \underline{10\ 8} \\ 1\ 00 \\ \underline{96} \\ 40 \end{array}$$

$$= 98\%$$

2. Estimate the gallons per day of sludge pumped to a digester from the above primary clarifier if the flow is 1 MGD (1 million gallons per day). In your plant, the Imhoff cone may not measure or indicate the exact performance of your clarifier

or sedimentation tank, but with some experience you should be able to relate or compare your lab tests with actual performance.

Sludge Removed by Clarifier, ml/l

= Influent Set Sol, ml/l - Effluent Set Sol, ml/l

= 12 ml/l - 0.2 ml/l

= 11.8 ml/l

To estimate the gpd (gallons per day) of sludge pumped to a digester, use the following formula:

Sludge to Digester, gpd

= Total Set Sol Removed, ml/l x 1000 x Flow, MGD

$$= 11.8 \frac{\text{ml}}{\text{M mg}} \times \frac{1000 \text{ mg}}{\text{ml}} \times \frac{1 \text{ M gal}}{\text{day}}$$

= 11,800 gpd

This value may be reduced by 30 to 75% due to compaction of the sludge in the clarifier.

If you figure sludge removed as a percentage (1.18%), the sludge pumped to the digester would be calculated as follows:

$$\frac{1.18\%}{100\%} = \frac{\text{Sludge to Digester, gpd}}{\text{Flow of 1,000,000 gpd}}$$

$$\text{Sludge to Digester, gpd} = \frac{1.18\% \times 1{,}000{,}000 \text{ gpd}}{100\%}$$

$$= 11{,}800 \text{ gpd}$$

G. Clinical Centrifuge

Settleable solids also may be measured by a small clinical centrifuge. A mixed sample is placed in 15 ml graduate API tubes and spun for 15 minutes. The solid deposition in the tip of the tube is related to plant performance for plant control. A centrifuge also is used in Section 16, Suspended Solids, II, Centrifuge.

QUESTION

12.A Estimate the volume of solids pumped to a digester in gallons per day (gpd) if the flow is 1 MGD, the influent settleable solids is 10 ml/l, and the effluent settleable solids is 0.4 ml/l for a primary clarifier.

13. Sludge Age

A. Discussion

Sludge age is a control guide that is widely used and is a rough indicator of the length of time a pound of solids is maintained under aeration in the system. The basis for calculating the sludge age is weight of suspended solids in the mixed liquor in the aeration tank divided by weight of suspended solids added per day to the aerator.

$$\text{Sludge Age, days} = \frac{\text{Suspended Solids in Mixed Liquor, mg/l} \times \text{Aerator Volume in MG} \times 8.34 \text{ lbs/gal}}{\text{SS in Primary Effluent, mg/l}^{*} \times \text{Daily Flow, MGD} \times 8.34 \text{ lbs/gal}}$$

Any significant additional loading placed on the aerator by the digester supernatant liquor must be added to the above loadings by considering the additional flow (MGD) and concentration (mg/l). The selection of the method of determining sludge age is discussed in Chapter 7, Activated Sludge.

B. What is Tested?

Sample	Common Range, mg/l
Suspended solids in aerator and BOD or suspended solids in primary effluent	Depends on process
Sludge age	Conventional process, 2.5 - 6 days

---

* NOTE: Sludge age is calculated by three different methods:

1. Suspended solids in primary effluent, mg/l
2. Suspended solids removed from primary effluent, mg/l, or primary effluent, suspended solids, mg/l - final effluent, suspended solids, mg/l
3. BOD or COD in primary effluent, mg/l

C. Apparatus

See 16, Suspended Solids Test.

D. Reagents

None.

E. Procedure

See 16, Suspended Solids Test.

F. Example

Suspended Solids in Mixed Liquor	=	1500 mg/l
Aeration Tank Volume	=	0.50 MG
Suspended Solids in Primary Effl.	=	100 mg/l
Daily Flow	=	2.0 MGD

G. Calculations

$$\text{Sludge Age, days} = \frac{\text{Susp. Solids in Mixed Liquor, mg/l} \times \text{Aerator Vol., MG} \times 8.34\ \text{lbs/gal}}{\text{Susp. Solids in Primary Effl., mg/l} \times \text{Flow, MGD} \times 8.34\ \text{lbs/gal}}$$

$$= \frac{\text{Mixed Liquor Susp. Solids, lbs}}{\text{Primary Effluent SS, lbs/day}}$$

$$= \frac{1500\ \text{mg/l} \times 0.50\ \text{MG} \times 8.34\ \text{lbs/gal}}{100\ \text{mg/l} \times 2.0\ \text{MGD} \times 8.34\ \text{lbs/gal}}$$

$$= \frac{1500 \times 0.50}{100 \times 2.0}$$

$$= \frac{7.5}{2.0}$$

$$= 3.75\ \text{days}$$

QUESTION

13.A Determine the sludge age in an activated sludge process if the volume of the aeration tank is 200,000 gallons and the suspended solids in the mixed liquor equals 2000 mg/l. The primary effluent SS is 115 mg/l, and the average daily flow is 1.8 MGD.

14. Sludge (Digested) Dewatering Characteristics

A. Discussion

The dewatering characteristics of digested sludge are very important. The better the dewatering characteristics or drainability of the sludge, the quicker it will dry and the less area will be required for sludge drying beds.

B. What is Tested?

Sample	PREFERRED RANGE Method A	Method B
Digested Sludge	Depends on appearance	100-200 ml

C. Apparatus

METHOD A

1000 ml graduated cylinder.

METHOD B

1. Imhoff cone with tip removed.
2. Sand from drying bed.
3. 500 ml beaker.

D. Reagents

None.

E. Procedure

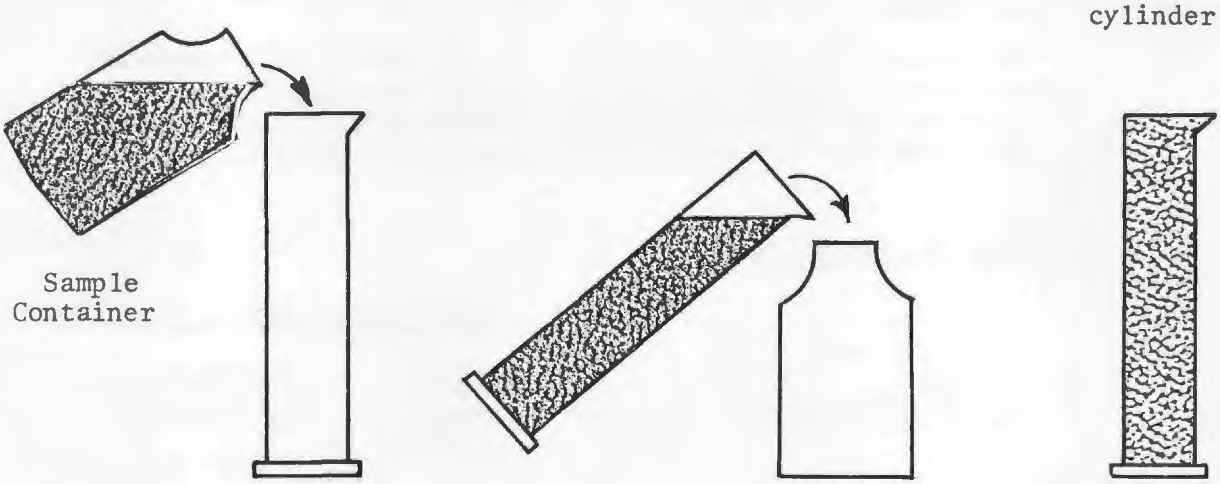
Two methods are presented in this section. Method A relies on a visual observation and is quick and simple. The only problem is that operators on different shifts might record the same sludge draining characteristics differently. Method B requires 24 hours, but the results are recorded by measuring the volume of liquid that passed through the sand. Method B would be indicative of what would happen if you had sand drying beds.

METHOD A

1. Add digested sludge to 1000 ml graduate.

2. Pour sample from graduate back into container.

3. Watch solids adhere to cylinder walls.



1. Add sample of digested sludge to 1000 ml graduate.

2. Pour sample back into sample container. Set graduated cylinder down.

3. Watch graduate. If solids adhere to cylinder wall and water leaves solids in form of rivulets, this is a <u>good</u> dewatering sludge on a sand drying bed (Fig. 14.6).

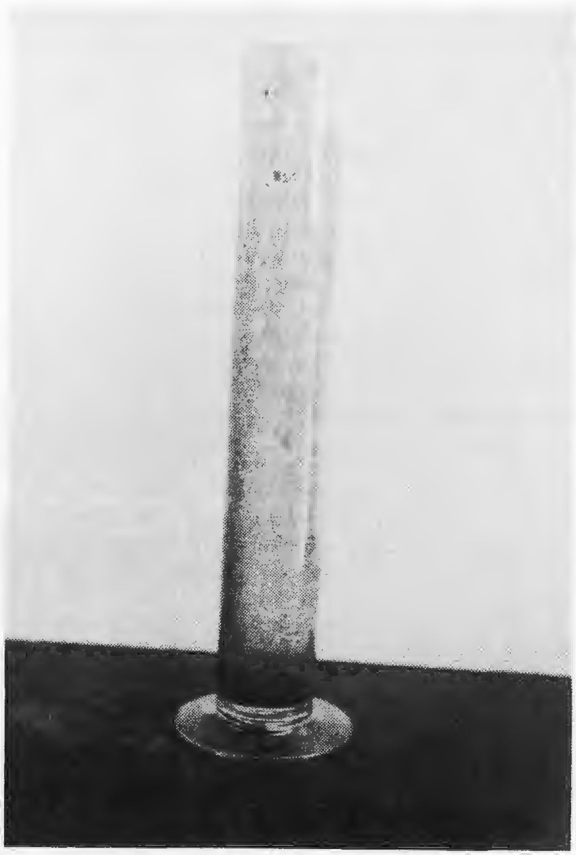
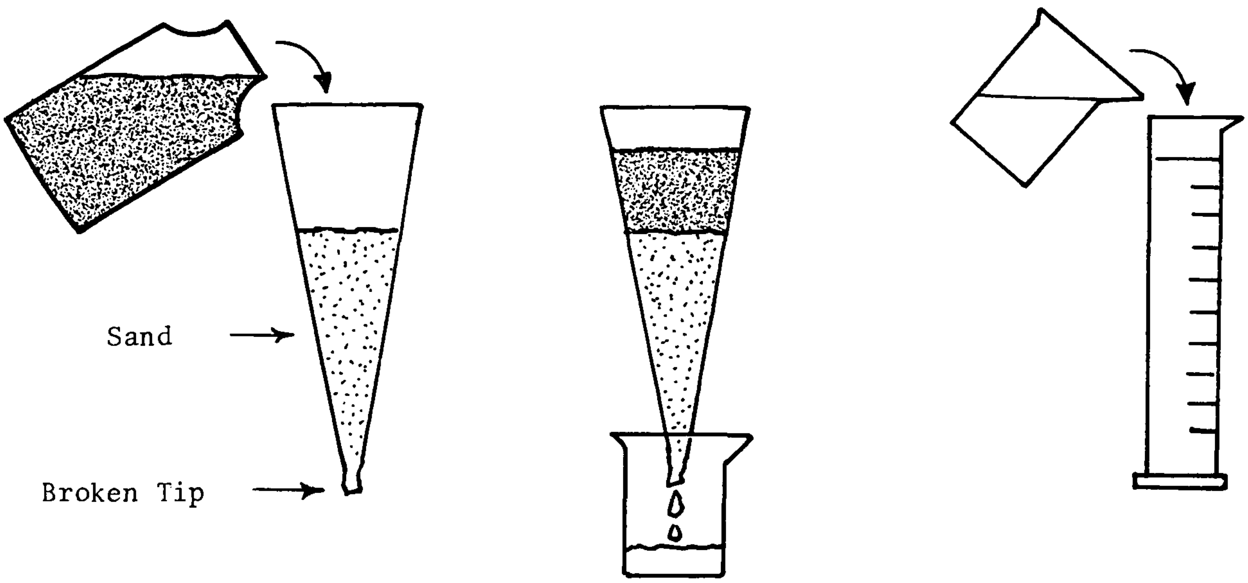


Fig. 14.6

Sludge on graduated cylinder walls for sludge dewatering test

METHOD B

1. Pour digested sludge on top of sand in Imhoff cone.
2. Place beaker under tip and wait 24 hours.
3. Measure liquid that has passed through the sand.



1. Broken glass Imhoff cone that has tip removed and a glass wool plug in the end to hold the sand in the cone.

2. Fill halfway with sand from sand drying bed.

3. Fill remainder to 1 liter with digested sludge.

4. Place 500 ml beaker under cone tip and wait 24 hours.

5. Record liquid that has passed through sand in ml. If less than 100 ml has passed through sand, you have poor sludge drainability.

QUESTION

14.A What are the differences in the use of (1) a graduated cylinder and (2) an Imhoff cone, filled with sand, that has a broken tip, to measure the dewatering characteristics of digested sludge?

15. Supernatant Graduate Evaluation

A. Discussion

The digester supernatant solids test measures the percent of settleable solids being returned to the plant headworks. The settleable solids falling to the bottom of a graduate should not exceed the bottom 5% of the graduate in most secondary plants. When this happens, you are imposing a load on the primary settling tanks that they were not designed to handle. If the solids exceed 5% you should run a suspended solids Gooch crucible test (Section 16) on the sample and calculate the recycle load on the plant that is originating from the digester.

B. What is Tested?

Sample	Common Values
Supernatant	% Solids should be <5%

C. Apparatus

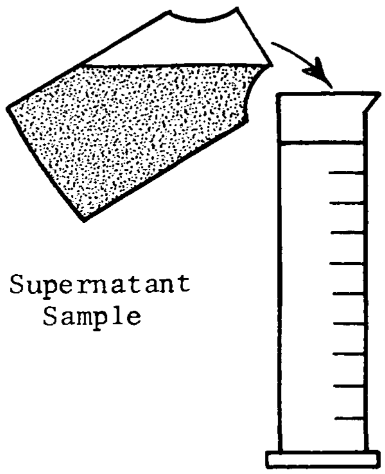
100 ml graduated cylinder.

D. Reagents

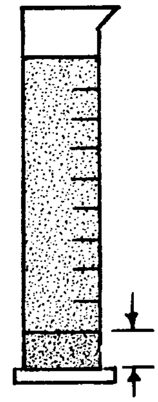
None.

E. Procedure

1. Fill 100 ml graduate with supernatant.



2. After 60 minutes, read ml of solids at bottom.



1. Fill a 100 ml graduated cylinder with supernatant sample.

2. After 60 minutes, read the ml of solids that have settled to the bottom.

3. Calculate supernatant solids, %.

   Supernatant Solids, % = ml of Solids

F. Example

Solids on bottom of cylinder, 10 ml.

G. Calculations

Supernatant Solids, % = ml of Solids

= 10 ml

= 10% Solids (High) by Volume

QUESTION

15.A Why should the results of the supernatant solids test be less than 5% solids?

END OF LESSON 6 OF 8 LESSONS

on

Laboratory Procedures and Chemistry

Work the next portion of discussion and review questions before continuing with Lesson 7.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 6 of 8 Lessons)

Chapter 14. Laboratory Procedures and Chemistry

Name ______________________________ Date ____________

Write the answers to these questions in your notebook. The problem numbering continues from Lesson 5.

22. Calculate the efficiency or percent removal of a primary clarifier when the influent settleable solids are 10 ml/l and the effluent settleable solids are 0.3 ml/l.

23. Why does the actual volume of sludge pumped from a clarifier not agree exactly with calculations based on the settleable solids test?

24. What does sludge age measure?

25. Why should the dewatering characteristics of digested sludge be measured?

26. What happens to the plant when the supernatant from the digester is high in solids?

CHAPTER 14. LABORATORY PROCEDURES AND CHEMISTRY

(Lesson 7 of 8 Lessons)

16. Suspended Solids

I. GOOCH CRUCIBLE

A. Discussion

One of the tests run on wastewater is to determine the amount of material suspended within the sample. The result obtained from the suspended solids test does not mean that all of the suspended solids settle out in the primary clarifier or, for that matter, in the final clarifier. Some of the particles are of such size and weight that they will not settle without additional treatment. Therefore, suspended solids are a combination of settleable solids and those solids that remain in suspension.

B. What is Tested?

Sample	Common Ranges, mg/1
Influent	Weak 150 - 400+ Strong
Primary Effluent	Weak 60 - 150+ Strong
Secondary Effluent	10 Good - 60+ Bad
Activated Sludge Tests	Depending on Type of Process
Mixed Liquor	1000 - < 5,000
Return or Waste Sludge	2000 - < 12,000
Digester Tests:	
Supernatant	3000 - < 10,000

When supernatant suspended solids are greater than 10,000 mg/1, the total solids test is usually performed.

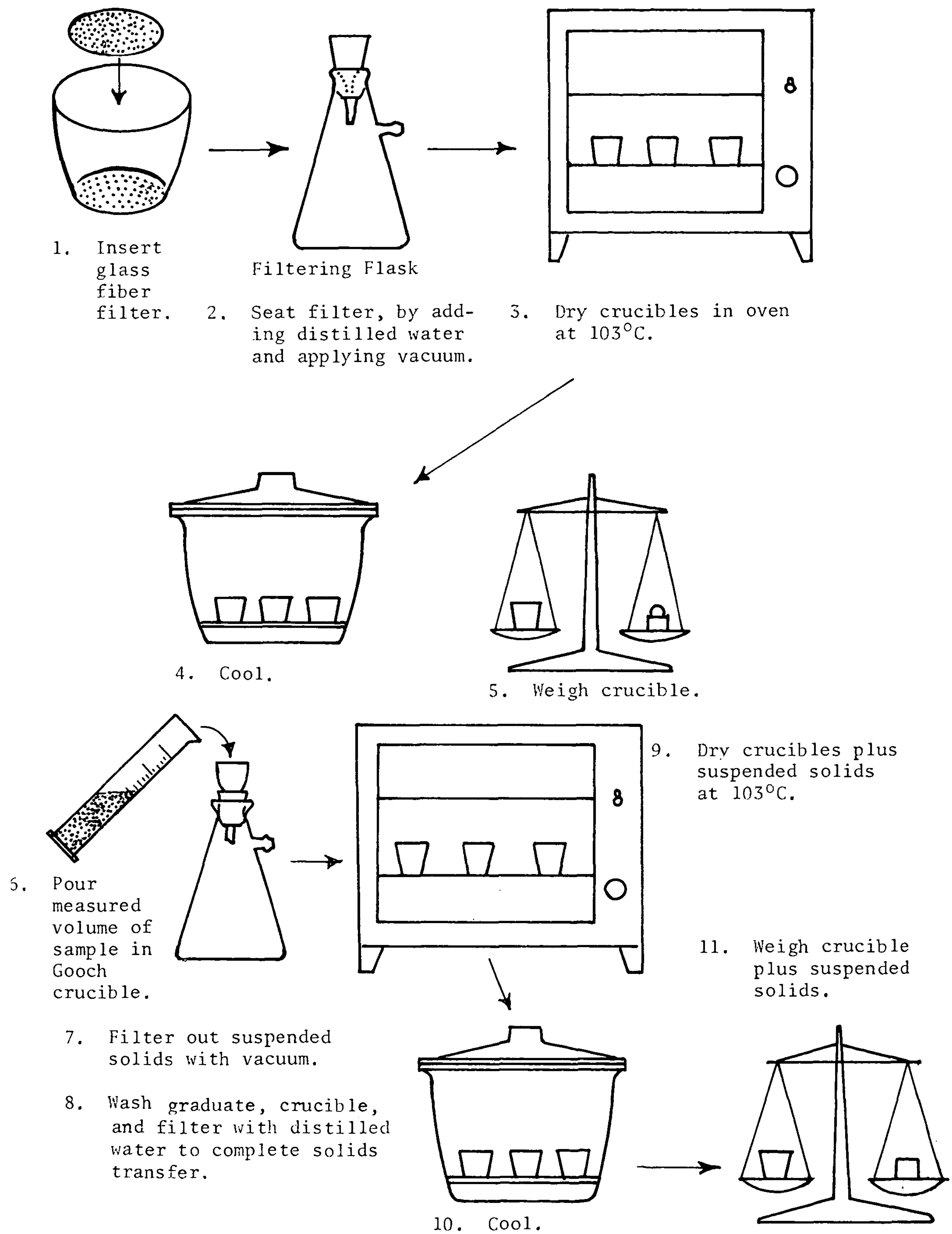
C. Apparatus

1. 2.4 cm glass fiber filter.
2. No. 4 Gooch crucible.
3. Distilled water.
4. Filter flask.
5. Graduated cylinder.
6. Vacuum pump or aspirator.
7. Oven.
8. Analytical balance.

D. Outline of Procedure

The procedure is outlined on Page 14-157.

(Method with Gooch Crucible and Glass Fiber Filter)


1. Insert glass fiber filter.
Filtering Flask
2. Seat filter, by adding distilled water and applying vacuum.
3. Dry crucibles in oven at 103°C.
4. Cool.
5. Weigh crucible.
6. Pour measured volume of sample in Gooch crucible.
7. Filter out suspended solids with vacuum.
8. Wash graduate, crucible, and filter with distilled water to complete solids transfer.
9. Dry crucibles plus suspended solids at 103°C.
10. Cool.
11. Weigh crucible plus suspended solids.

E. Preparation of Gooch Crucible

1. Put a No. 4 Gooch crucible into filtering apparatus.

2. Insert 2.4 cm glass fiber filter and center it.

3. Apply suction.

4. Wash filter with 100 ml of distilled water to seat well.

5. Dry at 103°C for one hour.

6. If volatile suspended solids are to be determined, ignite crucible in muffle furnace for one hour at 550°C.

7. Cool in desiccator.

8. Weigh and record tare weight.

F. How to Perform the Test

1. Depending on the suspended solids content, measure out a 25, 50, or 100 ml portion of a well mixed sample into a graduated cylinder. Use 25 ml if sample filters slowly. Use larger volumes of sample if samples filter easily, such as secondary effluent. Try to limit filtration time to about 15 minutes or less.

2. Wet prepared Gooch crucible with distilled water and apply suction.

3. Filter sample through the Gooch crucible.

4. Wash out dissolved solids on the filter with about 20 ml of distilled water. (Use two 10 ml portions.)

5. Dry crucible at 103°C for one hour or other specified time. Some samples may require up to three hours to dry if the residue is thick.

6. Cool crucible in desiccator for 20-30 minutes.

7. Weigh and record weight.

8. Total Weight = _______ g

   Tare Weight = _______ g

   Solids Weight = _______ g

G. Precautions

1. Check and regulate the oven temperature at 103° - 105°C.

2. Observe crucible and glass fiber for any possible leaks. A leak will cause solids to pass through and give low results. The glass fiber filter may become unseated and leaky when the crucible is placed on the filter flask. The filter should be reseated by adding distilled water to the filter in the crucible and applying vacuum before filtering the sample.

3. Mix the sample thoroughly so that it is completely uniform in suspended solids when measured into a graduated cylinder before sample can settle out. This is especially true of samples heavy in suspended solids, such as raw wastewater and mixed liquor in activated sludge which settle rapidly. The test can be no better than the mix.

4. It is a good practice to prepare a number of extra Gooch crucibles for additional tests if the need arises. If a test result appears faulty or questionable, the test should be repeated. Check filtration rate and clarity of water passing through the filter.

H. Example and Calculations

This section is provided to show you the detailed calculations. After some practice, most operators use the lab work sheet as shown at the end of the calculations.

CALCULATIONS FOR SUSPENDED SOLIDS TEST

(or use lab work sheet at end of calculations)

Example: Assume the following data.

Volume of sample = 50 ml.

	Recorded Weights
Crucible weight	21.6329 g
Crucible plus dry solids	21.6531 g
Crucible plus ash[11]	21.6360 g

[11] Obtained by placing the crucible plus dry solids in a muffle furnace at 550°C for one hour. The crucible plus remaining ash are cooled and weighed.

1. Compute total suspended solids.

21.6531 g	Weight of Crucible plus Dry Solids, grams
- 21.6329 g	- Weight of Crucible, grams
= 0.0202 g	= Weight of Dry Solids, grams

or

= 20.2 mg

1000 milligrams (mg) = 1 gram (g)

or

20.2 mg = 0.0202 g

$$\text{Total Suspended Solids, mg/l} = \frac{\text{Weight of Dry Solids, mg} \times 1000\ \text{ml/l}}{\text{Sample Volume, ml}}$$

$$= 20.2\ \text{mg} \times \frac{1000\ \text{ml/l}}{50\ \text{ml}}$$

$$= 404\ \text{mg/l}$$

```
       404.
50 / 20200.
     200
       200
       200
```

2. Compute volatile or organic suspended solids.

21.6531 g	Weight of Crucible plus Dry Solids, g
- 21.6360 g	- Weight of Crucible plus Ash, g
= 0.0171 g	= Weight of Volatile Solids, g

or

= 17.1 mg

$$\text{Volatile Suspended Solids, mg/l} = \frac{\text{Weight of Volatile Solids, mg} \times 1000\ \text{ml/l}}{\text{Sample Volume, ml}}$$

$$= \frac{17.1\ \text{mg} \times 1000\ \text{ml/l}}{50\ \text{ml}}$$

$$= 342\ \text{mg/l}$$

```
       342
50 / 17100
     150
      210
      200
       100
       100
```

3. Compute the percent volatile solids.

$$\text{Volatile Solids, \%} = \frac{(\text{Weight Volatile, mg})\ 100\%}{\text{Weight Total Dry Solids, mg}}$$

$$= \frac{17.1 \text{ mg}}{20.2 \text{ mg}} \times 100\%$$

$$= 84.7\%$$

$$\begin{array}{r}
.8465 \\
20.2 \overline{)\,17.10} \\
\underline{16\ 16} \\
940 \\
\underline{808} \\
1320 \\
\underline{1212} \\
1080 \\
1010
\end{array}$$

4. Compute fixed or inorganic suspended solids.

21.6360 g	Weight of Crucible plus Ash, g
- 21.6329 g	- Weight of Crucible, g
= 0.0031 g	= Weight of Fixed Solids, g

or

= 3.1 mg

$$\text{Fixed Suspended Solids, mg/l} = \frac{\text{Weight of Fixed Solids, mg} \times 1000 \text{ ml/l}}{\text{Sample Volume, ml}}$$

$$= \frac{3.1 \text{ mg} \times 1000 \text{ ml/l}}{50 \text{ ml}}$$

$$= 62 \text{ mg/l}$$

To check your work:

Fixed Susp. Solids = Total Susp. Solids, mg/l - Volatile Susp. Solids, mg/l

= 404 mg/l - 342 mg/l

= 62 mg/l (Check)

$$\begin{array}{r} 404 \\ \underline{-342} \\ 62 \end{array}$$

5. Compute the percent fixed solids.

$$\text{Fixed Solids, \%} = \frac{(\text{Weight Fixed, mg}) \times 100\%}{\text{Weight Total, mg}}$$

$$= \frac{3.1\text{ mg}}{20.2\text{ mg}} \times 100\%$$

$$= 15.3\%$$

The above calculations are also performed on a Laboratory Work Sheet (Fig. 14.7) to illustrate the use of the work sheet.

CALCULATIONS FOR OVERALL PLANT REMOVAL OF SUSPENDED SOLIDS IN PERCENT

Example: Assume the following data.

Influent suspended solids	202 mg/l
Primary Effluent suspended solids	110 mg/l
Secondary Effluent suspended solids	52 mg/l
Final Effluent suspended solids	12 mg/l

To calculate the percent removal or treatment efficiency for a particular process or the overall plant, use the following formula:

$$\text{Removal, \%} = \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

Compute percentage removed between influent and primary effluent:

$$\text{Removal, \%} = \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

$$= \frac{(202\text{ mg/l} - 110\text{ mg/l})}{202\text{ mg/l}} \times 100\%$$

$$= \frac{92}{202} \times 100\% \qquad \begin{array}{r} 202 \\ -110 \\ \hline 92 \end{array}$$

$$= 45.5\%$$

Compute percentage removed between influent and secondary effluent:

$$\text{Removal, \%} = \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

$$= \frac{(202\ \text{mg/l} - 52\ \text{mg/l})}{202\ \text{mg/l}} \times 100\%$$

$$\begin{array}{r} 202 \\ \underline{-52} \\ 150 \end{array}$$

$$= \frac{150}{202} \times 100\%$$

$$\begin{array}{r} .74 \\ 202 \overline{)\ 150.00} \\ \underline{141.4} \\ 8\ 60 \\ \underline{8\ 08} \\ 52 \end{array}$$

$$= 74\%$$

Compute percentage removed between influent and final effluent (overall plant percentage removed):

$$\text{Removal, \%} = \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

$$= \frac{(202\ \text{mg/l} - 12\ \text{mg/l})}{202\ \text{mg/l}} \times 100\%$$

$$= \frac{190}{202} \times 100\%$$

= 94.1% removal for the plant in suspended solids

CALCULATIONS FOR POUNDS SUSPENDED SOLIDS REMOVED PER DAY

Example: Assume the following data.

Influent suspended solids	200 mg/1
Effluent suspended solids	10 mg/1
Flow in million gallons/day	2 MGD
1 gallon of water weighs	8.34 lbs

Compute pounds suspended solids removed:

The general formula for computing pounds removed is

$$\text{Material Removed, lbs/day} = (\text{Concentration In, mg/l} - \text{Concentration Out, mg/l}) \times \text{Flow, MGD} \times 8.34\ \text{lb/gal}$$

$$= (200\ \text{mg/l} - 10\ \text{mg/l}) \times 2\ \text{MGD} \times 8.34\ \text{lb/gal}$$

$$= 190 \times 2 \times 8.34$$

= 3169 lbs/day of suspended solids removed by plant

$$\begin{array}{r} 8.34 \\ \underline{380} \\ 000 \\ 6672 \\ \underline{2502} \\ 3169.20 \end{array}$$

DERIVATION

This section is not essential to efficient plant operation, but is provided to furnish you with a better understanding of the calculation if you are interested. For practical purposes,

1 mg/l = 1 ppm or 1 part per million

or = 1 mg/million mg, because 1 liter = 1,000,000 mg

Therefore:

$$\frac{\text{lbs}}{\text{day}} = \frac{\text{mg}}{\text{M mg}} \times \frac{\text{M gal}}{\text{day}} \times \frac{\text{lbs}}{\text{gal}}$$

$$= \text{lbs/day}$$

PLANT CLEAN WATER

DATE

SUSPENDED SOLIDS & DISSOLVED SOLIDS

SAMPLE	INFL.						
Crucible	#015						
Ml Sample	50						
Wt Dry & Dish Wt Dish	21.6531 21.6329						
Wt Dry	0.0202						
$mg/l = \frac{\text{Wt Dry, gm} \times 1{,}000{,}000}{\text{Ml Sample}}$	404 mg/l						
Wt Dish & Dry Wt Dish & Ash	21.6531 21.6360						
Wt Volatile	0.0171						
$\% \text{ Vol} = \frac{\text{Wt Vol}}{\text{Wt Dry}} \times 100\%$	84.7%						

BOD

\# Blank

SAMPLE										
DO Sample										
Bottle #										
% Sample										
Blank or adj blank DO after incubation										
Depletion, 5 days										
Dep %										

Nitrate NO_3

Sample

Graph Reading

Sett. Solids

Sample

Direct Ml/l

COD

Sample

Blank Titration

Sample Titration

Depletion

$$mg/l = \frac{\text{Dep} \times N \text{ FAS} \times 8000}{\text{Ml Sample}}$$

Fig. 14.7 Calculation of solids content on Laboratory Work Sheet

TOTAL SOLIDS

AMPLE						
Dish No.						
Wt Dish & Wet Wt Dish						
Wt Wet						
Wt Dish + Dry Wt Dish						
Wt Dry						
% Solids = $\frac{\text{Wt Dry x 100\%}}{\text{Wt Wet}}$						
Wt Dish + Dry Wt Dish + Ash						
Wt Volatile						
% Volatile = $\frac{\text{Wt Vol x 100\%}}{\text{Wt Dry}}$						
pH						
Vol. Acid						
Alkalinity as $CaCO_3$						

Grease (Soxlet) ________

Sample ________

Ml Sample ________

Wt Flask + Grease
Wt Flask ________

Wt Grease ________

mg/1 = $\frac{\text{Wt Grease, mg x 1000}}{\text{Ml Sample}}$ ________

H_2S (Gas) (Starch-Iodine)

Blank ________ Ml

Sample ________ Ml

Diff ________ Ml

Diff x .68 ________ mg/1

mg/1 x 43.6 ________ grain/100 cu ft

Fig. 14.7 Calculation of solids content on Laboratory Work Sheet (continued)

QUESTIONS

16.A Why does some of the suspended material in wastewater fail to be removed by settling or flotation within one hour?

16.B Given the following data:

100 ml of sample	
Crucible weight	19.3241 g
Crucible plus dry solids	19.3902 g
Crucible plus ash	19.3469 g

Compute:

a. Total suspended solids
b. Volatile suspended solids
c. Percent volatile
d. Fixed suspended solids
e. Percent fixed

16.C Compute the percent removal of suspended solids by the primary clarifier, secondary process (removal between primary effluent and secondary effluent), and overall plant:

Influent suspended solids	=	221 mg/1
Primary effluent SS	=	159 mg/1
Final effluent SS	=	33 mg/1

16.D If the data in problem 16.C is from a 1.5 MGD plant, calculate the pounds of suspended solids removed:

a. By the primary unit
b. By the secondary unit
c. By the overall plant

16. Suspended Solids

II. CENTRIFUGE

A. Discussion

This procedure is frequently used in plants as a quick and easy method to estimate the suspended solids concentration of the mixed liquor in the aeration tank instead of the regular suspended solids test. Many operators control the solids in their aerator on the basis of centrifuge readings. Others prefer to control solids using Fig. 14.8. In either case, the operator should periodically compare centrifuge readings with values obtained from suspended solids tests. If the solids are in a good settling condition, a 1% centrifuge solids reading could have a suspended solids concentration of 1000 mg/l. However, if the sludge is feathery, a 1% centrifuge solids reading could have a suspended solids concentration of 600 mg/l.

The centrifuge reading versus mg/l suspended solids chart (Fig 14.8) must be developed for each plant by comparing centrifuge readings with suspended solids determined by the regular Gooch crucible method. The points are plotted and a line of best fit is drawn as shown in Fig. 14.8. This line must be periodically checked by comparing centrifuge readings with regular suspended solids tests because of the large number of variables influencing the relationship, such as characteristics of influent waste, mixing in aerator, and organisms in aerator. If you don't have a centrifuge or if your solids content is over 1500 mg/l, determine suspended solids by the regular method.

B. What is Tested?

Sample	Common Range
Suspended Solids in Mechanical Aeration Tanks	800 - 1200 mg/l
Suspended Solids in Diffused Aeration Tanks	1000 - 3000 mg/l

C. Apparatus

1. Centrifuge.

2. Graduated centrifuge tubes, 15 ml.

D. Reagents

None.

E. Procedure

1. Collect sample in regular sampling can.

2. Mix sample well and fill each centrifuge tube to the 15 ml line with sample.

3. Place filled sample tubes in centrifuge holders.

4. Crank centrifuge at fast speed as you count slowly to 60. Be sure to count and crank at the same speed for all tests. It is extremely important to perform each step exactly the same every time.

5. Remove one tube and read the amount of suspended solids concentrated in the bottom of the tube. This reading will be 1/10 of ml. Results in other tubes should be compared.

6. Refer to the conversion graph to determine suspended solids in mg/l.

NOTE: The reason for filling tubes to the 15 ml mark is that the graph (Fig. 14.8) is computed for samples of this size.

F. Example

Suspended solids concentration on bottom of centrifuge tube is 0.4 ml.

G. Calculations

From Fig. 14.8, find 0.4 ml on centrifuge reading side and follow line horizontally to line on chart. Drop downward from line on chart to mg/l suspended solids and read result of 900 mg/l.

If the suspended solids concentration is above or below the desired range, then you should make the proper changes in the pumping rate of the waste and return sludge. For details on controlling the solids concentration, refer to Chapter 7, Activated Sludge.

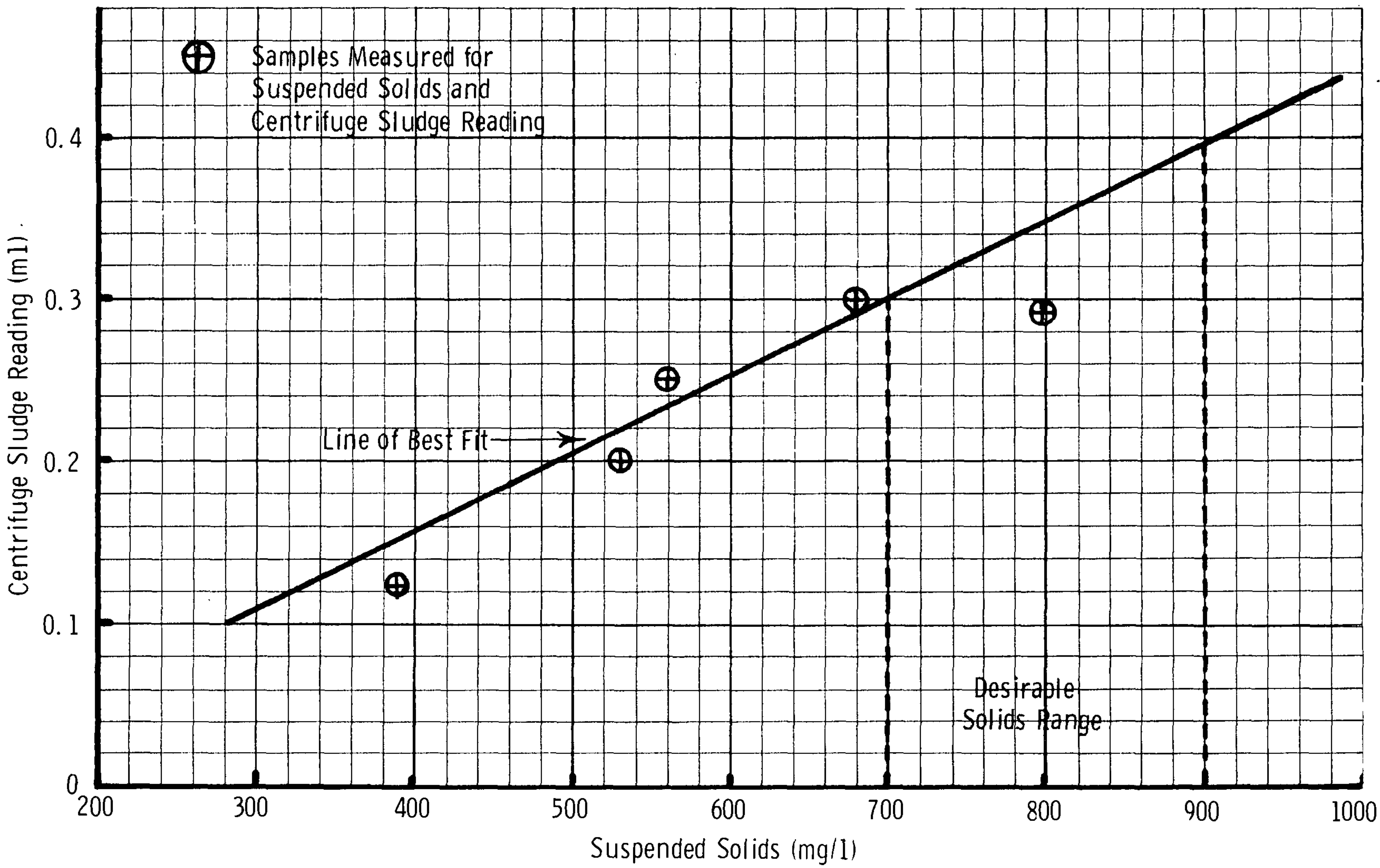


Fig. 14.8 Plant control by centrifuge solids in aeration tank, centrifuge speed, 1750 RPM

H. Development of Fig. 14.8

To develop Fig. 14.8 take a sample from the aeration tank and measure suspended solids and also centrifuge a portion of the sample to obtain the centrifuge sludge reading in ml of sludge at the bottom of the tube. Obtain other samples of different solids concentrations to obtain the points on the graph. Draw a line of best fit through the points. Periodically the points should be checked because the influent characteristics and conditions in the aeration tank change.

QUESTION

16.E What is the advantage of the centrifuge test for determining suspended solids in an aeration tank in comparison with other methods of measuring suspended solids?

17. Temperature

I. WASTEWATER

A. Discussion

This is one of the most frequently taken tests. One of the many uses is to calculate the percent saturation of dissolved oxygen in the DO test. (Refer to DO Test for procedure.)

Changes of plus or minus 4°F from the average or expected value should be investigated and the cause corrected if possible.

For example, an influent temperature drop may indicate large volumes of cold water from infiltration. An increase in temperature may indicate hot water discharged by industry is reaching your plant.

A temperature measurement should be taken where samples are collected for other tests. This test is always immediately performed on a grab sample because it changes so rapidly. Always leave the thermometer in the liquid while reading the temperature. Record temperature on suitable work sheet, including time, location, and sampler's name.

B. What is Tested?

Sample	Common Range
Influent[12]	65°F to 85°F[13]
Effluent[12]	60°F to 95°F or higher from ponds
Receiving Water[12]	60°F to ambient temperature[14]
Digester (Recirculated Sludge before Heat Exchanger--Supernatant)	60°F to 100°F

---

[12] If dissolved oxygen (DO) measurements are performed on any samples, the temperature should be measured and recorded.

[13] Depends on season, location, and temperature of water supply.

[14] Ambient Temperature (AM-bee-ent). Temperature of the surroundings.

C. Apparatus

1. One NBS (National Bureau of Standards) thermometer for calibration of the other thermometers.

2. One Fahrenheit mercury-filled, 1^{o} subdivided thermometer.

3. One Celsius (formerly called Centigrade) mercury-filled, 1^{o} subdivided thermometer.

4. One metal case to fit each thermometer.

There are three types of thermometers and two scales.

Scales

1. Fahrenheit, marked ^{o}F.

2. Celsius, marked ^{o}C (formerly Centigrade).

Thermometers

1. Total immersion. This type of thermometer must be totally immersed when read. This will change most rapidly when removed from the liquid to be recorded.

2. Partial immersion. This type thermometer will have a solid line around the stem below the point where the scale starts.

3. Dial. This type has a dial that can be easily read while the thermometer is still immersed. Dial thermometer readings should be checked (calibrated) against the NBS thermometer. Some dial thermometers can be recalibrated (adjusted) to read the correct temperature of the NBS thermometer.

D. Reagents

None.

E. Procedures

Use a large volume of sample, preferably at least a 2-pound coffee can or equivalent volume. The temperature will have less chance to change in a large volume than in a small container. Collect sample in container and immediately measure and record temperature. Do not touch the bottom or sides of the sample container with the thermometer. To avoid breaking or damaging glass thermometer, store it in a shielded metal case. Check your thermometer accuracy against the NBS certified thermometer by measuring the temperature of a sample with both thermometers simultaneously. Some of the poorer quality thermometers are substantially inaccurate (off as much as $6^\circ F$).

F. Example

To measure influent temperature, obtain sample in large coffee can, immediately immerse thermometer in can, and record temperature when reading becomes constant. For example, $72^\circ F$.

G. Calculations

Normally, we measure and record temperatures using a thermometer with the proper scale. However, we could measure a temperature in $^\circ F$ and convert to $^\circ C$, or we might measure a temperature in $^\circ C$ and convert to $^\circ F$. The following formulas are used to convert temperatures from one scale to the other.

1. Measure in $^\circ F$, want $^\circ C$:

$$^\circ C = 5/9\ (^\circ F - 32^\circ)$$

2. Measure in $^\circ C$, want $^\circ F$:

$$^\circ F = 9/5\ (^\circ C) + 32^\circ$$

3. Example Calculation:

The measured influent temperature was $77^\circ F$.
What was the temperature in $^\circ C$?

$$
\begin{aligned}
{}^{o}C &= 5/9\ ({}^{o}F - 32^{o}) \\
&= 5/9\ (77^{o} - 32^{o}) \\
&= 5/9\ (45^{o}) \\
&= 25^{o}
\end{aligned}
$$

$$
\begin{array}{r} 77 \\ -32 \\ \hline 45 \end{array}
\qquad
9\,\overline{)\,45}^{\,5}
\qquad
\begin{array}{r} 5 \\ \times 5 \\ \hline 25 \end{array}
$$

QUESTIONS

17.A What could a change in influent temperature indicate?

17.B Why should the thermometer remain immersed in the liquid while being read?

17.C Why should thermometers be calibrated against an accurate NBS certified thermometer?

17. <u>Temperature</u>

II. DIGESTER SLUDGE

A. Discussion

The rate of sludge digestion in a digester is a function of the digester temperature. The normal temperature range in a digester is around 95 to 98°F. The temperature of a digester should not be changed by more than 1°F per day because then the helpful organisms in the digester are unable to adjust to rapid temperature changes.

B. Apparatus and Procedure

Refer to I., WASTEWATER.

END OF LESSON 7 OF 8 LESSONS

on

Laboratory Procedures and Chemistry

Work the next portion of the discussion and review questions before continuing with Lesson 8.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 7 of 8 Lessons)

Chapter 14. Laboratory Procedures and Chemistry

Name ____ Date ______________

Write the answers to these questions in your notebook. The problem numbering continues from Lesson 6.

27. Given the following data:

100 ml of sample	
Crucible weight	19.9850 g
Crucible plus dry solids	20.0503 g
Crucible plus ash	20.0068 g

Compute:

1. Total suspended solids
2. Volatile suspended solids
3. Percent volatile

28. Estimate the pounds of solids removed per day by a primary clarifier if the influent suspended solids is 220 mg/1 and the effluent suspended solids is 120 mg/1 when the flow is 1.5 MGD.

29. What is the ambient temperature?

30. Convert a temperature reading of 50°F to °C.

31. Why should the temperature of a digester not be changed by more than 1°F per day?

18. Total and Volatile Solids (Sludge)

A. Discussion

Total solids measure the combined amount of suspended and dissolved materials in the sample.

This test is used for wastewater sludges or where the solids can be expressed in percentages by weight and the weight can be measured on an inexpensive beam balance to the nearest .01 of a gram. The total solids are composed of two components, volatile and fixed solids. Volatile solids are composed of organic compounds which are of either plant or animal origin. Fixed solids are inorganic compounds such as sand, gravel, minerals, or salts.

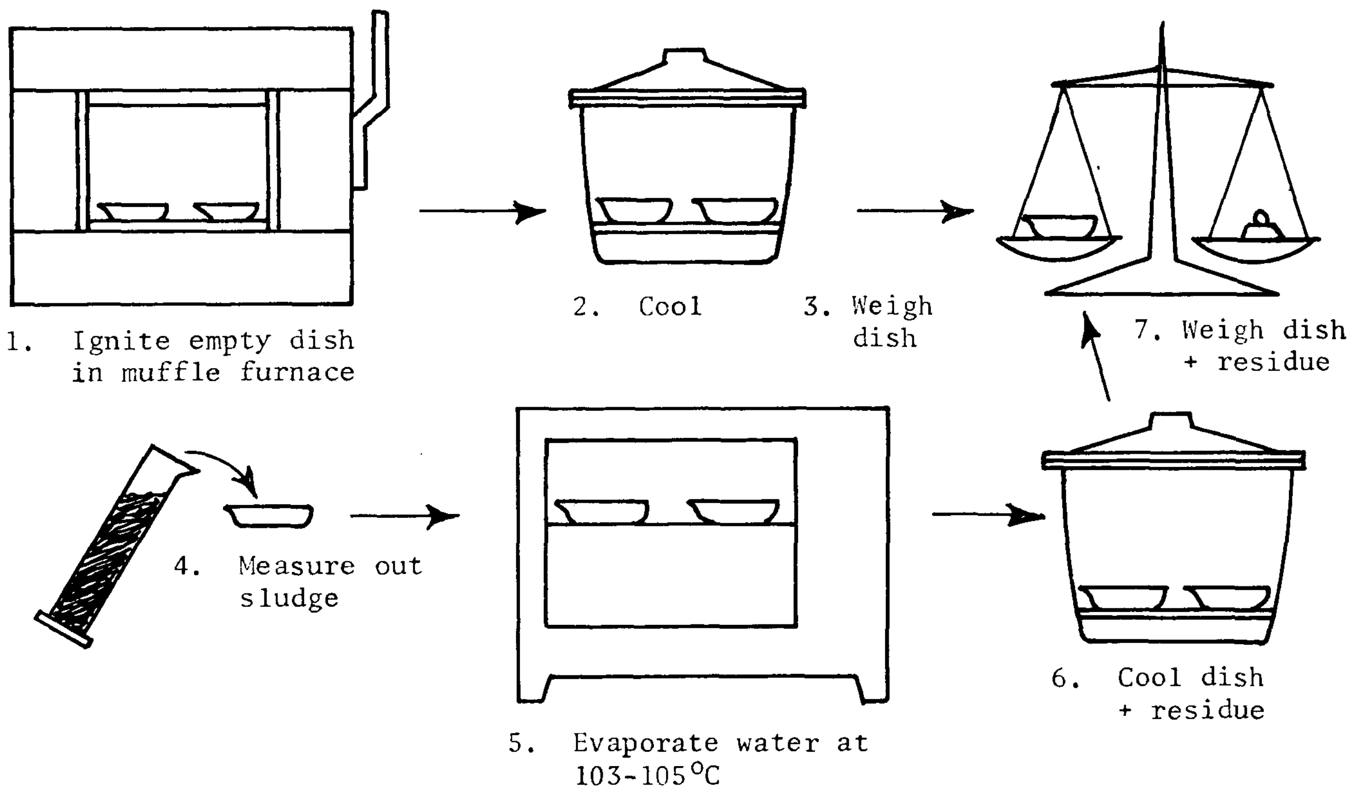
B. What is Tested?

	COMMON RANGE, % BY WEIGHT		
Sample	Total	Volatile	Fixed
Raw Sludge	6% to 9%	75%	25% ± 6%
Raw Sludge plus Waste Activated Sludge	2% to 5%	80%	20% ± 5%
Recirculated Sludge	1.5% to 3%	75%	25% ± 5%
Supernatant:			
Good Quality, has Suspended Solids	< 1%	50%	50% ± 10%
Poor Quality	> 5%		
Digested Sludge to Air Dry	3% too Thin to < 8%	50%	50% ± 10%

C. Apparatus

1. Evaporating dish.
2. Analytical balance.
3. Drying oven, 103° - 105°C.
4. Measuring device--graduated cylinder.
5. Muffle furnace, 550°C.

D. Outline of Procedure



PROCEDURE

1. Dry the dish by ignition in a muffle furnace at 550°C for one hour. Cool dish in desiccator.

2. Tare the evaporating dish to the nearest 10 milligrams, or 0.01 g on the Mettler single pan balance. Record the weight as Tare Weight = ________________ gms.

3. Weigh dish plus 50 to 100 ml of well mixed sludge sample. Record total weight to nearest 0.01 gram as Gross Weight = __________ gms.

4. Evaporate the sludge sample to dryness in the 103°C drying oven.

5. Weigh the dried residue in the evaporating dish to the nearest 10 milligrams, or 0.01 g. Record the weight as Dry Sample and Dish = ___________ gms.

6. Compute the net weight of the residue by subtracting the tare weight of the dish from the dry sample and dish.

E. Precautions

1. Be sure that the sample is thoroughly mixed and is representative of the sludge being pumped. Generally, where sludge pumping is intermittent, sludge is much heavier at the beginning and is less dense toward the end of pumping. Take several equal portions of sludge at regular intervals and mix for a good sample.

2. Take a large enough sample. Measuring a 50 or 100 ml sample which is closely equal to 50 or 100 grams is recommended. Since this material is so heterogeneous (non-uniform), it is difficult to obtain a good representative sample with less volume. Smaller volumes will show greater variations in answers, due to the uneven and lumpy nature of the material.

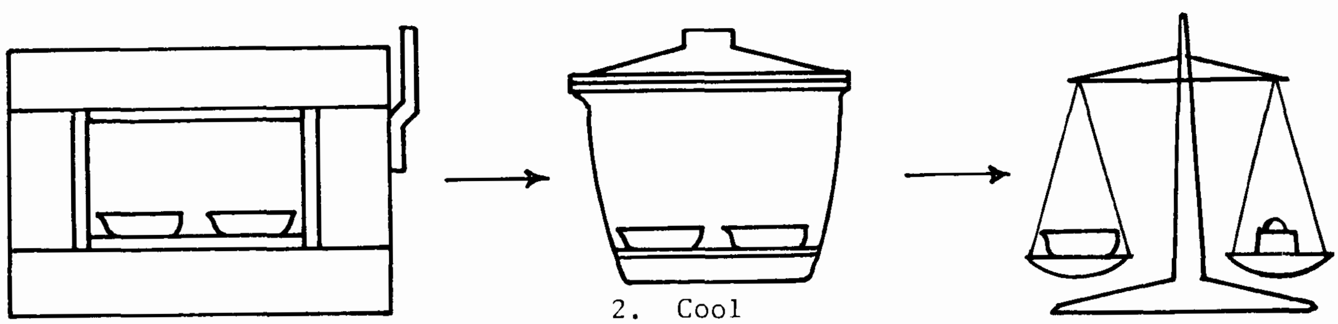
3. Control oven temperature closely at 103° - 105°C. Some solids are lost at any drying temperature. Close control of oven temperatures increase the losses of volatile solids in addition to the evaporated water.

4. Heat dish long enough to insure evaporation of water, usually about 3-4 hours. If heat drying and weighing are repeated, stop when the weight change becomes small per unit of drying time. The oxidation, dehydration, and degradation of the volatile fraction won't completely stabilize until it is carbonized or becomes ash.

5. Since sludge is so non-uniform, weighing on the analytical balance should probably be made only to the nearest 0.01 grams or 10 milligrams.

F. Outline of Procedure for Volatile Solids

(continue from total solids test)



1. Ignite dried solids at 550°C

2. Cool

3. Weigh fixed solids

PROCEDURE

1. Determine the total solids as previously described in Section D.

2. Ignite the dish and residue from total solids test at 550°C for one hour or until a white ash remains.

3. Cool in desiccator for about 30 minutes.

4. Weigh and record weight of Dish Plus Ash = __________ gms.

G. Example

Weight of Dish (Tare)	=	20.31 g
Weight of Dish plus Wet Solids (Gross)	=	70.31 g
Weight of Dish plus Dry Solids	=	22.81 g
Weight of Dish plus Ash	=	20.93 g

H. Calculations

See Laboratory Work Sheet (Fig. 14.9) or calculations shown below.

1. Find weight of sample.

Weight of Dish plus Wet Solids (Gross)	=	70.31 g
Weight of Dish (Tare)	=	20.31 g
Weight of Sample	=	50.00 g

2. Find weight of total solids.

Weight of Dish plus Dry Solids	=	22.81 g
Weight of Dish (Tare)	=	20.31 g
Weight of Total Solids	=	2.50 g

3. Find % solids.

$$\% \text{ Solids} = \frac{(\text{Weight of Solids, g})\ 100\%}{\text{Weight of Sample, g}}$$

$$= \frac{(2.50\text{ g})\ 100\%}{50.00\text{ g}}$$

$$= 5\%$$

4. Find weight of volatile solids.

Weight of Dish plus Dry Solids	=	22.81 g
Weight of Dish plus Ash	=	20.93 g
Weight of Volatile Solids	=	1.88 g

5. Find % volatile solids.

$$\% \text{ Volatile Solids} = \frac{(\text{Weight of Volatile Solids, g})\ 100\%}{\text{Weight of Total Solids, g}}$$

$$= \frac{(1.88\ \text{g})\ 100\%}{2.50\ \text{g}}$$

$$= 76\%$$

QUESTION

18.A What is the origin of the volatile solids found in a digester?

18.B What is the significance of volatile solids in a treatment plant?

19. Turbidity

See Clarity.

PLANT ______________________

DATE ______________________

SUSPENDED SOLIDS & DISSOLVED SOLIDS

SAMPLE							
Crucible							
Ml Sample							
Wt Dry & Dish Wt Dish							
Wt Dry							
$mg/l = \frac{\text{Wt Dry, gm} \times 1{,}000{,}000}{\text{Ml Sample}}$							
Wt Dish & Dry Wt Dish & Ash							
Wt Volatile							
$\% \text{ Vol} = \frac{\text{Wt Vol}}{\text{Wt Dry}} \times 100\%$							

BOD

\# Blank ________

SAMPLE										
DO Sample										
Bottle #										
% Sample										
Blank or adj blank DO after incubation										
Depletion, 5 days										
Dep %										

Nitrate NO_3

Sample ________ ________

Graph Reading ________ ________

Sett. Solids

Sample ________ ________

Direct Ml/l ________ ________

COD

Sample ________ ________ ________

Blank Titration ________ ________ ________

Sample Titration ________ ________ ________

Depletion ________ ________ ________

$mg/l = \frac{\text{Dep} \times N \text{ FAS} \times 8000}{\text{Ml Sample}}$ ________ ________ ________

Fig. 14.9 Calculation of total solids on Laboratory Work Sheet

TOTAL SOLIDS

SAMPLE	RAW					
Dish No.	7					
Wt Dish & Wet Wt Dish	70.31 20.31					
Wt Wet	50.00					
Wt Dish + Dry Wt Dish	22.81 20.31					
Wt Dry	2.50					
% Solids = $\frac{\text{Wt Dry x 100\%}}{\text{Wt Wet}}$	5.0%					
Wt Dish + Dry Wt Dish + Ash	22.81 20.93					
Wt Volatile	1.88					
% Volatile = $\frac{\text{Wt Vol x 100\%}}{\text{Wt Dry}}$	76%					
pH						
Vol. Acid						
Alkalinity as $CaCO_3$						

Grease (Soxlet) ________________

Sample ________________

Ml Sample ________________

Wt Flask + Grease
Wt Flask ________________

Wt Grease ________________

mg/l = $\frac{\text{Wt Grease, mg x 1000}}{\text{Ml Sample}}$ ________________

H_2S (Gas) (Starch-Iodine)

Blank ________ Ml

Sample ________ Ml

Diff ________ Ml

Diff x .68 ________ mg/l

mg/l x 43.6 ________ grain/100 cu ft

Fig. 14.9 Calculation of total solids on Laboratory Work Sheet (continued)

20. Volatile Acids and Total Alkalinity

A. Discussion

Volatile acids are determined on sludge samples from the digesters. Most modern digesters have sampling pipes where you can draw a sample from various levels of the tank. Be sure to allow the sludge in the line to run for a few minutes in order to obtain a representative sample of the digester contents. Samples also may be collected from supernatant draw-off tubes, or thief holes.[15]

The concentrations of volatile acids and alkalinity are the first measurable changes that take place when the process of digestion is becoming upset. The volatile acid/alkalinity relationship can vary from 0.1 to about 0.5 without significant changes in digester performance. When the relationship starts to increase, this is a warning that undesirable changes will occur unless the increase is stopped. If the relationship increases above 0.5, the composition of the gas produced can change very rapidly, followed by changes in the rate of gas production, and finally pH.

In a healthy and properly functioning digester, the processes or biological action taking place inside the digester are in equilibrium. When fresh sludge is pumped into a digester, some of the organisms in the digester convert this material to volatile (organic) acids. In a properly operated digester, other organisms feed on the newly produced volatile acids and eventually convert the acids to methane (CH_4) gas, which is burnable and carbon dioxide (CO_2). If too much raw sludge is pumped to the digester or the digester is not functioning properly, an excess of volatile acids are produced. If excessive amounts of volatile acids are produced, an acid environment unsuitable for some of the organisms in the digester will develop and the digester may cease to function properly unless the alkalinity increases too.

Routine volatile acids and alkalinity determinations during the start-up process for a new digester are a must in bringing the digester to a state of satisfactory digestion.

Routine volatile acids and alkalinity determinations during digestion are important in providing the information which will enable the operator to determine the health of the digester.

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[15] Thief Hole. A digester sampling well.

For digester control purposes, the volatile acid/alkalinity relationship should be determined. When the volatile acid/alkalinity relationship is from less than 0.1/1.0 to 0.5/1.0, the loading and seed retention of the digester are under control. When the relationship starts increasing and becomes greater than 0.5/1.0, the digester is out of control and will become "stuck" unless effective corrective action is taken.

B. What is Tested?

Sample	Desirable Range
Recirculated Sludge	150 - 600 mg/l (expect trouble if alkalinity less than two times volatile acids)

METHOD A

(Silic Acid Method)

C. Apparatus

1. Centrifuge or filtering apparatus.
2. Two 50 ml graduated cylinders.
3. Two medicine droppers.
4. Crucibles, Gooch or fritted glass
5. Filter flask
6. Vacuum source
7. One 50 ml beaker
8. Two 5 ml pipettes
9. Buret

D. Reagents

1. Silic acid, solids, 100-mesh. Remove fines from solid portion of acid by slurrying the acid in distilled water and removing the supernatant after allowing settling for 15 minutes. Repeat the process several times. Dry the washed acid solids in an oven at 103°C and then store in a desiccator.

2. Chloroform-butanol reagent. Mix 300 ml chloroform, 100 ml n-butanol, and 80 ml 0.5 N H_2SO_4 in separatory funnel and allow the water and organic layers to separate. Drain off the lower organic layer through filter paper into a dry bottle.

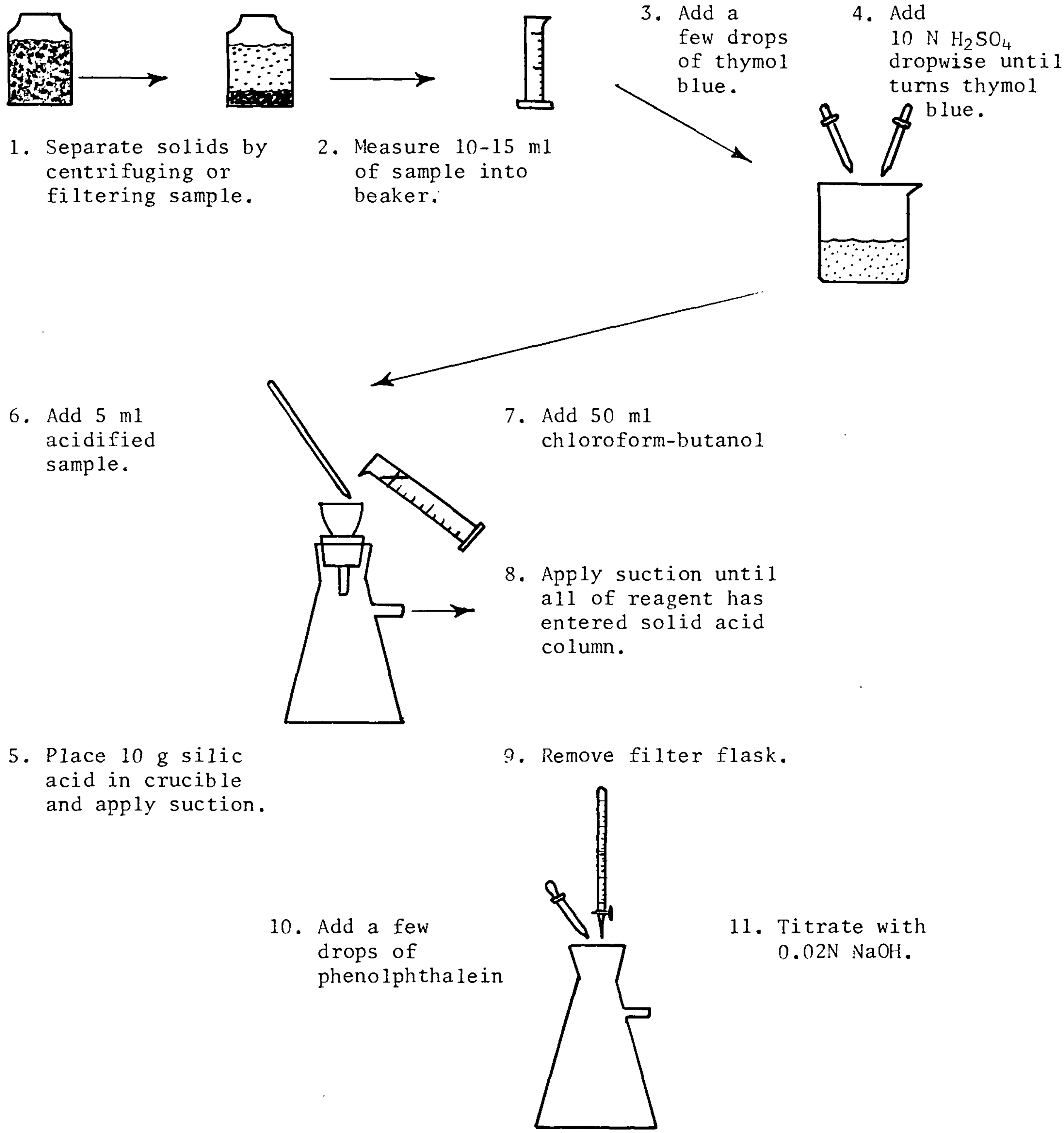
3. Thymol blue indicator solution. Dissolve 80 mg thymol blue in 100 ml absolute methanol.

4. Phenolphthalein indicator solution. Dissolve 80 mg phenolphthalein in 100 ml absolute methanol.

5. Sulfuric acid, 10 N.

6. Standard sodium hydroxide reagent, 0.02 N. Prepare in absolute methanol from conc. NaOH stock solution in water.

E. Outline of Procedure



PROCEDURE

1. Centrifuge or filter enough sludge to obtain a sample of 10 to 15 ml. This same sample and filtrate should be used for both the volatile acids test and the total alkalinity test.

2. Measure volume (10 to 15 ml) of sample and place in a beaker.

   Volume of sample, B = ______ ml.

3. Add a few drops of thymol blue indicator solution.

4. Add 10 N H_2SO_4, dropwise, until red color just turns to thymol blue color.

5. Place 10 grams of silic acid (solid acid) in crucible and apply suction. This will pack the acid material and the packed material is sometimes called a column.

6. With a pipette, distribute 5.0 ml acidified sample (from step 4) as uniformly as possible over the column. Apply suction briefly to draw the acidified sample into the silic acid column. Release the vacuum as soon as the sample enters the column.

7. Quickly add 50 ml chloroform-butanol reagent to the column.

8. Apply suction and stop just before the last of the reagent enters the column.

9. Remove the filter flask from the crucible.

10. Add a few drops of phenolphthalein indicator solution to the liquid in the filter flask.

11. Titrate with 0.02 N NaOH titrant in absolute methanol, taking care to avoid aerating the sample. Nitrogen gas or CO_2 - free air delivered through a small glass tube may be used both to mix the sample and to prevent contact with atmospheric CO_2 during titration (CO_2 - free air may be obtained by passing air through ascarite or equivalent).

    Volume of NaOH used in sample titration, a = _____ ml.

12. Repeat the above procedure using a blank of distilled water.

    Volume of NaOH used in blank titration, b = _____ ml.

F. Precautions

1. The sludge sample must be representative of the digester. The sample line should be allowed to run for a few minutes before the sample is taken. The sample temperature should be as warm as the digester itself.

2. The sample for the volatile acids test should not be taken immediately after charging the digester with raw sludge. Should this be done, the raw sludge may short-circuit to the withdrawal point and result in the withdrawal of raw sludge rather than digested sludge. Therefore, after the raw sludge has been fed into the tank, the tank should be well mixed by recirculation or other means before a sample is taken.

3. If a digester is performing well with low volatile acids and then if one sample should unexpectedly and suddenly give a high value, say over 1000 mg/l of volatile acids, do not become alarmed. The high result may be caused by a poor, nonrepresentative sample of raw sludge instead of digested sludge. Resample and retest. The second test may give a more typical value. When increasing volatile acids and decreasing alkalinity are observed, this is a definite warning of approaching control problems. Corrective action should be taken immediately, such as reducing the feed rate, reseeding from another digester, maintaining optimum temperatures, improving digester mixing, decreasing sludge withdrawal rate, or cleaning the tank of grit and scum.

G. Example

Equivalent Weight of Acetic Acid, A	=	60 mg/ml
Volume of Sample, B	=	10 ml
Normality of NaOH titrant, N	=	0.02 N
Volume of NaOH used in sample titration, a	=	2.3 ml
Volume of NaOH used in blank titration, b	=	0.5 ml

H. Calculation

Volatile Acids, mg/l (as acetic acid)

$$= \frac{A \times 1000\ \text{ml/l} \times N\ (a - b)}{B}$$

$$= \frac{60\ \text{mg/ml} \times 1000\ \text{ml/l} \times 0.02\ (2.3\ \text{ml} - 0.5\ \text{ml})}{10\ \text{ml}}$$

$$= 216\ \text{mg/l}$$

METHOD B

(Nonstandard Titration Method)

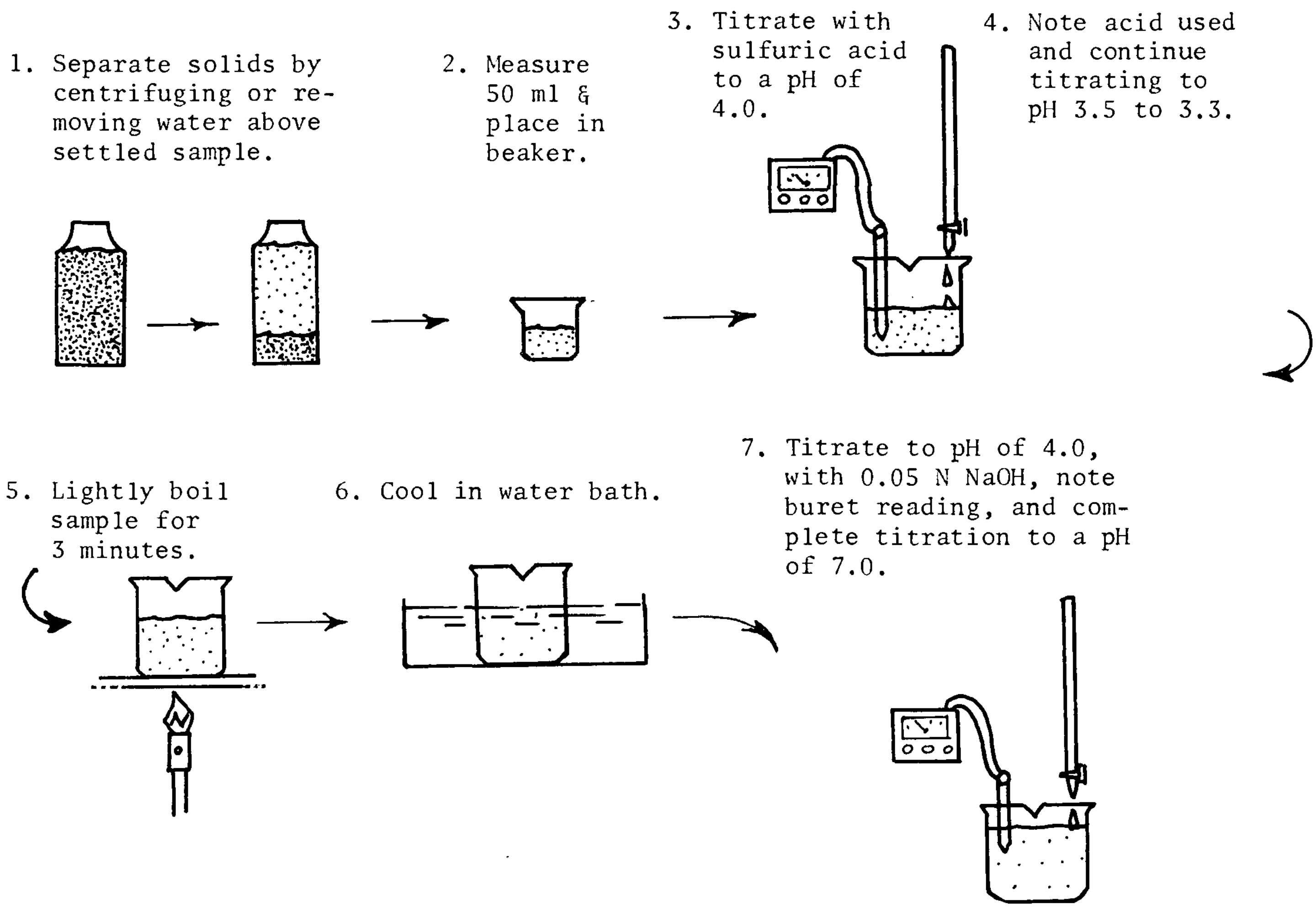
C. Apparatus

1. One pH meter.
2. One adjustable hot plate.
3. Two Burets and stand.
4. One 100 ml beaker.

D. Reagents

1. pH 7.0 buffer solution
2. pH 4.0 buffer solution
3. Standard acid.
4. Standard base.

E. Outline of Procedure



PROCEDURE

1. Buffer the pH meter at 7.0 and check pH before treatment of sample to remove the solids. Filtration is not necessary. Decanting (removing water above settled material) or centrifuging sample is satisfactory. Do not add any coagulant aids.

2. Titrate 50 ml of the sample in a 100 ml beaker to pH 4.0 with the appropriate strength sulfuric acid (depends on alkalinity), note acid used, and continue to pH 3.5 to 3.3. A magnetic mixer is extremely useful for this titration.

3. Carefully buffer pH meter at 4.00 while lightly boiling the sample a minimum of three minutes. Cool in cold water bath to original temperature.

4. Titrate sample with standard 0.050 N sodium hydroxide up to pH 4.00, and note buret reading. Complete the titration at pH 7.0. (If this titration consistently takes more than 10 ml of the standard hydroxide, use 0.100 N NaOH.)

5. Calculate volatile acid alkalinity (alkalinity between pH 4.0 and 7.0).

   $$\text{Volatile Acid Alkalinity} = \frac{\text{ml } 0.050 \text{ N NaOH} \times 2500}{\text{ml Sample}}$$

   For a 50 ml sample the volatile acid alkalinity equals 50 x ml 0.050 N NaOH, or 100 x ml 0.100 N NaOH.

6. Calculate volatile acids.

   Case 1: > 180 mg/l volatile acid alkalinity.

   Volatile Acids = Volatile Acid Alkalinity x 1.50

   Case 2: < 180 mg/l volatile acid alkalinity.

   Volatile Acids = Volatile Acid Alkalinity x 1.00

   Steps 1 and 2 will give the analyst the pH and total alkalinity, two control tests normally run on digesters. The difference between the total and the volatile acid alkalinity is bicarbonate alkalinity. The time required for Steps 3 and 4 is about ten minutes.

   This is an acceptable method for digester control to determine the volatile acid/alkalinity relationship, but not of sufficient accuracy for research work.

For details regarding this test see DeLallo, R., and Albertson, O.E., *Volatile Acids by Direct Titration*, Water Pollution Control Federation, Vol. 33, No. 4, pp 356-365, April 1961. The procedure is reproduced from the article.

F. Example and Calculation

Titration of pH 4.0 to 7.0 of a 50 ml sample required 8 ml of 0.05 N NaOH.

Step 5 - Calculate volatile acid alkalinity (alkalinity between pH 4.0 and 7.0).

$$\text{Volatile Acid Alkalinity, mg/l} = \frac{\text{ml } 0.05 \text{ N NaOH} \times 2500}{\text{ml Sample}}$$

$$= \frac{8 \text{ ml} \times 2500}{50 \text{ ml}}$$

$$= 400 \text{ mg/l}$$

Step 6 - Calculate volatile acids.

Case 1: 400 mg/l > 180 mg/l. Therefore,

$$\text{Volatile Acids, mg/l} = \text{Volatile Acid Alkalinity} \times 1.50$$

$$= 400 \text{ mg/l} \times 1.50$$

$$= 600 \text{ mg/l}$$

QUESTION

20.A What is the volatile acid concentration in a digester if a 50 ml sample required 5 ml of 0.05 N NaOH for a titration from a pH of 4.0 to 7.0?

Total Alkalinity

A. Discussion

Tests for total alkalinity of digesters are normally run on settled supernatant samples. The alkalinity of the recirculated sludge is a measure of the buffer capacity in the digester. When organic matter in a digester is decomposed anaerobically, organic acids are formed which could lower the pH, if buffering materials (buffer capacity) were not present. If the pH drops too low, the organisms in the digester could become inactive or die and the digester becomes upset (no longer capable of decomposing organic matter).

For digester control purposes, the volatile acid/alkalinity relationship should be determined. When the volatile acid/alkalinity relationship is from less than 0.1/1.0 to 0.5/1.0, the loading and seed retention of the digester are under control. When the relationship starts increasing and becomes greater than 0.5/1.0, the digester is out of control and will become stuck unless effective corrective action is taken. The pH will not be out of range as long as the volatile acid/alkalinity relationship is low. This relationship gives a warning before trouble starts.

All samples must be settled so that a liquid free of solids is available for the test. Tests cannot be calculated correctly if solids are in the sample.

B. What is Tested?

Sample	Common Range
Recirculated Sludge	2-10 Times Volatile Acids

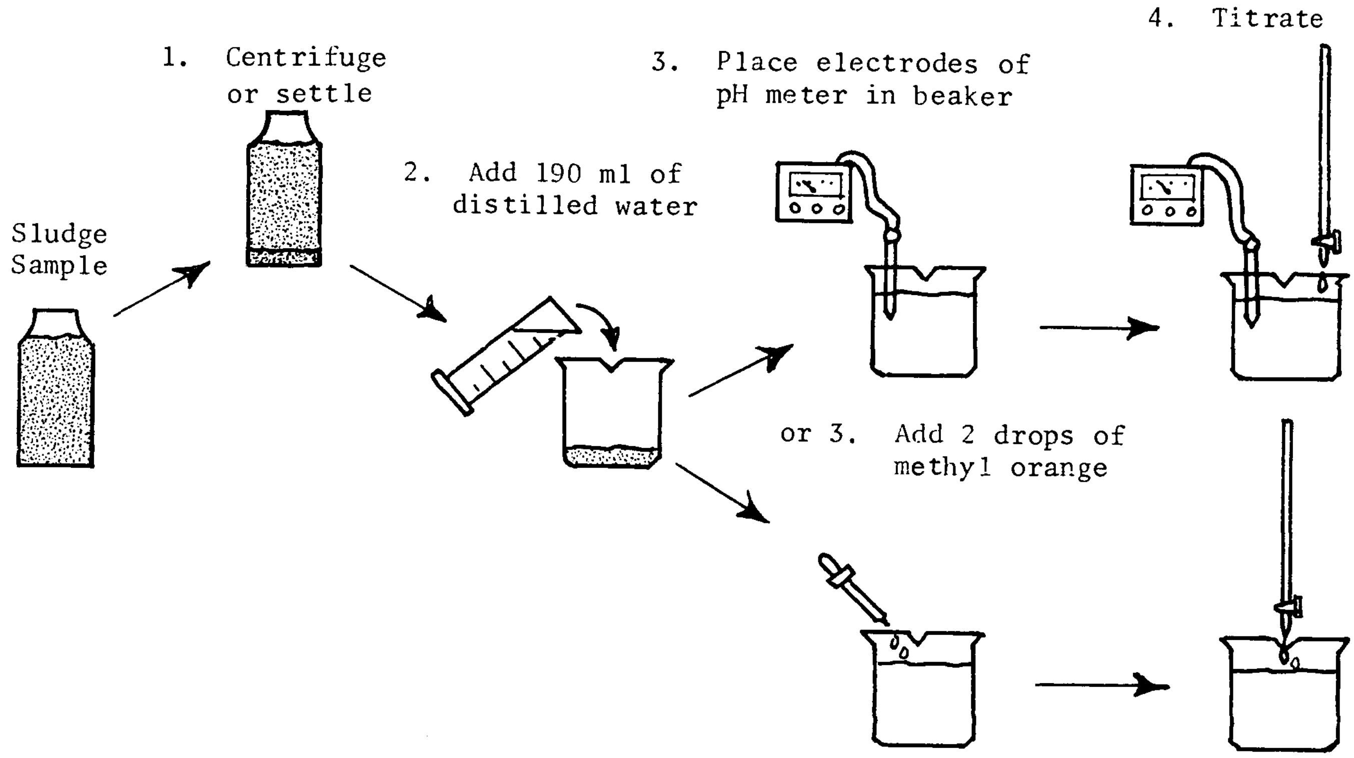
C. Apparatus

1. Centrifuge and centrifuge tubes, or settling cylinder.
2. Graduated cylinders (25 ml and 100 ml)
3. 50 ml Buret
4. 400 ml Erlenmeyer Flask or 400 ml beaker
5. pH Meter or a methyl orange chemical color indicator may be used (see Procedure)

D. Reagents

1. Sulfuric Acid, 0.2 N. Cautiously add 30 ml of concentrated sulfuric acid (H_2SO_4) to 300 ml of distilled water. Dilute to 1 liter with boiled distilled water. Standardize against 0.02 N sodium carbonate (Step 2).
2. Sodium Carbonate, 0.02 N. Dry in oven before weighing. Dissolve 1.06 g of anhydrous sodium carbonate (Na_2CO_3) in boiled distilled water and dilute to 1 liter with distilled water.
3. Methyl Orange Chemical Color Indicator. Dissolve 0.5 g methyl orange in 1 liter of distilled water.

E. Procedure



This procedure is followed to measure the alkalinity of a sample and also the alkalinity of a distilled water blank.

1. Take a clean 400 ml beaker and add 10 ml or less of clear supernatant (in case of water or distilled water, use 200 ml sample). Select a sample volume that will give a useable titration volume. If the liquid will not separate from the sludge by standing and a centrifuge is not available, use the top portion of the sample. This same sample and filtrate should be used for both the total alkalinity test and the volatile acids test.

2. Add 190 ml distilled water (in case of water or distilled water determination skip this step).

3. Place the electrodes of pH meter into the 400 ml beaker containing the sample.

4. Titrate to a pH of 4.5 with 0.02 N sulfuric acid. (In case of a lack of pH meter, add 2 drops of methyl orange indicator. In this case, titrate to the first permanent change of color to a red-orange color. Care must be exercised in determining the change of color and your ability to detect the change will improve with experience.)

5. The alkalinity of the distilled water should be checked and if significant, subtracted from the calculation.

6. Calculate alkalinity.

Alkalinity of Distilled Water, mg/l = ml of 0.02 N H_2SO_4 x 5*

Total Alkalinity, mg/l = ml of 0.02 N H_2SO_4 x 100* - mg/l alkalinity of distilled H_2O

F. Example

Results from alkalinity titrations on

1. Distilled Water 4 ml 0.02 N H_2SO_4

2. Recirculated Sludge 19.8 ml 0.02 N H_2SO_4

G. Calculations

Alkalinity of Distilled H_2O, mg/l = ml of 0.02 N H_2SO_4 x 5

= 4 ml x 5

= 20 mg/l

*Use 5 if measuring alkalinity of water or distilled water (200 ml sample) and 100 if measuring alkalinity of sludge (10 ml sample).

Total Alkalinity, mg/l, of recirculated sludge = ml of 0.02 N H_2SO_4 x 100 - mg/l alkalinity of distilled H_2O

= 19.8 ml x 100 - 20 mg/l

= 1980 mg/l - 20 mg/l

= 1960 mg/l

QUESTIONS

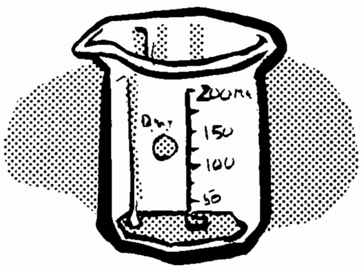
20.B Why would you run a total alkalinity test on recirculated sludge?

20.C What is meant by the buffer capacity in a digester?

20.D If the total alkalinity in a digester is 2000 mg/l and the volatile acids concentration is 300 mg/l per liter, what is the volatile acid/alkalinity relationship?

21. Volatile Solids

See Total Solids.



END OF LESSON 8 OF 8 LESSONS

on

Laboratory Procedures and Chemistry

DISCUSSION AND REVIEW QUESTIONS

(Lesson 8 of 8 Lessons)

Chapter 14. Laboratory Procedures and Chemistry

Name ______________________________ Date ____________

Write the answers to these questions in your notebook. The problem numbering continues from Lesson 7.

32. Why are solids only weighed to the nearest 0.01 gram when determining the total and volatile solids content of digesters?

33. What is a thief hole?

34. What relationship is the critical control factor in digester operation?

14.6 RECOMMENDED GENERAL LABORATORY SUPPLIES

Supplies needed in addition to apparatus listed for tests. Source: WPCF Publication No. 18, *Simplified Laboratory Procedures for Wastewater Examination.*

Quantity	Description
12	Pinch clamps, medium
200	Corks, assorted
1	Cork borer set, sizes 1 through 6
1	Cork borer sharpener
2 lb	Glass tubing, 8 mm
4	Thermometers, -20° to 100°C
40 ft	Rubber tubing, 1/4-in. ID, 3/32-in. wall
2 lb	Rubber stoppers, assorted (sizes 6 through 12)
1	Tripod, concentric ring, 6 in. OD
1	Latest edition, *Standard Methods for the Examination of Water & Wastewater*
2	Funnels, 50 mm
2	Funnels, 100 mm
2 pair	Balance watch glasses, 3 in.
4	Beakers, Pyrex, 1000 ml
4	Beakers, Pyrex, 600 ml
6	Beakers, Pyrex, 400 ml
4	Beakers, Pyrex, 250 ml
4	Beakers, Pyrex, 100 ml
4	Beakers, Pyrex, 50 ml
2	Bunsen burners
2	Brushes, medium
2	Brush, B
2	Brush, A
2	Brush, Flask
2	Aprons, plastic, 42 in. length
3	Wire gauzes, 4 x 4 in.
3	Triangles, 2-1/2 in. per side
1 tube	Stopcock lubricant

SUPPLEMENTAL EQUIPMENT FOR THE BOD TEST

Quantity	Description
12	Flask, Erlenmeyer, 500 ml
12	Flask, Erlenmeyer, 250 ml
2	Pipettes, volumetric, 25 ml
2	Pipettes, volumetric, 10 ml
2	Pipettes, volumetric, 5 ml
2	Flasks, volumetric, graduated to contain and deliver 1000 ml
2	Flasks, volumetric, graduated to contain and deliver 500 ml
2	Flasks, volumetric, graduated to contain and deliver 100 ml
6	Bottles, 32 oz
6	Bottles, 16 oz
6	Bottles, 8 oz
24	BOD bottles, with funnel opening
2	Burets, 50 ml
1	Buret clamp, double
2	Bottles, dropping, 30 ml
2	Spatulas, 75-mm blade
3	Bottles, storage, 2-1/2 gal
1	Buret support, medium
9 lb	Sulfuric acid, CP
5 lb	Sodium hydroxide pellets, CP
12	Bulb, rubber, pipette, 2 ml
24	Holder, rubber, stopper
4	Flask, volumetric, w/o stopper, 100 ml
2 lb	Potassium iodide, CP
1 lb	Starch, soluble potato
1 lb	Sodium thiosulfate, CP
5 lb	Manganous sulfate, CP
100 g	Sodium azide, CP
1 lb	Magnesium sulfate
1/4 lb	Ferric chloride
1 lb	Potassium phosphate, mono-basic
1 lb	Potassium phosphate, dibasic

Quantity	Description
1 lb	Sodium phosphate, dibasic heptahydrate
1/4 lb	Ammonium chloride
1 oz	Potassium bi-iodate, primary standard
1 lb	Potassium dichromate
10 g	Sodium diethyldithio carbamate
1	Incubator, BOD
1	Refrigerator
1 lb	Calcium chloride, 20 mesh

SUPPLEMENTAL EQUIPMENT FOR THE CHLORINE RESIDUAL TEST

Quantity	Description
1	Comparator, water analysis
1	Disc for comparator, chlorine
6 lb	Hydrochloride acid, CP
25 g	Orthotolidine dihydrochloride

SUPPLEMENTAL EQUIPMENT FOR SOLIDS ANALYSES

Quantity	Description
1	Brush, camel hair, 1-in. wide
1	Balance with cover
1	Weights, balance set, 50 g
12	Crucibles, Gooch, No. 4
2	Holders, crucible
2	Cylinder, graduated, 1000 ml
2	Cylinder, graduated, 500 ml
2	Cylinder, graduated, 250 ml
4	Cylinder, graduated, 100 ml
4	Cylinder, graduated, 50 ml
2	Cylinder, graduated, 25 ml
1	Cylinder, graduated, 10 ml
1	Desiccator, 250 mm
1	Desiccator plate
12	Dishes, evaporating, size 0

Quantity	Description
3	Flask, filtering, 500 ml
2	Pipettes, 25 ml
6	Pipettes, 10 ml
2	Pipettes, 5 ml
1	Hot plate, 660 w
2	Tongs, crucible
1	Tongs, furnace, 18 in.
8 ft	Tubing, rubber, (heavy) 1/4-in. ID
2	Filter pumps
1	Clock, interval timer, 2 hr
1	Furnace, muffle
2 boxes	Paper, filter, glass fiber, 2.4 cm
1	Water baths, four-hole
1	Balance, platform, triple beam
2	Bottles, washing, polyethylene, 500 ml
6	Pencils, wax, red
2 boxes	Filter paper, 12.5 cm, Whatman No. 41
1 bottle	Ink, marking, black
1 lb	Rod, glass, 6 mm
1	File, triangular, 4 in.
12	Bulb, rubber, pipet, 2 oz
1	Balance desiccator
1	Oven, drying
24	2.4 cm glass fiber filter
2	Buchner funnel, size 2A
6	Tube "T", connecting, 1/4-in.
5 lb	Drierite

SUPPLEMENTAL EQUIPMENT FOR COLIFORM GROUP BACTERIA ANALYSES

Quantity	Description
1	Sterilizer or autoclave
12	3 mm wire transfer loop
24	Pipets, measuring, 10 ml
48	Pipets, measuring, 1 ml, or quantity of disposable sterile pipets

Many equipment suppliers will furnish suggested equipment lists upon request and indication of size of plant and tests being performed. Lists may be obtained from:

Central Scientific Company
1700 Irving Park Road
Chicago, Illinios

Van Waters & Rogers
Post Office Box 2062
Terminal Annex
Los Angeles, California 90054

14.7 ADDITIONAL READING

a. MOP 11

b. New York Manual, pages 127-148

c. Texas Manual, pages 565-587

d. *Laboratory Procedures for Operators of Water Pollution Control Plants*, Nagano, Joe. Obtain from Secretary-Treasurer, California Water Pollution Control Association, P.O. Box 61, Lemon Grove, California 92045. Price $3.25 to members of the CWPCA; $4.25 to others.

e. *Simplified Laboratory Procedures for Wastewater Examination*, WPCF Publication No. 18, Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016. Price $2.00 to members; $4.00 to others. Indicate your member association when ordering.

f. *Standard Methods for Examination of Water and Wastewater*, produced by APHA, AWWA, and WPCF, Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016. Price $16.50 to members prepaid only; otherwise $22.50 plus postage. Indicate your member association when ordering.

g. *Chemistry for Sanitary Engineers*, Sawyer, Clair N. and McCarty, Perry L., McGraw-Hill Book Company, New York, 1967. Price $13.50.

h. *FWPCA Methods for Chemical Analysis of Water and Wastes*, Federal Water Quality Control Administration, Division of Water Quality Reserach, Analytical Quality Control Laboratory, 1014 Broadway, Cincinnati, Ohio 45202 (November 1969).

SUGGESTED ANSWERS

Chapter 14. Laboratory Procedures and Chemistry

14.2A A bulb should always be used to pipette wastewater or polluted water to prevent infectious materials from entering your mouth.

14.2B Inoculations are recommended to reduce the possibility of contracting diseases.

14.2C Immediately wash area where acid spilled with water and neutralize the acid with sodium carbonate or bicarbonate.

14.2D True. You may add acid to water, but never reverse.

14.2E Work clothes should be changed before going home at night to prevent carrying unsanitary materials and diseases home which could infect you and your family.

14.3A The largest sources of errors found in laboratory results are usually caused by improper sampling; poor preservation; and lack of sufficient mixing, compositing, and testing.

14.3B A representative sample must be collected or the test results will not have any significant meaning. To efficiently operate a wastewater treatment plant, the operator must rely on test results to indicate to him what is happening.

14.3C A proportional composite sample may be prepared by collecting a sample every hour. The size of this sample is proportional to the flow when the sample is collected. All of these proportional samples are mixed together to produce a proportional composite sample. If an equal volume of sample was collected each hour and mixed, this would be simply a composite sample.

3.A The dangers encountered in running the CO_2 on digester gas include:

1. Digester gas contains methane, which is explosive when mixed with air.
2. The CO_2 gas absorbent is harmful to your skin.

3.B $\% \; CO_2 = \dfrac{(\text{Total Volume, ml} - \text{Gas Remaining, ml}) \times 100\%}{\text{Total Volume, ml}}$

$= \dfrac{(128 \text{ ml} - 73 \text{ ml}) \times 100\%}{128 \text{ ml}}$

$$\begin{array}{r} 128 \\ -\ 73 \\ \hline 55 \end{array}$$

$= \dfrac{55}{128} \times 100\%$

$= 43\%$

$$\begin{array}{r} .43 \\ 128 \overline{)\,55.0} \\ 51\ 2 \\ \hline 3\ 80 \\ 3\ 84 \end{array}$$

4.A The COD test is a measure of the strength of a waste in terms of its chemical oxygen demand. It is a good estimate of the first-stage oxygen demand. (Either answer is acceptable.)

4.B The advantage of the COD test over the BOD test is that you don't have to wait five days for the results.

5.A Plant effluents should be chlorinated for disinfection purposes to protect the bacteriological quality of the receiving waters.

5.B The idometric method gives good results with samples containing wastewater, such as plant effluent or receiving waters. Orthotolidine will give satisfactory results if used within 20 minutes of the application of chlorine; however, the entire chlorine demand may not yet have been satisfied. Amperometric titration gives satisfactory results, but the equipment is expensive.

6.A The clarity test indicates the relative change of depth you can see down in the final clarifier or contact basin. This reflects a visual comparison of color, solids, and turbidity from one test to the next. OR Indication of quality of effluent.

6.B When clarity is measured under different conditions the results can not be compared. You won't be able to tell whether your plant performance is improving, staying the same, or deteriorating.

7.A Sodium thiosulfate crystals should be added to sample bottles for coliform bacteria tests before sterilization to neutralize any chlorine that may be present when the sample is collected. Care must be taken not to wash the bottles out when a sample is collected.

7.B 121°C within 15 minutes.

7.C

Dilutions	-2	-3	-4	-5
Readings	<u>5</u>	<u>1</u>	<u>2</u>	0

MPN = 63,000/100 ml

7.D The number of coliforms is estimated by counting the number of colonies grown on the membrane filter.

8.A

$$\text{DO Saturation, \%} = \frac{\text{DO of Sample, mg/l x 100\%}}{\text{DO at Saturation, mg/l}}$$

$$= \frac{(7.9\text{ mg/l})\ 100\%}{11.3\text{ mg/l}}$$

$$= 70\%$$

$$\begin{array}{r} .699 \\ 11.3\overline{)\,7.90\,} \\ \underline{6\ 78} \\ 1\ 120 \\ \underline{1\ 017} \\ 1\ 030 \\ 1\ 017 \end{array}$$

8.B To calibrate the DO probe in an aeration tank, a sample of effluent can be collected and split. The DO of the effluent is measured by the modified Winkler procedure, and the probe DO reading is adjusted to agree with the Winkler results.

8.C When the DO in the aeration tank is very low, the copper sulfate-sulfamic acid procedure can give high results. The results are high because oxygen enters the sample from the air when the sample is collected, when the copper sulfate-sulfamic acid inhibitor is added, while the solids are settling, and when the sample is transferred to a BOD bottle for the DO test.

8.D BOD test or volatile solids test.

8.E To prepare dilutions for a cannery waste with an expected BOD of 2000 mg/l, take 10 ml of sample and add 90 ml of dilution water to obtain a new sample with an estimated BOD of 200 mg/l (10 to 1 dilution):

$$\text{BOD Dilution, ml} = \frac{1200}{\text{Estimated BOD, mg/l}}$$

$$= \frac{1200}{200}$$

$$= 6 \text{ ml}$$

8.F
$$\text{BOD, mg/l} = \left(\begin{array}{l}\text{Initial DO of} \\ \text{Diluted Sam-} \\ \text{ple, mg/l}\end{array} - \begin{array}{l}\text{DO of Diluted} \\ \text{Sample After} \\ \text{5-Day Incuba-} \\ \text{tion, mg/l}\end{array}\right)\left(\frac{\text{BOD Bottle Vol., ml}}{\text{Sample Volume, ml}}\right)$$

$$= (7.5 \text{ mg/l} - 3.9 \text{ mg/l})\left(\frac{300 \text{ ml}}{2 \text{ ml}}\right)$$

$$= (3.6 \text{ mg/l})\ (150)$$

$$= 540 \text{ mg/l}$$

8.G Samples for the BOD test should be collected before chlorination because chlorine interferes with the organisms in the test. It is difficult to obtain accurate results with dechlorinated samples.

8.H A solution of sodium thiosulfate at 0.0375 N is very weak and unstable and will not remain accurate over two weeks.

9.A (1) You would measure the H_2S in the wastewater to know the strength of H_2S and an indication of the corrosion taking place on the concrete.

(2) H_2S in the atmosphere produces a rotten egg odor. It is indicative of anaerobic decomposition of organics in wastewater which occurs in the absence of oxygen.

10.A (1) To measure plant influent pH with a paper tape, collect representative sample, mix sample with a clean stirring rod, and dip tape in sample while it is still moving. Compare tape color with package color and record results.

(2) To measure raw sludge pH with a paper tape first allow raw sludge sample to settle. Dip tape in liquid at top, compare resulting color, and record results.

pH of both samples should be measured in place or as soon as possible.

10.B Precautions to be exercised when using a pH meter include:

(1) Prepare fresh buffer solution weekly for calibration purposes.

(2) pH meter, samples, and buffer solutions should all be at the same temperature.

(3) Watch for erratic results arising from faulty operation of pH meter or fouling of electrodes with interfering matter.

11.A Settleability tests should be run on the mixed liquor to determine the settling characteristics of the sludge floc at regular intervals for 60 minutes. The results are used in the SVI and SDI determinations.

11.B The SVI is the volume in ml occupied by one gram of mixed liquor suspended solids after 30 minutes of settling.

11.C The SVI test is used to indicate changes in sludge characteristics.

11.D Sludge Density Index (SDI) = 100/SVI

12.A Sludge to Digester, gpd = (Total Set Sol Removed, ml/l) (1000) (Flow, MGD)

$$= (10\ ml/l - 0.4\ ml/l)\ (1000\ mg/ml)\ (1\ M\ Gal/day)$$

$$= \left(\frac{9.6\ ml}{M\ mg}\right)\left(\frac{1000\ mg}{ml}\right)\left(\frac{1\ M\ Gal}{day}\right)$$

$$= 9600\ gpd$$

This value may be reduced by 30 to 75% due to compaction of the sludge in the clarifier.

13.A The sludge age of a 200,000 gallon aeration tank that has 2000 mg/l mixed liquor suspended solids, a primary effluent of 115 mg/l SS, and an average flow of 1.8 MGD:

$$\text{Sludge Age, days} = \frac{\underset{.2\ MG}{\text{Vol of Aeration Tank}} \times \text{Sus Solids, 2000 mg/l}}{\text{Flow, MGD, 1.8} \times \text{Primary Effl, 115 mg/l}}$$

$$= \frac{0.2\ MG \times 2000\ mg/l}{1.8\ MGD \times 115\ mg/l}$$

$$= 1.93$$

14.A (1) Results from the graduated cylinder are available immediately, but different operators may interpret the results differently.

(2) Results are not available until the next day, but different operators will record the same result.

15.A If the supernatant solids test is greater than 5%, the supernatant could be placing a heavy solids load on the plant and the appropriate operational adjustments should be made.

16.A The specific gravity is very near that of H_2O and is not light enough to float nor heavy enough to settle.

16.B Solids calculations will be shown in detail here to illustrate the computational approach and the units involved. After you understand this approach, use of the laboratory work sheet on the following pages is more convenient.

a. Total Suspended Solids

Volume of Sample, ml = 100 ml

Weight of Dried Sample & Dish, grams	=	19.3902 g
Weight of Dish (Tare Weight), grams	=	19.3241 g
Dry Weight	=	0.0661 g
or	=	66.1 mg

$$\text{Total Suspended Solids, mg/l} = \frac{\text{Weight of Solids, mg} \times 1000 \text{ ml/l}}{\text{Volume of Sample, ml}}$$

$$= \frac{66.1 \text{ mg} \times 1000 \text{ ml/l}}{100 \text{ ml}}$$

$$= 661 \text{ mg/l}$$

b. Volatile Suspended Solids

Weight of Dried Sample & Dish, grams	=	19.3902 g
Weight of Ash & Dish, grams	=	19.3469 g
Weight Volatile, grams	=	0.0433 g
or	=	43.3 mg

$$\text{Volatile Suspended Solids, mg/l} = \frac{\text{Weight of Volatile, mg} \times 1000 \text{ ml}}{\text{Volume of Sample, ml}}$$

$$= \frac{(43.3 \text{ mg})\ (1000 \text{ ml/l})}{100 \text{ ml}}$$

$$= 433 \text{ mg/l}$$

c. Percent Volatile Solids

$$\%\ \text{Volatile Solids} = \frac{\text{Weight Volatile, mg} \times 100\%}{\text{Weight Dry, mg}}$$

$$= \frac{433 \text{ mg}}{661 \text{ mg}} \times 100\%$$

$$= 65.5\%$$

$$\begin{array}{r} .655 \\ 661 \overline{)\,433.0} \\ \underline{396\ 6} \\ 36\ 40 \\ \underline{33\ 05} \\ 3\ 350 \\ 3\ 305 \end{array}$$

d. Fixed Solids

Total Suspended Solids, mg/l	=	661 mg/l
Volatile Suspended Solids, mg/l	=	433 mg/l
Fixed Solids, mg/l	=	228 mg/l

e. Percent Fixed Solids

Total Solids, %	=	100.00%
Volatile Solids, %	=	65.50%
Fixed Solids, %	=	34.5 %

<u>or</u>

$$\%\ \text{Fixed} = \frac{\text{Fixed, mg}}{\text{Total, mg}} \times 100\%$$

$$= \frac{228 \text{ mg}}{661 \text{ mg}} \times 100\%$$

$$= 34.5\% \quad \text{(Check)}$$

16.C Calculate Percent Reduction through Primary:

$$\% \text{ Removal} = \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

In = Influent to plant or unit

Out = What is leaving plant or unit

$$= \frac{(221 \text{ mg/l} - 159 \text{ mg/l})}{221 \text{ mg/l}} \times 100\%$$

$$= \frac{62}{221} \times 100\%$$

= 28% reduction through primary

```
       .28
221 ) 62.0
      44 2
      17 80
      17 68
```

Calculate Percent Removal by Secondary System:

$$\% \text{ Removal} = \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

In = 159 mg/l SS in primary effluent

Out = 33 mg/l SS in final effluent

$$= \frac{(159 \text{ mg/l} - 33 \text{ mg/l})}{159 \text{ mg/l}} \times 100\%$$

= 79% removal from primary effluent to final effluent

```
        .79
159 ) 126.0
      111 3
       14 70
       14 31
```

Calculate Overall Plant Efficiency:

$$\% \text{ Removal} = \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

In = 221 mg/l SS in plant influent

Out = 33 mg/l SS in plant effluent

$$= \frac{(221 \text{ mg/l} - 33 \text{ mg/l})}{221 \text{ mg/l}} \times 100\%$$

$$= \frac{188}{221} \times 100\%$$

= 85.5% overall plant removal

16.D Calculate the pounds of solids removed per day by each unit:

Amount Removed, lb/day = Conc. Reduction, mg/l x Flow, MGD x 8.34 lb/gal

where MGD = million gallons per day

A. Influent, mg/l = 221 mg/l

Primary Effluent, mg/l = 159 mg/l

Primary Removal, mg/l = 62 mg/l

Amount Removed, lb/day (Primary) = (62 mg/l) (1.5 MGD) (8.34 lb/gal)

= 775.6 lbs/day removed by primary

B. Primary Effluent, mg/l = 159 mg/l

Final Effluent, mg/l = 33 mg/l

Secondary Removal, mg/l = 126 mg/l

Amount Removed, lb/day (Secondary) = (126 mg/l) (1.5 MGD) (8.34 lb/gal)

= 1576 lb/day removed by secondary

C. Influent, mg/l = 221 mg/l

Final Effluent, mg/l = 33 mg/l

Overall Removal, mg/l = 188 mg/l

Amount Removed, mg/l = (188 mg/l) (1.5 MGD) (8.34 lb/gal)

= 2351 lbs/day removed by plant

or = Primary Removal, lb/day + Secondary, lb/day

= 775 + 1576

= 2351 (Check)

16.E The advantages of the centrifuge over the regular suspended solids test are:

(1) Speed of answer! Not as accurate as other methods, but results are sufficiently close.

(2) Answers very acceptable if suspended solids concentration is below 1000 mg/l.

Disadvantage: Small plants cannot always afford the $500 or more cost of the centrifuge.

17.A Changes in influent temperature could indicate a new influent source. A drop in temperature could be caused by cold water from infiltration, and an increase in temperature could be caused by an industrial waste discharge.

17.B The thermometer should remain immersed in the liquid while being read for accurate results. When removed from the liquid, the reading will change.

17.C All thermometers should be calibrated against an accurate National Bureau of Standards thermometer because some thermometers can be purchased that are substantially inaccurate (off as much as 6^{o}).

18.A Volatile solids found in a digester are organic compounds of either plant or animal origin.

18.B Volatile solids in a treatment plant represent the waste material that may be treated by biological processes.

20.A
$$\text{Volatile Acid Alkalinity, mg/l} = \frac{\text{ml } 0.05 \text{ N NaOH} \times 2500}{\text{ml Sample}}$$

$$= \frac{5 \text{ ml} \times 2500}{50 \text{ ml}}$$

$$= 250 \text{ mg/l}$$

Since 250 mg/l > 180 mg/l,

$$\text{Volatile Acids, mg/l} = \text{Volatile Acid Alkalinity} \times 1.50$$

$$= 250 \text{ mg/l} \times 1.50$$

$$= 375 \text{ mg/l}$$

20.B The alkalinity test is run to determine the buffer capacity and the volatile acids/alkalinity relationship in a digester.

20.C The buffer capacity in a digester as measured by the total alkalinity tests indicates the capacity of the digester to resist changes in pH.

20.D $$\frac{\text{Volatile Acid}}{\text{Alkalinity}} = \frac{300 \text{ mg/l}}{2000 \text{ mg/l}}$$

$$= 0.15$$

OBJECTIVE TEST

Chapter 14. Laboratory Procedures and Chemistry

Name ______________________________ Date ______________

Please write your name and mark the correct answers on the IBM answer sheet. There may be more than one correct answer to each question.

TRUE OR FALSE (1-10):

1. A rubber bulb should be used to pipette wastewater or polluted water.
   1. True
   2. False

2. Acid may be added to water, but not the reverse.
   1. True
   2. False

3. Always wear safety goggles when conducting any experiment in which there may be danger to the eyes.
   1. True
   2. False

4. Smoking and eating should be avoided when working with infectious material such as wastewater and sludge.
   1. True
   2. False

5. In the washing of hands after working with wastewater, the kind of soap is less important than the thorough use of soap.
   1. True
   2. False

6. The pH scale may range from 0 to 14, with 7 being a neutral solution.
   1. True
   2. False

7. If at all possible, samples for the BOD test should be collected before chlorination.

   1. True
   2. False

8. The COD test is a measure of the chemical oxygen demand of wastewater.

   1. True
   2. False

9. The BOD test is a measure of the organic content of wastewater.

   1. True
   2. False

10. The answers from the total solids and suspended solids tests are always the same.

   1. True
   2. False

Possible definitions of the words listed below are given on the right. If the definition of a word is after the number 2, mark column 2 on your answer sheet.

	Word		Definition
		1.	Surrounding
11.	Aliquot	2.	Capacity to resist pH change
12.	Ambient	3.	Portion of a sample
13.	Blank	4.	Inside
14.	Buffer	5.	Test run without sample

15. Large errors in laboratory tests may be caused by:

   1. Improper sampling
   2. Large samples
   3. Poor preservation
   4. Poor quality effluent
   5. Lack of mixing during compositing

16. The most critical factor in controlling digester operation is the:

    1. CO_2
    2. Gas production
    3. Volatile solids
    4. Volatile acids/alkalinity relationship
    5. pH

17. The COD test:

    1. Measures the biochemical oxygen demand
    2. Estimates the first-stage oxygen demand
    3. Measures the carbon oxygen demand.
    4. Estimates the total oxygen consumed
    5. Provides results quicker than the BOD test

18. A clarity test on plant effluent:

    1. Tells if the effluent is safe to drink
    2. Is measured by an amperometer
    3. Should always be measured at the same time
    4. Should always be measured under the same light conditions
    5. Is measured by a Secchi Disc

19. Coliform group bacteria are:

    1. Measured by the membrane filter method
    2. Measured by the multiple fermentation technique
    3. Measured by the modified Winkler procedure
    4. Harmful to humans
    5. Indicative of the potential presence of bacteria originating in the intestines of warm-blooded animals

20. The saturation concentration of dissolved oxygen in water does not vary with temperature.

    1. True
    2. False

21 DO probes are commonly used to measure dissolved oxygen in water in:

    1. Aeration tanks
    2. Sludge digesters
    3. Manholes
    4. Streams
    5. BOD bottles

22. Hydrogen sulfide:

1. Reacts with moisture and oxygen to form a substance corrosive to concrete
2. Is sometimes written as H_2S
3. Smells like rotten eggs
4. Is formed under aerobic conditions
5. Should not be controlled in the collection system.

23. Results from the settleability test of activated sludge solids may be used to:

1. Calculate SVI
2. Calculate SDI
3. Calculate sludge age
4. Determine ability of solids to separate from liquid in final clarifier
5. Calculate mixed liquor suspended solids.

24. Results of the settleable solids test run using Imhoff cones may be used to:

1. Calculate the Imhoff Settling Index
2. Calculate the efficiency of a plant
3. Calculate the pounds of solids pumped to the digester
4. Indicate the quality of the influent
5. Indicate the quality of the effluent

25. Precautions that must be observed in running the suspended solids-Gooch crucible test include:

1. Collecting and testing a representative sample
2. Proper temperature level in oven at all times
3. Lack of leaks around and through the glass fiber
4. Thoroughly mixing sample before testing
5. Discarding any large chunks of material in sample

26. A chlorine residual should be maintained in a plant effluent:

1. To keep the chlorinator working
2. For disinfection purposes
3. For testing purposes
4. To protect the bacteriological quality of the receiving waters
5. None of these

PLANT ____________________

DATE ____________________

SUSPENDED SOLIDS & DISSOLVED SOLIDS

SAMPLE							
Crucible							
Ml Sample							
Wt Dry & Dish Wt Dish							
Wt Dry							
$mg/l = \frac{\text{Wt Dry, gm} \times 1{,}000{,}000}{\text{Ml Sample}}$							
Wt Dish & Dry Wt Dish & Ash							
Wt Volatile							
$\% \text{ Vol} = \frac{\text{Wt Vol}}{\text{Wt Dry}} \times 100\%$							

BOD

Blank ____________

SAMPLE										
DO Sample										
Bottle #										
% Sample										
Blank or adj blank DO after incubation										
Depletion, 5 days										
Dep %										

Nitrate NO_3

Sample ____________ ____________

Graph Reading ____________ ____________

Sett. Solids

Sample ____________ ____________

Direct Ml/l ____________ ____________

COD

Sample ____________ ____________ ____________

Blank Titration ____________ ____________ ____________

Sample Titration ____________ ____________ ____________

Depletion ____________ ____________ ____________

$mg/l = \frac{\text{Dep} \times N \text{ FAS} \times 8000}{\text{Ml Sample}}$ ____________ ____________ ____________

Typical Laboratory Work Sheet

TOTAL SOLIDS

SAMPLE						
Dish No.						
Wt Dish & Wet Wt Dish						
Wt Wet						
Wt Dish + Dry Wt Dish						
Wt Dry						
% Solids = $\frac{\text{Wt Dry}}{\text{Wt Wet}}$ x 100%						
Wt Dish + Dry Wt Dish + Ash						
Wt Volatile						
% Volatile = $\frac{\text{Wt Vol}}{\text{Wt Dry}}$ x 100%						
pH						
Vol. Acid						
Alkalinity as $CaCO_3$						

Grease (Soxlet)

Sample ____________

Ml Sample ____________

Wt Flask + Grease
Wt Flask ____________

Wt Grease ____________

$$\text{mg/l} = \frac{\text{Wt Grease, mg x 1000}}{\text{Ml Sample}}$$ ____________

H_2S (Gas) (Starch-Iodine)

Blank ________ Ml

Sample ________ Ml

Diff ________ Ml

Diff x .68 ________ mg/l

mg/l x 43.6 ________ grain/100 cu ft

Typical Laboratory Work Sheet (continued)

CHAPTER 15

BASIC MATHEMATICS AND TREATMENT PLANT PROBLEMS

by

William Crooks

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EXPLANATION OF PRE-TEST

READ SECTION 15.0, INTRODUCTION, BEFORE WORKING PRE-TEST

This Pre-Test is designed to determine those areas of math in which you may need additional help. It is suggested that you work all problems in the Pre-Test and compare your answers with the answers provided. If you do not obtain the answer written beside the problem, turn to the page number in this chapter which appears directly beside the answer. On this page you will find an explanation for solving that particular problem.

If you obtain the correct answer for a problem, you may skip that section in the chapter. If time is available, however, it may be worthwhile to at least thumb through that particular section.

If you cannot obtain the given answer, ask a friend to help you or notify your Program Director. Tell your Program Director what you tried and what happened, and he will try to help you.

You are not required to mail your calculations or answers for the Pre-Test to your Program Director; however, if you would like him to review any or all of your work, please mail it to him.

Since the purpose of this chapter is to help you work math problems, you are not expected to have memorized formulas and conversion factors (7.5 gal = 1 cu ft). While working the Pre-Test you may refer to Sections 15.14, Summary of Formulas, and 15.15, Conversion Tables, for helpful information. On many examinations you are expected to have memorized certain basic formulas and conversion factors. By working many problems you will gradually memorize this information.

PRE-TEST

Chapter 15. Basic Mathematics and Treatment Plant Problems

		Answer	Page
1.	Add 349 and 75.	424	15-2
2.	Subtract 296 from 485.	189	15-3
3.	Multiply 24 x 17.	408	15-5
4.	Divide 1.25 by 0.045.	27.78	15-10
5.	Change 13/8 to a mixed number.	$1\frac{5}{8}$	15-12
6.	Reduce 216/324 to its lowest terms.	$\frac{2}{3}$	15-13
7.	Add $\frac{1}{3} + \frac{1}{4}$.	$\frac{7}{12}$	15-14
8.	Multiply $2\frac{1}{2}$ by $\frac{2}{5}$.	1	15-15
9.	Divide $\frac{5}{6}$ by $\frac{3}{12}$.	$3\frac{1}{3}$	15-16
10.	Express $\frac{5}{6}$ as a decimal.	0.833	15-16
11.	Express $\frac{2}{5}$ as a percent.	40%	15-17
12.	Express 0.4% as a fraction.	$\frac{1}{250}$	15-17
13.	What percent is 20 of 25?	80%	15-19
14.	Find 90% of 5.	4.5	15-19
15.	16 is 80% of what amount?	20	15-20

		Answer	Page
16.	Certain bolts cost 90¢ a dozen. How much would three bolts cost?	23¢	15-22
17.	If three men can do a certain job in 10 hours, how long would it take five men to do the same job?	6 hrs	15-24
18.	Find the square root of 20.	4.47	15-26
19.	Find the cube root of 64.	4	15-27
20.	Find the arithmetic mean and median of 210, 180, 175, 215, 195, 155, and 200.	190 and 195	15-28
21.	If the area of a settling basin is 330 square feet and one side measures 15 feet, how long is the other side?	22 ft	15-30
22.	If the height of a triangle is five feet and the base is four feet, what is the area?	10 sq ft	15-31
23.	What is the area of a 20 cm diameter circle?	314 sq cm	15-33
24.	What is the total surface area (including side, top, and bottom) of a 60 ft diameter tank 20 ft high?	9420 sq ft	15-35
25.	What is the total surface area of a cone with a diameter of 30 inches and height of 20 inches?	1884 sq in	15-36
26.	What is the surface area of a 20-foot diameter sphere?	1256 sq ft	15-37
27.	Find the volume in cubic feet of a box two feet by 15 inches by 18 inches.	$3\frac{3}{4}$ cu ft	15-38
28.	Find the volume of a 100-foot diameter tank, 12 feet deep.	94,200 cu ft	15-39

		Answer	Page
29.	Convert 20° centigrade (Celsius) to fahrenheit.	68°F	15-44
30.	Convert -13°F to °C.	-25°C	15-44
31.	Flow is 3.5 MGD with a BOD concentration of 200 mg/l. Calculate pounds of BOD per day.	5838 lb/day	15-46
32.	Change 1000 cu ft of water to gallons.	7480 gal	15-48
33.	How many gallons of water weigh 750 lbs?	90 gal	15-48
34.	What is the gauge pressure under two feet of water?	0.866 psi	15-50
35.	What is the force acting on a five feet long wall, four feet deep?	2496 lbs	15-51
36.	Flow in a 2.5 foot wide channel is 1.4 ft deep and measures 11.2 cfs. What is the average velocity?	3.2 ft/sec	15-56
37.	A flow of 500 gpm is pumped 100 ft by a pump with an efficiency of 70%. What is the pump horsepower?	18.0 HP	15-59

CHAPTER 15. BASIC MATHEMATICS AND TREATMENT PLANT PROBLEMS

15.0 INTRODUCTION

This chapter has been provided early in your training program to help you gain the greatest benefit from your efforts. Whether to start this lesson now or wait until later is your decision. The lessons on treatment processes were written in a manner requiring very little background in mathematics. You may wish to concentrate your efforts on the treatment processes at this time and refer to this lesson when you need help. Some operators prefer to complete this lesson now so they will not have to worry about how to do the mathematical manipulations when they are studying the treatment process lessons. You are encouraged to try to work this chapter now, rather than waiting until later.

The intent of this chapter is to provide you with a quick review of some basic mathematical principles and examples of typical plant problems. It is not intended to be a math textbook. Some operators will be able to skip over the review of addition, subtraction, multiplication, and division. Others may need more help in these and other areas. Basic arithmetic textbooks are available at every local library or bookstore and should be referred to if needed. Deserving special mention is a manual, *Elementary Mathematics and Basic Calculations*, a reprint available from Water and Sewage Works magazine.

When possible, you may wish to perform multiplication and division with the aid of a slide rule. Handbooks frequently have tables containing the square, square root, and other valuable information which saves computational time. These methods also are good ways to check your calculations. After you have worked a problem involving plant operations, you should check your calculations, examine your answer to see if it appears reasonable, and if possible, have another operator check your work before making any operational changes.

15.1 WHOLE NUMBERS AND DECIMALS

15.10 Addition

Not many people will make a mistake when adding 2 plus 2. However, it is surprising how many cannot correctly add 22.222 and 0.0022. The reason is they violate one of the main rules of addition or subtraction, and that is:

1. KEEP ALL DECIMAL POINTS AND NUMBERS IN COLUMNS

   When the rule is followed correctly, the above addition is easily performed.

$$\begin{array}{r} 22.222 \\ +\ \underline{0.0022} \\ 22.2242 \end{array}$$

Another common error is made in the following manner:

$$\begin{array}{r} 349 \\ +\ \underline{75} \\ 414 \end{array} \text{ (Wrong)}$$

In this case another rule is violated.

2. WRITE DOWN ALL CARRYOVER NUMBERS

   If this rule is followed, the previous problem becomes:

$$\begin{array}{r} {}^{1}3{}^{1}49 \\ +\ \underline{75} \\ 424 \end{array}$$

   Carryover numbers should be written lightly over the next column to the left.

Many can remember a teacher saying to them, "You can't add apples and oranges". This is our third rule of addition.

3. ALL NUMBERS MUST BE IN THE SAME DIMENSIONAL (ft, lb, sec) UNITS

   If we needed a string 2 feet long and one 6 inches long, we would either say:

2 ft + 1/2 ft = 2 1/2 ft of string, or

$$\begin{array}{rl} 2 & \text{ft} \\ 1/2 & \text{ft} \\ \hline 2\ 1/2 & \text{ft} \end{array}$$

or we might say:

24 inches + 6 inches = 30 inches of string, or

$$\begin{array}{rl} 24 & \text{in} \\ 6 & \text{in} \\ \hline 30 & \text{in} \end{array}$$

Two and one-half feet and 30 inches are the same length. We must use the same dimensional units when we add any series of numbers.

15.11 Subtraction

Since subtraction is simply the reverse of addition, the three rules for addition generally apply to subtraction:

1. KEEP ALL DECIMAL POINTS AND NUMBERS IN COLUMNS

   Example: Subtract 0.042 from 3.574.

$$\begin{array}{r} 3.574 \\ -0.042 \\ \hline 3.532 \end{array}$$

Since subtraction is the reverse of addition, carryovers are not made, but "borrowing" is sometimes necessary.

2. WRITE DOWN ALL BORROWED NUMBERS

   Example: Subtract 296 from 485.

   As before, the numbers should be grouped in columns.

COLUMN LABELS		
Hundreds	Tens	Units
4	8	5
-1	-1	+10
3	7	15
	+10	
	17	
-2	9	6
1	8	9

or

$$\begin{array}{r} \overset{3}{\cancel{4}}\overset{17}{\cancel{8}}5 \\ -296 \\ \hline 189 \end{array}$$

1st Step - Borrow one from the eight (leaving seven) and add ten to the five to get 15--Subtract six from 15 and write down nine.

2nd Step - Borrow one from the four and add ten to the seven to get 17--subtract nine from 17 and write down eight.

3rd Step - Subtract two from three and write down one.

The best way to check a subtraction is by addition. Thus, the preceding problem can be checked by:

$$\begin{array}{r} {}^{1}1^{1}89 \\ +296 \\ \hline 485 \end{array} \quad \text{(Check)}$$

The final rule of subtraction is the same as for addition.

3. ALL NUMBERS MUST BE IN THE SAME DIMENSIONAL UNITS

15.12 Multiplication

Multiplication is simply a short-cut method of addition. In other words, 3 x 4 is simply:

$$3 + 3 + 3 + 3 = 12$$

or

$$4 + 4 + 4 = 12$$

Thus a multiplication problem can always be checked by addition. In the interest of time, however, every operator should memorize the multiplication table through 10.

Multiplication problems involving larger numbers can be solved by addition also. For example, 24 x 17 can be solved by adding a column of seventeen 24's or a column of twenty-four 17's. This procedure, however, would take considerable time, and therefore the simple multiplication steps are preferred.

$$\begin{array}{r} {}^{2}24 \\ \times\ \underline{17} \\ 8 \end{array}$$

1st Step - 4 x 7 = 28--write down eight and carry the two to the next column.

$$\begin{array}{r} {}^{2}24 \\ \times\ \underline{17} \\ 168 \end{array}$$

2nd Step - 2 (from 2 in 24) x 7 = 14; 14 + 2 (carried 2) = 16--write down 16.

$$\begin{array}{r} 24 \\ \times\ \underline{17} \\ 168 \\ 4 \end{array}$$

3rd Step - Erase all carryovers. 4 x 1 = 4--write down four in second row, but <u>one place to left</u>.

$$\begin{array}{r} 24 \\ \times\ \underline{17} \\ 168 \\ 24 \end{array}$$

4th Step - 2 x 1 = 2--write down two.

$$\begin{array}{r} 24 \\ \times\ \underline{17} \\ 168 \\ \underline{24} \\ 408 \end{array}$$

5th Step - Add numbers.

Another approach to multiplication is the regrouping concept we illustrated in the subtraction section by placing the number in the appropriate hundreds (H), tens (T), and units (U) columns. The idea behind this approach is that

10 ones or 10 units (U) = 1 ten (T) = 10

and

10 tens or 10 tens (T) = 1 hundred (H) = 100

Problem: Multiply 24 x 17 or

$$\begin{array}{r} 24 \\ \times\ \underline{17} \end{array}$$

	H	T	U		
1st Step 7 x 4 =		2	8	=	28 units or 2T + 8U
2nd Step 7 x 2 =	1	4			Unit (7) times Ten (2) makes right digit (4) go in T column or 1H + 4T
3rd Step 1 x 4 =		4			T x U = the Tens column
4th Step 1 x 2 =	2				T x T = the Hundreds column
5. Add Columns	3	10	8		
6. Regroup	1				Since 10T = 1H
7. Answer	4	0	8		

To multiply numbers, you may use any method that you understand. These methods are presented to show you different approaches used by many operators which give the same answers.

The first important rule to remember in multiplication is:

1. THE NUMBER OF DECIMAL PLACES IN THE ANSWER IS EQUAL TO THE SUM OF DECIMAL PLACES IN THE NUMBERS MULTIPLIED

```
Example:      14.032             3 decimal places
               1.03            + 2 decimal places
              42096
             00000
            14032
           14.45296              5 decimal places
```

Another way to determine the location of the decimal point is to multiply the numbers without the numbers past the decimal point. For example 14 x 1 = 14. Therefore, 14.032 x 1.03 must be equal to more than 14.

A basic difference between addition and multiplication is that the multiplied numbers do not have to have similar dimensional units.

2. NUMBERS DO NOT HAVE TO HAVE THE SAME DIMENSIONAL UNITS

   For this reason it is important to specify the units that go with the numbers and carry them through to the answer.

   Example: A 20-pound weight on the end of an 8-foot lever would produce--

   20 lbs x 8 ft = 160 ft-lbs

   Example: Three men working five hours each would put in--

   3 men x 5 hours = 15 man-hours of labor

The multiplication operation is indicated by several different symbols. The most common, of course, is the multiplication sign (x) or times sign. Multiplication also can be indicated by parentheses ( ) or by brackets [ ] or simply with a dot • . Thus, the above example can be written five ways:

3 men x 5 hours	=	15 man-hours
(3 men)(5 hours)	=	15 man-hours
[3 men][5 hours]	=	15 man-hours
3 men • 5 hours	=	15 man-hours
(3 men) x 5 hours	=	15 man-hours

When solving a problem with parentheses or brackets, <u>always</u> complete the indicated operation within the parentheses or brackets prior to performing the multiplication.

Example: $(25 - 4)\ (8 + 2)\ (3 \cdot 2) =$

$(21)\ (10)\ (6) =$

$21 \times 10 \times 6 = 1260$

Example: $[15 - (3 + 2)\ (4 - 2)]\ [6 + (7 - 3)] =$

$[15 - (5)\ (2)]\ [6 + 4] =$

$[15 - 10]\ [10] = 50$

15.13 Division

Division offers a means of determining how many times one number is contained in another. It is a series of subtractions. For example, if we say divide 48 by 12, we are also saying, how many times can we take 12 away from 48?

By subtraction:

$48 - 12 = 36$ (one)

$36 - 12 = 24$ (two)

$24 - 12 = 12$ (three)

$12 - 12 = 0$ (four)

By division:

$$12\overline{)48}^{\,4}$$

1st Step - Twelve will not divide into four, but will divide into 48 at least four times.

$$\begin{array}{r} 4 \\ 12\overline{)48} \\ \underline{48} \\ 0 \end{array}$$

2nd Step - Multiply 4 x 12 and write answer under 48. Remainder is zero. Answer is four even.

Division problems can be written in many ways:

$5\overline{)10}^{\,2}$ $\qquad 10 \div 5 = 2 \qquad \frac{10}{5}$* $= 2 \qquad 10/5 = 2$

In each case,

5 = divisor

10 = dividend

2 = quotient

It is always easier to divide by a whole number.

---

* You will encounter this form in Section 15.2 as a fraction.

1. MOVE THE DECIMAL POINT OF THE DIVISOR ALL THE WAY TO THE RIGHT AND THE DECIMAL POINT OF THE DIVIDEND THE SAME NUMBER OF PLACES TO THE RIGHT

Example: Divide 1.25 by 0.045.

$$0.045.\overline{)1.250.}$$

1st Step - Move decimal point three places to right in divisor and dividend.

$$\begin{array}{r} 2. \\ 45\overline{)1250.0} \end{array}$$

2nd Step - Forty-five will not divide into one or 12, but will go into 125 about two times.

$$\begin{array}{r} 2 \\ 45\overline{)1250.0} \\ \underline{90} \\ 35 \end{array}$$

3rd Step - Multiply 45 by 2 and subtract answer from 125.

$$\begin{array}{r} 2 \\ 45\overline{)1250.0} \\ \underline{90} \\ 350 \end{array}$$

4th Step - Bring down zero.

$$\begin{array}{r} 27 \\ 45\overline{)1250.0} \\ \underline{90} \\ 350 \end{array}$$

5th Step - Forty-five will go into 350 about seven times.

$$\begin{array}{r} 27 \\ 45\overline{)1250.0} \\ \underline{90} \\ 350 \\ \underline{315} \\ 35 \end{array}$$

6th Step - Multiply 45 by 7 and subtract answer from 350.

$$\begin{array}{r} 27.7 \\ 45\overline{)1250.0} \\ \underline{90} \\ 350 \\ \underline{315} \\ 35 \end{array}$$

7th Step - Bring down zero. Once again, 45 will go into 350 about 7 times.

If this problem is continued, sevens will continue to show up in the answer. The answer, then, is 27.777, etc. In most cases 27.78 will be sufficiently accurate. This is called "rounding off" the numbers. The last number 7 was increased to 8 because the number after it was 5 or higher.

When solving a division problem, complete the indicated operations above and below the division line before dividing.

Example:

$$\frac{25 - (2)\ (3) + 18/2}{19 - (3)\ (4)} + \frac{(4)\ (9)}{12} - 5 =$$

$$\frac{25 - 6 + 9}{19 - 12} + \frac{36}{12} - 5 =$$

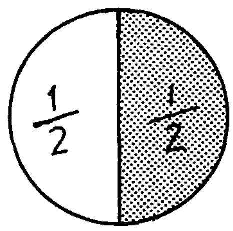
$$\frac{28}{7} + 3 - 5 =$$

$$4 + 3 - 5 = 2$$

15.2 FRACTIONS

15.20 General

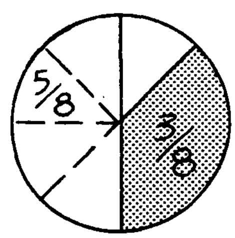
A fraction in its most common form is a part of a whole. For instance, if a pie is divided into two equal parts and one part is eaten, only one half of the pie remains.



1/2 + 1/2 = 1

Thus it can be seen that a fraction is division that has not been completed. As previously explained, in the fraction 1/2, one is the dividend and two is the divisor. More commonly, however, one is called the <u>numerator</u> and two is called the <u>denominator</u>.

If the pie were divided into eight equal pieces and five were eaten, we would have less than one half a pie. We would have 3/8 of a pie remaining.



5/8 + 3/8 = 1

15.21 Improper Fraction

An improper fraction has a larger numerator than denominator and is therefore greater than one. An improper fraction may be reduced to a whole or mixed number by dividing the denominator into the numerator.

Example: $\frac{13}{8}$ (numerator) / (denominator) $= 8\overline{)13}$ with quotient 1; $13 - 8 = 5$; $= 1\frac{5}{8}$

$$\begin{array}{r} 1 \\ 8\overline{)13} \\ \underline{8} \\ 5 \end{array} = 1\,\frac{5}{8}$$

The reverse of this operation would be changing a whole or mixed number into a fraction. To accomplish this the whole number is multiplied by the denominator, the numerator is added, and this total is written over the denominator.

Example: $2\ 1/4 = \dfrac{4 \times 2 + 1}{4}$

$$= \frac{8 + 1}{4}$$

$$= \frac{9}{4}$$

15.22 Reducing a Fraction to Lowest Terms

To change a fraction to its lowest terms, divide the numerator and denominator by the largest number that will divide evenly into both:

Example: $\dfrac{15}{45} = \dfrac{15 \div 15}{45 \div 15} = \dfrac{1}{3}$

NOTE: At this point it should be remembered that the numerator and denominator can be divided or multiplied by the same number without changing the value of the fraction.

Sometimes it will not be possible to reduce the fraction to its lowest terms with the first trial division. In this case, division continues until it can no longer be performed by a number larger than one.

Example:

$$\frac{216}{324} = \frac{216 \div 3}{324 \div 3} = \frac{72}{108} = \frac{72 \div 9}{108 \div 9} = \frac{8}{12} = \frac{8 \div 4}{12 \div 4} = \frac{2}{3}$$

In solving this problem all of these steps could have been eliminated if we had realized that 108 will divide into the numerator twice and into the denominator three times. This is usually difficult to see, however, and smaller numbers must be used as trial divisors.

15.23 Adding and Subtracting

Whenever fractions are added or subtracted it is necessary that the denominators be the same. In adding or subtracting fractions, you simply add or subtract numerators.

Example: $\frac{3}{5} + \frac{4}{5} = \frac{7}{5} = 1\frac{2}{5}$

Example: $\frac{7}{8} - \frac{3}{8} = \frac{4}{8} = \frac{1}{2}$

If the denominators are not the same, they must be made the same before addition or subtraction takes place. In changing the form of a fraction, the numerator and denominator must be multiplied by the same number.

Example: $\frac{3}{5} + \frac{5}{10} = \frac{3(2)}{5(2)} + \frac{5}{10} = \frac{6}{10} + \frac{5}{10} = \frac{11}{10} = 1\frac{1}{10}$

Example: $\frac{2}{3} - \frac{4}{9} = \frac{2(3)}{3(3)} - \frac{4}{9} = \frac{6}{9} - \frac{4}{9} = \frac{2}{9}$

In some cases the denominators cannot be changed to one of the problem's existing denominators. For instance, in adding 1/3 and 1/4, the 1/3 can't be changed to an even fourth, and the 1/4 can't be changed to an even third. In this case, they must both be changed to the least common denominator. The least common denominator is the smallest number that each denominator will go into one or more times without a remainder.

Example: $\frac{1}{3} + \frac{1}{4}$

The lowest number that both 3 and 4 will both go into is 12. Three will go into twelve 4 times; four will go into twelve 3 times.

Therefore, the least common denominator is 12. We obtained 12 by multiplying 3 x 4.

$$\frac{1 \times 4}{3 \times 4} + \frac{1 \times 3}{4 \times 3} = \frac{4}{12} + \frac{3}{12} = \frac{7}{12}$$

15.24 Multiplication

Multiply all of the numerators together for a new numerator, and multiply all of the denominators together for a new denominator. In multiplication, denominators need not be the same.

Example: $\frac{5}{7} \times \frac{2}{4} = \frac{10}{28} = \frac{5}{14}$

Before multiplying mixed numbers, change the mixed numbers to improper fractions:

Example: $2\frac{1}{2} \times \frac{2}{5} = \frac{5}{2} \times \frac{2}{5} = \frac{10}{10} = 1$

In some cases a problem can be simplified by dividing (or canceling) prior to beginning the multiplication. This operation also speeds up the process of reducing the answer to its simplest form. To reduce numbers by cancellation, look for a number in the numerator and denominator that can be divided by the same number.

Example: $\frac{\overset{1}{\cancel{2}}}{\underset{1}{\cancel{3}}} \times \frac{\overset{1}{\cancel{3}}}{\underset{2}{\cancel{4}}} \times \frac{1}{5} = \frac{1}{10}$ (2 goes into 4--2 times) (3 goes into 3--1 time)

Example - the same problem without cancellation:

$$\frac{2}{3} \times \frac{3}{4} \times \frac{1}{5} = \frac{6}{60} = \frac{1}{10}$$

Another example of calculation:

$$\frac{\overset{3}{\cancel{9}}}{\underset{4}{\cancel{28}}} \times \frac{\overset{5}{\cancel{35}}}{\underset{8}{\cancel{24}}} = \frac{3}{4} \times \frac{5}{8} = \frac{15}{32}$$ (3 goes into 9 and 24) (7 goes into 28 and 35)

15.25 Division

To divide two fractions, invert the divisor and multiply.

Example: $\frac{1}{2} \div \frac{1}{3} = \frac{1}{2} \times \frac{3}{1} = \frac{3}{2} = 1\frac{1}{2}$

Example: $\frac{5}{6} \div \frac{3}{12} = \frac{5}{\cancel{6}_{1}} \times \frac{\cancel{12}^{2}}{3} = \frac{10}{3} = 3\frac{1}{3}$

15.26 Decimal Fractions

Decimal fractions are fractions which have 10, 100, 1000, etc., for denominators. They are usually called decimals.

$\frac{5}{10}$ = 0.5 = five-tenths

$\frac{15}{100}$ = 0.15 = fifteen-hundredths

$375\frac{25}{1000}$ = 375.025 = three hundred seventy-five and twenty-five thousandths

or = three hundred seventy-five point zero two five

To change any fraction to a decimal, divide the numerator by the denominator.

Example: $\frac{3}{4} = 3 \div 4 =$

$$\begin{array}{r} 0.750 \\ 4\overline{)3.000} \\ \underline{2\ 8} \\ 20 \\ \underline{20} \\ 0 \end{array}$$

Example: $\frac{5}{6} = 5 \div 6 =$

$$\begin{array}{r} 0.833\ .\ .\ .\ .\ \text{(not even)} \\ 6\overline{)5.000} \\ \underline{4\ 8} \\ 20 \\ \underline{18} \\ 20 \\ \underline{18} \\ 2 \end{array}$$

To change a decimal to a fraction, multiply the decimal by 10/10, 100/100, 1000/1000, etc. It should be noted that multiplying by these factors is multiplying by one (100/100 = 1) and does not change the value of the answer.

Example: $$0.25 \times \frac{100}{100} = \frac{25}{100} = \frac{1}{4}$$

Example: $$0.375 \times \frac{1000}{1000} = \frac{375}{1000} = \frac{15}{40} = \frac{3}{8}$$

15.27 Percentage

Expressing a number in percentage is just another, and sometimes simpler, way of writing a fraction or a decimal. It can be thought of as parts per 100 parts, since the percentage is the numerator of a fraction whose denominator is always 100. Twenty-five parts per 100 parts is more easily recognized as 25/100 or 0.25. However, it is also 25%. In this case, the symbol % takes the place of the 100 in the fraction and the decimal point in the decimal fraction.

For the above example it can be seen that changing from a fraction or a decimal to percent is not a difficult procedure.

1. To change a fraction to percent, multiply by 100%.

   Example: $$\frac{2}{5} \times 100\% = \frac{200\%}{5} = 40\%$$

   Example: $$\frac{5}{4} \times 100\% = \frac{500\%}{4} = 125\%$$

2. To change percent to a fraction, divide by 100%.

   Example: $$15\% \div 100\% = 15\% \times \frac{1}{100\%} = \frac{15}{100} = \frac{3}{20}$$

   Example: $$0.4\% \div 100\% = 0.4\% \times \frac{1}{100\%} = \frac{.4}{100} = \frac{4}{1000} = \frac{1}{250}$$

   In these examples note that the two percent signs cancel each other.

Following is a table comparing common fractions, decimal fractions, and percent to indicate their relationship to each other:

Common Fraction	Decimal Fraction	Percent
$\frac{285}{100}$	2.85	285%
$\frac{100}{100}$	1.0	100%
$\frac{20}{100}$	0.20	20%
$\frac{1}{100}$	0.01	1%
$\frac{1}{1000}$	0.001	0.1%
$\frac{1}{1,000,000}$	0.000001	0.0001%

15.28 Sample Problems Involving Percent

Problems involving percent are usually not complicated since their solution consists of only one or two steps. The principal error made is usually a misplaced decimal point. The most common type percentage problem is finding:

1. WHAT PERCENT ONE NUMBER IS OF ANOTHER

   In this case, the problem is simply one of reading carefully to determine the correct fraction and then converting to a percentage.

Example: What percent is 20 of 25?

$$\frac{20}{25} = \frac{4}{5} = 0.8$$

$$0.8 \times 100\% = 80\%$$

Example: Four is what percent of 14?

$$\frac{4}{14} = 0.2857$$

$$0.2857 \times 100\% = 28.57\%$$

Example: Influent BOD to a clarifier is 200 mg/l. Effluent BOD is 140 mg/l. What is the percent removal in the clarifier? (NOTE: 200-140 = the part removed in the clarifier.)

$$\frac{200 - 140}{200} = \frac{60}{200} = 0.30 \text{ of the original load is removed}$$

$$0.30 \times 100\% = 30\% \text{ removal}$$

$$\text{Therefore \% removal} = \frac{(\text{In} - \text{Out})}{\text{In}} \times 100\%$$

Another type of percentage problem is finding:

2. PERCENT OF A GIVEN NUMBER

In this case the percent is expressed as a decimal, and the two numbers are multiplied together.

Example: Find 7% of 32.

$$0.07 \times 32 = 2.24$$

Example: Find 90% of 5.

$$.90 \times 5 = 4.5$$

Example: What is the weight of dry solids in a ton (2000 lbs) of wastewater sludge containing 5% solids and 95% water?

NOTE: 5% solids means there are 5 lbs of dry solids for every 100 lbs of wet sludge.

Therefore

2000 lbs x 0.05 = 100 lbs of solids

A variation of the preceding problem is:

3. FINDING A NUMBER WHEN A GIVEN PERCENT OF IT IS KNOWN

Since this problem is similar to the previous problem, the solution is to convert to a decimal and divide by the decimal.

Example: If 5% of a number is 52, what is the number?

$$\frac{52}{0.05} = 1040$$

A check calculation may now be performed--what is 5% of 1040?

0.05 x 1040 = 52 (Check)

Example: 16 is 80% of what amount?

$$\frac{16}{0.80} = 20$$

Example: Percent removal of BOD in a clarifier is 35%. If 70 mg/l are removed, what is the influent BOD?

$$\text{Influent BOD} = \frac{70}{0.35} = 200 \text{ mg/l}$$

Check:

Original load x % removal = load removed

200 mg/1 x 0.35 = 70 mg/1

15.29 Ratio and Proportion

Ratio is the comparison of two numbers of the same denomination. For example, 1 inch compared to 3 inches, or 3 boxes compared to 7 boxes. Ratios are written either as fractions, 1/3, or as 1:3 (which is read "the ratio of one to three").

Proportion is the equating of ratios. For example, 3/6 is equal to 1/2. A proportion is usually written in the form a/b = c/d, or a:b = c:d (which is read as *a* is to *b* as *c* is to *d*).

To solve the proportion a/b = c/d, we multiply diagonally across

$$\frac{a}{b} \times \frac{c}{d}$$

Therefore, a x d = b x c. This procedure is sometimes called cross multiplication.

This can be proved by substituting the previous example:

$$\frac{3}{6} = \frac{1}{2}$$

$$3 \times 2 = 6 \times 1$$

$$6 = 6$$

When one complete ratio is known and one term of the second ratio is known, the proportion relationship indicates what the unknown number should be.

For instance, if one number from the previous example were missing, the number could be found by cross multiplying.

$$\frac{a}{6} = \frac{1}{2}$$

$$a \times 2 = 6 \times 1$$

$$\frac{a \times 2}{2} = \frac{6 \times 1}{2}$$ Divide both sides of equation by 2.

$$a = \frac{6 \times 1}{2}$$

$$= \frac{6}{2}$$

$$= 3$$

A few example problems should indicate how to deal with ratios and proportions.

Example: Certain bolts cost 90 cents a dozen. How much would three bolts cost?

In setting up this proportion, we would say: 12 bolts cost 90 cents; 3 bolts cost x cents. Therefore, the proportion is written either as $12/3 = 90/x$ or $12/90 = 3/x$.

$$\frac{12}{90} = \frac{3}{x}$$

$$12 \times x = 90 \times 3$$

$$x = \frac{90 \times \cancel{3}^{1}}{\cancel{12}_{4}}$$

$$= \frac{90}{4}$$

$$= 22\ 1/2 \text{ or } 23¢ \text{ (to the nearest penny)}$$

Example: If 3 lbs of salt are added to 10 gallons of water to make a solution of a given strength, how many pounds would be added to 129 gallons to make a solution of the same concentration?

$$\frac{3 \text{ lbs}}{10 \text{ gal}} = \frac{x}{129 \text{ gal}}$$

$$x \text{ (10 gal)} = 3 \text{ lbs (129 gal)}$$

$$x = \frac{3 \text{ lbs } (129 \cancel{\text{gal}})}{10 \cancel{\text{gal}}}$$

$$= \frac{387 \text{ lbs}}{10}$$

$$= 38.7 \text{ lbs}$$

NOTE: Gallons in the numerator and gallons in the denominator can be canceled without changing the value of the solution.

Although proportions are usually not difficult to solve, some care must be taken when using them. Some varying quantities are <u>inversely proportional</u> to each other. Their products, rather than their ratios, are constant. This can be easily explained by an example.

Example: If three men can do a certain job in 10 hours, how long would it take five men to do the same job?

This problem is inversely proportional. If this fact were not noticed, many would solve it by direct proportion.

$$\frac{3 \text{ men}}{10 \text{ hours}} = \frac{5 \text{ men}}{x \text{ hrs}}$$

$$x = \frac{5 \cancel{\text{men}} \text{ x } 10 \text{ hrs}}{3 \cancel{\text{men}}}$$

$$= \frac{50 \text{ hrs}}{3}$$

$$= 16 \text{ 2/3 hrs} \quad \text{(Wrong)}$$

The solution is wrong since <u>increasing the manpower</u> should <u>decrease the time</u> required to do the job. The problem is therefore inversely proportional and the products of the varying quantities should be equated.

$$3 \text{ men} \times 10 \text{ hours} = 5 \text{ men } (x \text{ hrs})$$

$$x = \frac{3 \cancel{\text{men}} \times 10 \text{ hrs}}{5 \cancel{\text{men}}}$$

$$= 6 \text{ hrs}$$

It is important for the operator to remember that gas pressure-volume problems are also inversely proportional. The higher the pressure, the smaller the volume of gas.

Example: A vessel contains 100 cubic feet of gas at 5 lbs per square inch pressure. What is the pressure if the volume is reduced to 40 cubic feet?

$$100 \text{ cu ft} \times 5 \text{ psi} = 40 \text{ cu ft } (x \text{ psi})$$

$$x = \frac{100 \cancel{\text{cu}} \cancel{\text{ft}} \times 5 \text{ psi}}{40 \cancel{\text{cu}} \cancel{\text{ft}}}$$

$$= \frac{500 \text{ psi}}{40}$$

$$= 12.5 \text{ psi}$$

NOTE: In this problem the temperature was assumed to remain constant.

15.3 SQUARES, CUBES, AND ROOTS

15.30 Squares and Square Roots

Squaring a number simply means multiplying a number by itself. For instance, in squaring two we obtain four (2 x 2 = 4). In squaring three, the answer is nine. A short way of writing 2 x 2 is by using the superscript 2 in the following manner, 2^2. Thus, if we were trying to indicate the squaring of numbers we would write:

$$1^2 = 1$$

$$2^2 = 4$$

$$3^2 = 9$$

$$4^2 = 16$$

$$5^2 = 25, \text{ and so on}$$

A reverse of this process is to take a number that has been squared and find the number which was multiplied by itself to form the square. This process is called finding the square root. The sign $\sqrt{}$ indicates square root. The square root of 4 is written, $\sqrt{4}$, and the answer is 2. The reverse of the previous column would then be:

$$\sqrt{1} = 1$$

$$\sqrt{4} = 2$$

$$\sqrt{9} = 3$$

$$\sqrt{16} = 4$$

$$\sqrt{25} = 5, \text{ and so on}$$

A difficulty arises when the square root of a number does not result in a whole number. Such is the case for $\sqrt{20}$. Since the $\sqrt{16}$ is 4, and the $\sqrt{25}$ is 5, the answer is between 4 and 5. Two solutions are available to the operator who does not possess a calculating machine, slide rule, table of square roots, or a logarithm table. One method is an exact method which is similar to a long division problem. For this method, the operator must refer to a mathematical textbook. Quite frankly, this method is cumbersome and difficult to remember if you do not work with it frequently.

The other method is a trial and error method. This method is shown here because it is a method which will enable the solution of square root problems using only the knowledge of multiplication.

Example: Find the square root of 20.

As previously discussed, the answer is between 4 and 5. Therefore, simply guess a number and square it.

Assume 4.3:

4.3 x 4.3 = 18.49

$$\begin{array}{r} 4.3 \\ \underline{4.3} \\ 129 \\ \underline{172} \\ 18.49 \end{array}$$

Next assume 4.4:

4.4 x 4.4 = 19.36

Since $(4.4)^2$ is close to 20, next try 4.44 (these numbers are picked because they are quickly multiplied).

4.44 x 4.44 = 19.7136

Next assume 4.46:

4.46 x 4.46 = 19.8916

Next assume 4.47:

4.47 x 4.47 = 19.9809

For most purposes, 4.47 would be sufficiently close to use as the answer.

For most numbers the trial and error solution takes more time than the exact solution. Its advantage is that it requires no memorized steps for solution, except multiplication.

15.31 Cubes and Cube Roots

Multiplying a number by itself twice results in the cube of the number. For example, the cube of 2 is $2 \times 2 \times 2 = 2^3$, or 8. The cube of a number is indicated by a superscript 3.

$$1^3 = 1$$

$$2^3 = 8$$

$$3^3 = 27$$

$$4^3 = 64$$

$$5^3 = 125, \text{ and so on}$$

The reverse of this process is to take the cube root of a number.

The sign $\sqrt[3]{}$ indicates cube root.

$$\sqrt[3]{125} = 5$$

$$\sqrt[3]{64} = 4$$

$$\sqrt[3]{27} = 3$$

$$\sqrt[3]{8} = 2$$

$$\sqrt[3]{1} = 1$$

Cube roots can be found by methods similar to those discussed for square roots. The operator does not usually come in contact with many problems involving cubes or cube roots.

A rather simple solution for square roots and cube roots is by use of logarithms. The only mathematical step involved is division by 2 or 3. The only disadvantage is that you must have a logarithm table handy. Since logarithms also offer a quick means of multiplying large numbers, it is suggested that the operator become familiar with them and keep a "log" table handy at his desk. Directions for using logarithms are found in math textbooks and in Chapter 16, Section 16.6.

If at all possible you should obtain a handbook containing logarithms and tables of squares, square roots, cubes, cube roots, tank capacities and other valuable information. Manufacturers' literature sometimes contains this type of information.

15.4 AVERAGES AND MEDIAN

Computing an average from a set of data offers a way of simplifying the data or comparing one set of data with another. If an average value is computed by adding a series of items and then dividing the total by the number of items, the result is called an arithmetic mean.

Example: Influent BOD's at a treatment plant are determined every day. The following composite values were obtained during one week: 210, 180, 175, 215, 195, 155, and 200. What is the arithmetic mean for the week?

$$\text{Average} = \frac{\text{Sum of items or values}}{\text{Number of items or values}}$$

$$= \frac{210+180+175+215+195+155+200}{7}$$

$$= 190 \text{ mg/l}$$

$$\begin{array}{r} 210 \\ 180 \\ 175 \\ 215 \\ 195 \\ 155 \\ \underline{200} \\ 1330 \end{array}$$

$$\begin{array}{r} 190 \\ 7\overline{)1330} \\ \underline{7} \\ 63 \\ \underline{63} \\ 0 \end{array}$$

Weekly average or mean BOD = 190 mg/l

Another arithmetic tool to analyze a set of data is the median. The median in a set of data is the middle value. There are just as many values above a median as there are below.

To determine the median, the data should be written in ascending or descending order and the middle value identified.

Example: What is the median BOD in the preceding problem?

215
210
200
195 - Median Weekly median BOD = 195 mg/l
180
175
155

Median coliform numbers are sometimes used as a standard by regulatory agencies to avoid allowing too much weight to large coliform values.

Example: Five days of sampling resulted in most probable number (MPN) of coliform group bacteria per 100 ml of 23, 5, 2, 2300, and 16. Find the mean and median coliform content.

$$\text{Mean} = \frac{\text{Sum of values}}{\text{Number of values}}$$

$$\text{Mean MPN/100 ml} = \frac{23+5+2+2300+16}{5}$$

$$= \frac{2346}{5}$$

$$\text{Mean MPN/100 ml} = 469 \text{ coliform}$$

$$\begin{array}{r} 2300 \\ 23 \\ 16 \\ 5 \\ \underline{2} \\ 2346 \end{array}$$

$$\begin{array}{r} 469 \\ 5\overline{)2346} \\ \underline{20} \\ 34 \\ \underline{30} \\ 46 \\ 45 \end{array}$$

$$\text{Median MPN/100 ml} = 16 \text{ coliform}$$

The above example indicates that the median value completely eliminates the effect of the one large sample, while the mean value is affected a great deal. Most agencies feel that the minimum and maximum values of a group of data should always be stated along with a mean or median. The difference between the maximum and minimum values is called the range.

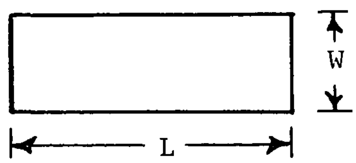
15.5 AREAS

15.50 General

Areas are measured in two dimensions or in square units. In the English system of measurement the most common units are square inches, square feet, square yards, and square miles. In the metric system the units are square millimeters, square centimeters, square meters, and square kilometers.

15.51 Rectangle

The area of a rectangle is equal to its length (L) multiplied by its width (W).



$$\boxed{A = L \times W}$$

Example: Find the area of a rectangle if the length is 5 feet and the width is 3.5 feet.

$$\begin{aligned} \text{Area, sq ft} &= \text{Length, ft} \times \text{Width, ft} \\ &= 5 \text{ ft} \times 3.5 \text{ ft} \\ &= 17.5 \text{ ft}^2 \\ &= 17.5 \text{ sq ft} \end{aligned}$$

Example: The surface area of a settling basin is 330 square feet. One side measures 15 feet. How long is the other side?

$$A = L \times W$$

$$330 \text{ sq ft} = L \text{ ft} \times 15 \text{ ft}$$

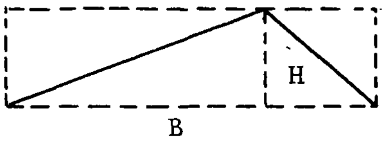
$$\frac{L \text{ ft} \times 15 \text{ ft}}{15 \text{ ft}} = \frac{330 \text{ ft}^2}{15 \text{ ft}}$$ Divide both sides of equation by 15 ft.

$$\begin{aligned} L \text{ ft} &= \frac{330 \text{ ft}^2}{15 \text{ ft}} \\ &= 22 \text{ ft} \end{aligned}$$

15.52 Triangle

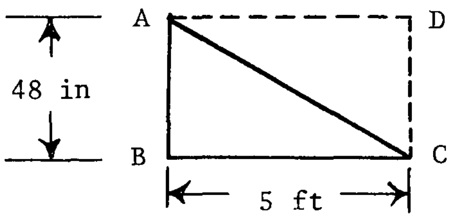
The area of a triangle is equal to one half the base multiplied by the height. This is true for any triangle.

$$\boxed{A = \frac{1}{2} B \times H}$$



NOTE: The area of any triangle is equal to 1/2 the area of the rectangle that can be drawn around it. The area of the rectangle is B x H. The area of the triangle is 1/2 B x H.

Example: Find the area of triangle ABC:



The first step in the solution is to make all the units the same. In this case, it is easier to change inches to feet.

$$48 \text{ in} = 48 \cancel{\text{in}} \times \frac{1 \text{ ft}}{12 \cancel{\text{in}}} = \frac{48}{12} \text{ ft} = 4 \text{ ft}$$

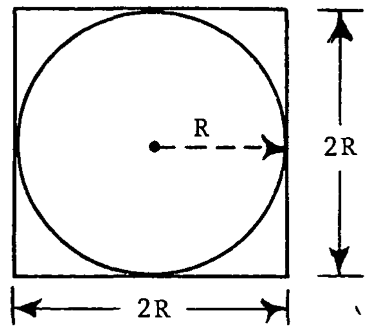
NOTE: All conversions should be calculated in the above manner. Since 1 ft/12 in is equal to unity, or one, multiplying by this factor changes the form of the answer but not its value.

$$\begin{aligned} \text{Area, sq ft} &= 1/2 \text{ (Base, ft)(Height, ft)} \\ &= 1/2 \times 5 \text{ ft} \times 4 \text{ ft} \\ &= \frac{20}{2} \text{ ft}^2 \\ &= 10 \text{ sq ft} \end{aligned}$$

NOTE: Triangle ABC is one half the area of rectangle ABCD. The triangle is a special form called a Right Triangle since it contains a 90° angle at point B.

15.53 Circle

A square with sides of 2R can be drawn around a circle with a radius of R.



The area of the square is: $A = 2R \times 2R = 4R^2$.

It has been found that the area of any circle inscribed within a square is slightly more than 3/4 of the area of the square. More precisely, the area of the preceding circle is:

$$A \text{ circle} = 3\frac{1}{7}R^2 = 3.14\ R^2$$

The formula for the area of a circle is usually written:

$$\boxed{A = \pi R^2}$$

The Greek letter π (pronounced pie) merely substitutes for the value 3.1416.

Since the diameter of any circle is equal to twice the radius, the formula for the area of a circle can be rewritten as follows:

$$A = \pi R^2 = \pi \times R \times R = \pi \times \frac{D}{2} \times \frac{D}{2} = \frac{\pi D^2}{4} = \frac{3.14}{4} D^2 = \boxed{0.785\ D^2}$$

The type of problem and the magnitude of the numbers in a problem will determine which of the two formulas will provide a simpler solution. All of these formulas will give the same results if you use the same number of digits to the right of the decimal point.

Example: What is the area of a circle with a diameter of 20 centimeters?

In this case, the formula using a radius is more convenient since it takes advantage of multiplying by 10.

$$\text{Area, sq cm} = \pi (\text{R, cm})^2$$
$$= 3.14 \times 10 \text{ cm} \times 10 \text{ cm}$$
$$= 314 \text{ sq cm}$$

Example: What is the area of a trickling filter with a 50-foot radius?

In this case, the formula using diameter is more convenient.

$$\text{Area, sq ft} = 0.785 (\text{Diameter, ft})^2$$
$$= 0.785 \times 100 \text{ ft} \times 100 \text{ ft}$$
$$= 7850 \text{ sq ft}$$

Occasionally the operator may be confronted with a problem giving the area and requesting the radius or diameter. This presents the special problem of finding the square root of the number.

Example: The surface area of a circular clarifier is approximately 5000 square feet. What is the diameter?

$A = 0.785\ D^2$, or

$$\text{Area, sq ft} = 0.785 (\text{Diameter, ft})^2$$

$5000 \text{ sq ft} = 0.785\ D^2$ -- To solve, substitute given values in equation.

$\frac{0.785\ D^2}{0.785} = \frac{5000 \text{ sq ft}}{0.785}$ -- Divide both sides by 0.785 to find D^2.

$$D^2 = \frac{5000 \text{ sq ft}}{0.785}$$

$= 6369$ sq ft. Therefore,

$D =$ square root of 6369 sq ft, or

$$\text{Diameter, ft} = \sqrt{6369 \text{ sq ft}}$$

As previously mentioned, it is sometimes easier to use a trial and error method of finding square roots. Since 80 x 80 = 6400, we know the answer is close to 80 feet.

Try 79 x 79 = 6241

Try 79.5 x 79.5 = 6320.25

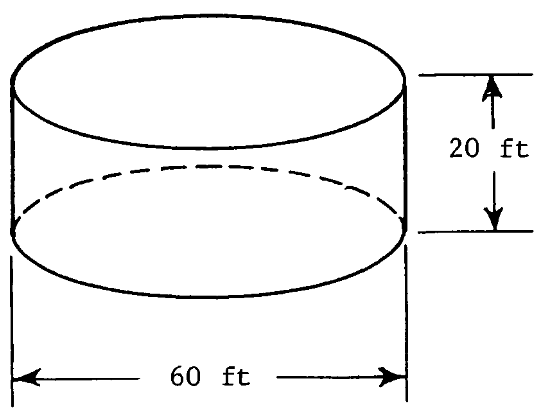
Try 79.8 x 79.8 = 6368.04

The diameter is 79.8 ft, or approximately 80 feet.

15.54 Cylinder

With the formulas presented thus far, it would be a simple matter to find the number of square feet in a room that was to be painted. The length of each wall would be added together and then multiplied by the height of the wall. This would give the surface area of the walls (minus any area for doors and windows). The ceiling area would be found by multiplying length times width and the result added to the wall area gives the total area.

The surface area of a circular cylinder, however, has not been discussed. If we wanted to know how many square feet of surface area are in a tank with a diameter of 60 feet and a height of 20 feet, we could start with the top and bottom.



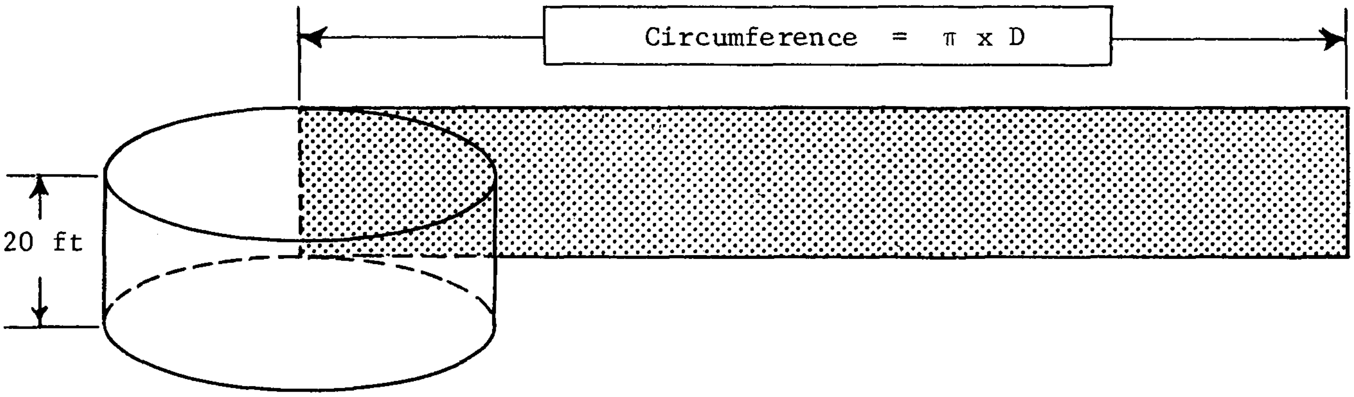
The area of the top and bottom ends are both $\pi \times R^2$

$$\text{Area, sq ft} = 2 \text{ ends } (\pi)(\text{Radius, ft})^2$$

$$= 2 \times \pi \times (30 \text{ ft})^2$$

$$= 5652 \text{ sq ft}$$

The surface area of the wall must now be calculated. If we made a vertical cut in the wall and unrolled it, the straightened wall would be the same length as the circumference of the floor and ceiling.



This length has been found to always be π x D. In the case of the tank, the length of the wall would be:

Length, ft = (π) (Diameter, ft)
= 3.14 x 60 ft
= 188.4 ft

Area would be:

A_w, sq ft = Length, ft x Height, ft

= 188.4 ft x 20 ft

= 3768 sq ft

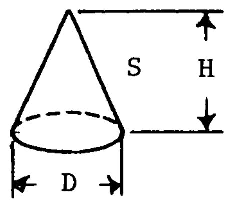
Outside Surface Area
to Paint, sq ft = Area of top and bottom, sq ft + Area of wall, sq ft

= 5652 sq ft + 3768 sq ft

= 9420 sq ft

A container has inside and outside surfaces and you may need to paint both of them.

15.55 Cone



The lateral area of a cone is equal to 1/2 of the slant height (S) multiplied by the circumference of the base.

$$\boxed{A_L = 1/2\ S \times \pi \times D = \pi \times S \times R}$$

In the case the slant height is not given, it may be calculated by:

$$S = \sqrt{R^2 + H^2}$$

Example: Find the entire outside area of a cone with a diameter of 30 inches and a height of 20 inches.

$$\text{Slant Height, in} = \sqrt{(\text{Radius, in})^2 + (\text{Height, in})^2}$$

$$= \sqrt{(15\text{ in})^2 + (20\text{ in})^2}$$

$$= \sqrt{225\text{ in}^2 + 400\text{ in}^2}$$

$$= \sqrt{625\text{ in}^2}$$

$$= 25\text{ in}$$

$$\text{Area of Cone, sq in} = \pi\ (\text{Slant Height, in})(\text{Radius, in})$$

$$= 3.14 \times 25\text{ in} \times 15\text{ in}$$

$$= 1177.5\text{ sq in}$$

Since the entire area was asked for, the area of the base must be added.

Area, sq in $= 0.785\ (\text{Diameter, in})^2$

$= 0.785 \times 30\ \text{in} \times 30\ \text{in}$

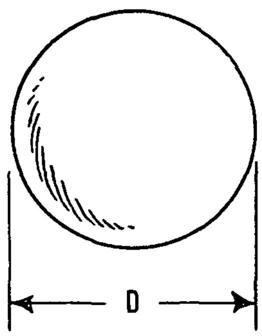
$= 706.5\ \text{sq in}$

= Area of Cone, sq in + Area of Bottom, sq in

Total Area, sq in $= 1177.5\ \text{sq in} + 706.5\ \text{sq in}$

$= 1884\ \text{sq in}$

15.56 Sphere



The surface area of a sphere or ball is equal to π multiplied by the diameter squared.

$$\boxed{A_S = \pi D^2}$$

If the radius is used, the formula becomes:

$$A_S = \pi D^2 = \pi \times 2R \times 2R = 4\pi R^2$$

Example: What is the surface area of a sphere shaped methane gas container 20 feet in diameter?

Area, sq ft $= \pi\ (\text{Diameter, ft})^2$

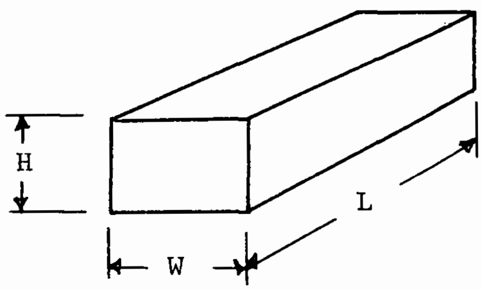
$= 3.14 \times 20\ \text{ft} \times 20\ \text{ft}$

$= 1256\ \text{sq ft}$

15.6 VOLUMES

15.60 Rectangle

Volumes are measured in three dimensions or in cubic units. To calculate the volume of a rectangle, the area of the base is calculated in square units and then multiplied by the height. The formula then becomes:



$$\boxed{V = L \times W \times H}$$

Example: The length of a box is two feet, the width is 15 inches, and the height is 18 inches. Find its volume.

$$\text{Volume, cu ft} = \text{Length, ft} \times \text{Width, ft} \times \text{Height, ft}$$

$$= 2 \text{ ft} \times 1\frac{1}{4} \text{ ft} \times 1\frac{1}{2} \text{ ft}$$

$$= \cancel{2} \text{ ft} \times \frac{5}{4} \text{ ft} \times \frac{3}{\cancel{2}} \text{ ft}$$

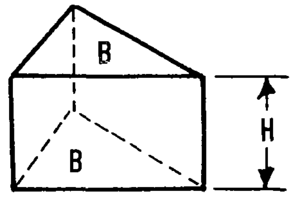
$$= \frac{15}{4} \text{ cu ft}$$

$$= 3\frac{3}{4} \text{ cu ft}$$

15.61 Prism

The same general rule that applies to a rectangle also applies to a prism.

$$\boxed{\text{Volume} = \text{Area of Base x Height}}$$



Example: Find the volume of a prism with a base area of 10 square feet and a height of 5 feet.

Volume, cu ft = Area of Base, sq ft x Height, ft

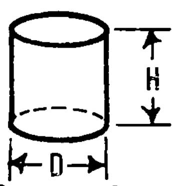
= 10 sq ft x 5 ft

= 50 cu ft

15.62 Cylinder

The volume of a cylinder is equal to the area of the base multiplied by the height.

$$\boxed{V = \pi R^2 \times H = 0.785\ D^2 \times H}$$



Example: A primary clarifier has a diameter of 100 feet and a depth of 12 feet. Find the volume.

Volume, cu ft = 0.785 x (Diameter, ft)^2 x Height, ft

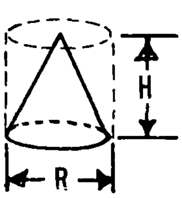
= 0.785 x 100 ft x 100 ft x 12 ft

= 94,200 cu ft

15.63 Cone

The volume of a cone is equal to 1/3 the volume of circular cylinder of the same height and diameter.

$$\boxed{V = \frac{\pi}{3} R^2 \times H}$$



Example: Calculate the additional volume in the cone portion of the clarifier in Section 15.62 if the depth at the center of the clarifier is 16 ft. H = 16 ft - 12 ft.

$$\text{Volume, cu ft} = \frac{\pi}{3} \times (\text{Radius})^2 \times \text{Height, ft}$$

$$= \frac{\pi}{3} \times 50 \text{ ft} \times 50 \text{ ft} \times 4 \text{ ft}$$

$$= 10{,}500 \text{ cu ft}$$

15.64 Sphere

The volume of a sphere is equal to $\pi/6$ times the diameter cubed.

$$\boxed{V = \frac{\pi}{6} \times D^3}$$

Example: How much gas can be stored in a sphere with a diameter of 12 feet? (Assume atmospheric pressure.)

$$\text{Volume, cu ft} = \frac{\pi}{6} \times (\text{Diameter, ft})^3$$

$$= \frac{\pi}{\cancel{6}} \times \overset{2}{\cancel{12}} \text{ ft} \times 12 \text{ ft} \times 12 \text{ ft}$$

$$= 904.32 \text{ cubic feet}$$

15.7 METRIC SYSTEM

The two most common systems of weights and measures are the English system and the Metric system. Of these two, the Metric system is more popular with most of the nations of the world. The reason for this is that the metric system is based on a system of tens and is therefore easier to remember and easier to use than the English system. Even though the basic system in this country is the English system, the scientific community uses the Metric system almost exclusively. Although many organizations have urged, for good reason, that the United States switch to the Metric system, the English system still is the standard system of measurement in the United States.

In order to study the Metric system, one must know the meanings of the terminology used. Following is a list of Greek and Latin prefixes used in the Metric system.

PREFIXES USED IN THE METRIC SYSTEM

Prefixes	Meaning
Milli	1/1000 or 0.001
Centi	1/100 or 0.01
Deci	1/10 or 0.1
Unit	1
Deka	10
Hecto	100
Kilo	1000

15.70 Measures of Length

The basic measure of length is the meter.

1 kilometer (km)	=	1000 meters (m)
1 meter (m)	=	100 centimeters (cm)
1 centimeter (cm)	=	10 millimeters (mm)

Kilometers are usually used in place of miles, meters are used in place of feet and yards, centimeters are used in place of inches, and millimeters are used for fractions of an inch.

LENGTH EQUIVALENTS

1 kilometer	=	0.621 mile	1 mile	=	1.64 kilometers
1 meter	=	3.28 feet	1 foot	=	0.305 meter
1 meter	=	39.37 inches	1 inch	=	0.0254 meter
1 centimeter	=	0.3937 inch	1 inch	=	2.54 centimeters
1 millimeter	=	0.0394 inch	1 inch	=	25.4 millimeters

NOTE: The above equivalents are reciprocals. If one equivalent is given, the reverse can be obtained by division. For instance, if one meter equals 3.28 feet, one foot equals 1/3.28 meter, or 0.305 meter.

15.71 Measures of Capacity or Volume

The basic measure of capacity in the Metric system is the liter. For measurement of large quantities the cubic meter is sometimes used.

1 kiloliter (kl) = 1000 liters (l) = 1 cu meter (m^3)

1 liter (l) = 1000 milliliters (ml)

Kiloliters, or cubic meters, are used to measure capacity of large storage tanks or reservoirs in place of cubic feet or gallons. Liters are used in place of gallons or quarts. Milliliters are used in place of quarts, pints, or ounces.

CAPACITY EQUIVALENTS

1 kiloliter	=	264.2 gallons	1 gallon	=	0.003785 kiloliter
1 liter	=	1.057 quarts	1 quart	=	0.946 liter
1 liter	=	0.2642 gallon	1 gallon	=	3.785 liters
1 milliliter	=	0.0338 ounce	1 ounce	=	29.57 milliliters

15.72 Measures of Weight

The basic unit of weight in the Metric system is the gram. One cubic centimeter of water at maximum density weighs one gram, and thus there is a direct, simple relation between volume of water and weight in the Metric system.

1 kilogram (kg) = 1000 grams (gm)

1 gram (gm) = 1000 milligrams (mg)

1 milligram (mg) = 1000 micrograms (μg)

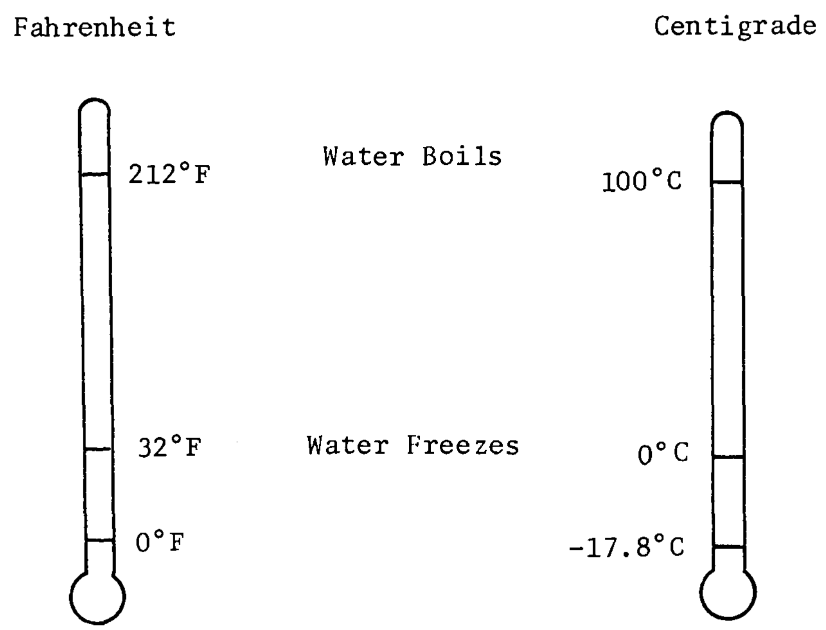
Grams are usually used in place of ounces, and kilograms are used in place of pounds.

WEIGHT EQUIVALENTS

1 kilogram	=	2.205 pounds	1 pound	=	0.4536 kilogram
1 gram	=	0.0022 pound	1 pound	=	453.6 grams
1 gram	=	0.0353 ounce	1 ounce	=	28.35 grams
1 gram	=	15.43 grains	1 grain	=	0.0648 gram

15.73 Temperature

Just as the operator should become familiar with the Metric system, he should also become familiar with the centigrade (Celsius) scale for measuring temperature. There is nothing magical about the centigrade scale--it is simply a different size than the Fahrenheit scale. The two scales compare as follows:



The two scales are related in the following manner:

$$\text{Fahrenheit} = (^{\circ}C \times 9/5) + 32^{\circ}$$

$$\text{Centigrade} = (^{\circ}F - 32^{\circ}) \times 5/9$$

Example: Convert 20° Centigrade to Fahrenheit.

$$F = (^{\circ}C \times 9/5) + 32^{\circ}$$

$$F = (20^{\circ} \times 9/5) + 32^{\circ}$$

$$F = \frac{180^{\circ}}{5} + 32^{\circ}$$

$$= 36^{\circ} + 32^{\circ}$$

$$= 68^{\circ}F$$

Example: Convert $-10^{\circ}C$ to $^{\circ}F$.

$$F = (-10^{\circ} \times 9/5) + 32^{\circ}$$

$$F = -90^{\circ}/5 + 32^{\circ}$$

$$= -18^{\circ} + 32^{\circ}$$

$$= 14^{\circ}F$$

Example: Convert $-13^{\circ}F$ to $^{\circ}C$.

$$C = (^{\circ}F - 32^{\circ}) \times \frac{5}{9}$$

$$C = (-13^{\circ} - 32^{\circ}) \times \frac{5}{9}$$

$$C = -45^{\circ} \times \frac{5}{9}$$

$$C = -5^{\circ} \times 5$$

$$C = -25^{\circ}C$$

15.74 Milligrams per Liter

Milligrams per liter (mg/l) is a unit of expression used in laboratory and scientific work to indicate very small concentrations or dilutions. Since wastewater contains small concentrations of dissolved substances and solids, and since small amounts of chemical compounds are sometimes used in wastewater treatment processes, the term milligrams per liter is also common in treatment plants. It is a weight/volume relationship.

As previously discussed:

1000 liters = 1 cubic meter = 1,000,000 cubic centimeters

Therefore

$$1 \text{ liter} = 1000 \text{ cubic centimeters}$$

Since one cubic centimeter of water weighs one gram,

$$1 \text{ liter of water} = 1000 \text{ grams or } 1{,}000{,}000 \text{ milligrams}$$

$$\boxed{1\,\frac{\text{milligram}}{\text{liter}} = \frac{1 \text{ milligram}}{1{,}000{,}000 \text{ milligrams}} = \frac{1 \text{ part}}{\text{million parts}} = \begin{array}{l}1 \text{ part per}\\ \text{million (ppm)}\end{array}}$$

Milligrams per liter and parts per million (parts) may be used interchangeably as long as the liquid density is 1.0 gm/cu cm or 62.43 lb/cu ft. A concentration of 1 milligram/liter (mg/l) or 1 ppm means that there is 1 part of substance by weight for every 1 million parts of water. A concentration of 10 mg/l would mean 10 parts of substance per million parts of water.

To get an idea of how small 1 mg/l is, divide the numerator and denominator of the fraction by 10,000. This, of course, does not change its value since 10,000 ÷ 10,000 is equal to one.

$$\boxed{1\,\frac{\text{mg}}{\text{l}} = \frac{1 \text{ mg}}{1{,}000{,}000 \text{ mg}} = \frac{1/10{,}000 \text{ mg}}{1{,}000{,}000/10{,}000 \text{ mg}} = \frac{0.0001 \text{ mg}}{100 \text{ mg}} = 0.0001\%}$$

Therefore, 1 mg/l is equal to one ten-thousandth of a percent, or

$$1\% \text{ is equal to } 10{,}000 \text{ mg/l}$$

To convert mg/l to %, move the decimal point four places or numbers to the left.

Working problems using milligrams per liter or parts per million is a part of everyday operation in most wastewater treatment plants.

15.75 Example Problems

Example: A plant effluent flowing at a rate of five million pounds per day contains 15 mg/l of solids. How many pounds of solids will be discharged per day?

$$15 \text{ mg/l} = \frac{15 \text{ lbs solids}}{\text{million lbs water}}$$

$$\text{Solids Discharged, lbs/day} = \text{Concentration, lbs/M lbs x Flow, lbs/day}$$

$$= \frac{15 \text{ lbs}}{\cancel{\text{million lbs}}} \times \frac{5 \cancel{\text{million lbs}}}{\text{day}}$$

$$= 75 \text{ lbs/day}$$

There is one thing that is unusual about the above problem and that is the flow is reported in pounds per day. In most treatment plants flow is reported in terms of gallons per minute or gallons per day. To convert these flow figures to weight, an additional conversion factor is needed. It has been found that one gallon of water (and wastewater, since it is almost all water) weighs 8.34 pounds. Using this factor, it is possible to convert flow in gallons per day to flow in pounds per day.

Example: A plant influent of 3.5 million gallons per day (MGD) contains 200 mg/l BOD. How many pounds of BOD enter the plant per day?

$$\text{Flow, lbs/day} = \text{Flow, } \frac{\text{M gal}}{\text{day}} \times 8.34 \frac{\text{lb}}{\text{gal}}$$

$$= \frac{3.5 \text{ million } \cancel{\text{gal}}}{\text{day}} \times \frac{8.34 \text{ lbs}}{\cancel{\text{gal}}}$$

$$= 29.19 \text{ million lbs/day}$$

BOD Loading, lbs/day = Concentration, mg/l x Flow, M lb/day

$$\text{BOD} = \frac{200\ \cancel{\text{mg}}^{*}}{\cancel{\text{million}}\ \cancel{\text{mg}}} \times \frac{29.19\ \cancel{\text{million}}\ \text{lbs}}{\text{day}}$$

$$= 5838\ \text{lbs/day}$$

In solving the above problem a relation was used that is most important to understand and commit to memory.

$$\boxed{\text{Lbs/day} = \text{Conc., mg/l} \times \text{Flow, MGD} \times 8.34\ \text{lb/gal}}$$

Example: A chlorinator is set to feed 50 pounds of chlorine per day to a flow of 0.8 MGD. What is the chlorine dose in ppm?

$$\text{Conc. or Dose, ppm} = \frac{\text{lbs/day}}{\text{MGD} \times 8.34\ \text{lb/gal}}$$

$$= \frac{50\ \text{lb/day}}{0.80\ \text{MG/day} \times 8.34\ \text{lb/gal}}$$

$$= \frac{50\ \text{lb}}{6.672\ \text{M lb}}$$

$$= 7.5\ \text{ppm, or } 7.5\ \text{mg/l}$$

Example: Treated effluent is pumped to a spray disposal field by a pump that delivers 500 gallons per minute. Suspended solids in the effluent average 10 mg/l. What is the total weight of suspended solids deposited on the spray field during a 24-hour day of continuous pumping?

$$\text{Flow, MGD} = \text{Flow, gpm} \times 60\ \text{min/hr} \times 24\ \text{hr/day}$$

$$= \frac{500\ \text{gal}}{\cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{\cancel{\text{hr}}} \times \frac{24\ \cancel{\text{hr}}}{\text{day}}$$

$$= 720{,}000\ \text{gal/day}$$

$$= 0.72\ \text{MGD}$$

---

* Remember that $\frac{1\ \text{mg}}{\text{M mg}} = \frac{1\ \text{lb}}{\text{M lb}}$. They are identical ratios.

$$\text{Weight of Solids, lbs/day} = \text{Conc., mg/l} \times \text{Flow, MGD} \times 8.34\ \text{lb/gal}$$

$$= \frac{10\ \cancel{mg}}{\cancel{M}\ \cancel{mg}} \times \frac{0.72\ \cancel{M}\ \cancel{gal}}{\text{day}} \times \frac{8.34\ \text{lb}}{\cancel{gal}}$$

$$= 60.248\ \text{lbs/day or about 60 lbs/day}$$

15.8 WEIGHT-VOLUME RELATIONS

Another factor for the operator to remember, in addition to the weight of a gallon of water, is the weight of a cubic foot of water. One cubic foot of water weighs 62.4 lbs. If these two weights are divided, it is possible to determine the number of gallons in a cubic foot.

$$\frac{62.4\ \cancel{pounds}/\text{cu ft}}{8.34\ \cancel{pounds}/\text{gal}} = 7.48\ \text{gal/cu ft}$$

Thus we have another very important relation to commit to memory.

$$\boxed{8.34\ \text{lb/gal} \times 7.48\ \text{gal/cu ft} = 62.4\ \text{lb/cu ft}}$$

It is only necessary to remember two of the above items since the third may be found by calculation. For most problems, 8 1/3 lbs/gal and 7 1/2 gal/cu ft will provide sufficient accuracy.

Example: Change 1000 cu ft of water to gallons.

1000 cu ft x 7.48 gal/cu ft = 7480 gallons

Example: What is the weight of three cubic feet of water?

62.4 lb/cu ft x 3 cu ft = 187.2 lbs

Example: The net weight of a tank of water is 750 lbs. How many gallons does it contain?

$$\frac{750\ \cancel{lb}}{8\ 1/3\ \cancel{lb}/\text{gal}} = \frac{750\ \text{gal}}{25/3} = \frac{\overset{30}{\cancel{750}}\ \text{gal}}{1} \times \frac{3}{\underset{1}{\cancel{25}}} = 90\ \text{gals}$$

15.9 FORCE, PRESSURE, AND HEAD

In order to study the forces and pressures involved in fluid flow, it is first necessary to define the terms used.

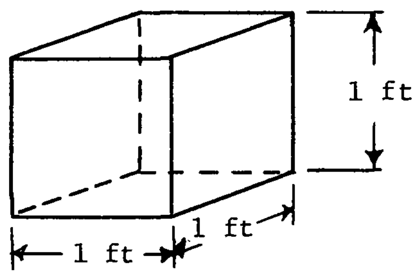
Force: The push exerted by water on any surface being used to confine it. Force is usually expressed in pounds, tons, grams, or kilograms.

Pressure: The force per unit area. Pressure can be expressed in many ways, but the most common term is pounds per square inch (psi).

Head: Vertical distance from the water surface to a reference point below the surface. Usually expressed in feet or meters.

An example should serve to illustrate these terms.

If water were poured into a one-foot cubical container, the force acting on the bottom of the container would be 62.4 pounds.



The pressure acting on the bottom would be 62.4 pounds per square foot. The area of the bottom is also 12 in x 12 in = 144 in^2. Therefore, the pressure may also be expressed as:

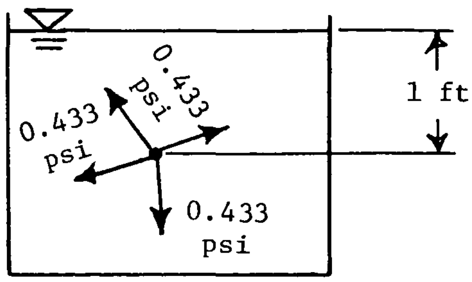
$$\text{Pressure, psi} = \frac{62.4 \text{ lb}}{\text{sq ft}} = \frac{62.4 \text{ lb/sq ft}}{144 \text{ sq in/sq ft}}$$

$$= 0.433 \text{ lb/sq in}$$

$$= 0.433 \text{ psi}$$

Since the height of the container is one foot, the head would be one foot.

The pressure in any vessel at one foot of depth or one foot of head is 0.443 psi acting in any direction.



If the depth of water in the previous example were increased to two feet, the pressure would be:

$$p = \frac{2\ (62.4\ \text{lb})}{144\ \text{sq in}} = \frac{124.8\ \text{lb}}{144\ \text{sq in}} = 0.866\ \text{psi}$$

Therefore we can see that for every foot of head the pressure increases by 0.433 psi. Thus, the general formula for pressure becomes:

$$\boxed{p,\ \text{psi} = 0.433\ (H,\ \text{ft})}$$

H = feet of head

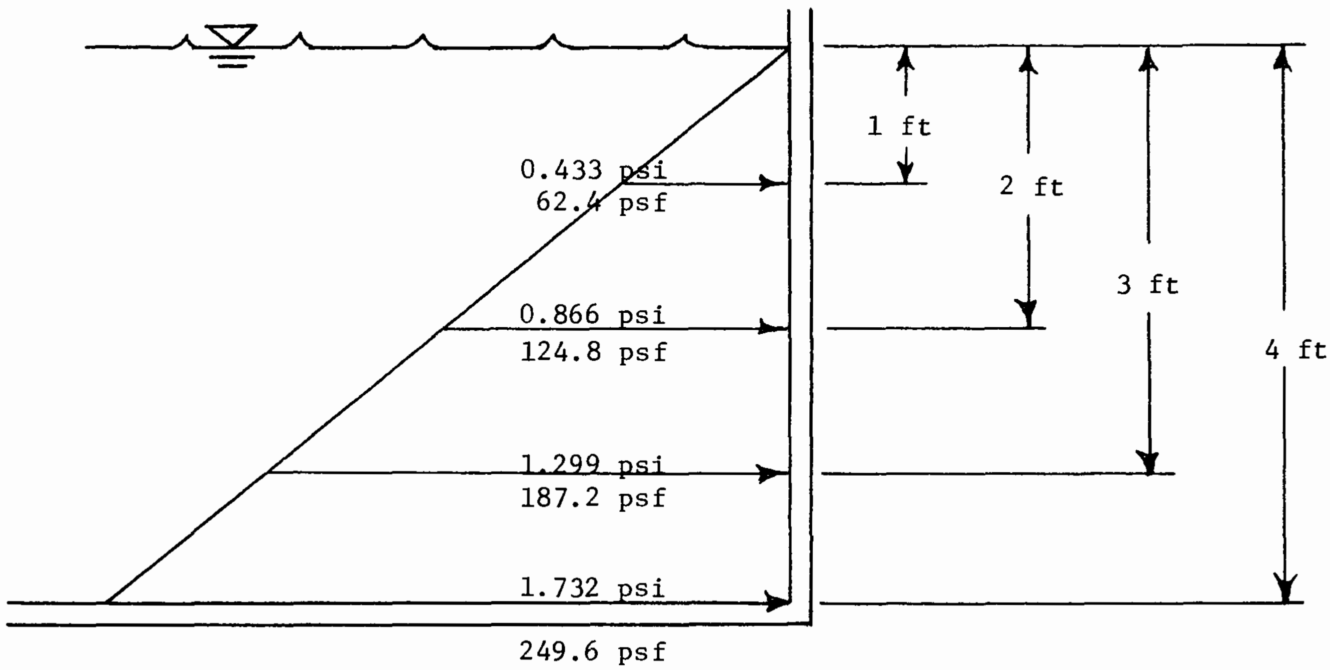
p = pounds per square <u>inch</u> of pressure

$$\boxed{P,\ \text{lb/sq ft} = 62.4\ (H,\ \text{ft})}$$

H = feet of head

P = pounds per square <u>foot</u> of pressure

We can now draw a diagram of the pressure acting on the side of a tank. Assume a four-foot deep tank. The pressures shown on the tank are gage pressures. These pressures do not include the atmospheric pressure acting on the surface of the water.



$p_0 = 0.433 \times 0 = 0.0$ psi	$P_0 = 62.4 \times 0 = 0.0$ lb/sq ft
$p_1 = 0.433 \times 1 = 0.433$ psi	$P_1 = 62.4 \times 1 = 62.4$ lb/sq ft
$p_2 = 0.433 \times 2 = 0.866$ psi	$P_2 = 62.4 \times 2 = 124.8$ lb/sq ft
$p_3 = 0.433 \times 3 = 1.299$ psi	$P_3 = 62.4 \times 3 = 187.2$ lb/sq ft
$p_4 = 0.433 \times 4 = 1.732$ psi	$P_4 = 62.4 \times 4 = 249.6$ lb/sq ft

The average pressure acting on the tank wall is 1.732 psi/2 = 0.866 psi, or 249.6 psf/2 = 124.8 psf.

If the wall were five feet long, the pressure would be acting over the entire 20 square foot (5 ft x 4 ft) area of the wall. The total force acting to push the wall would be:

Force, lb = (Pressure, lb/sq ft)(Area, sq ft)

= 124.8 lb/sq ft x 20 sq ft

= 2496 lbs

If the pressure in psi were used, the problem would be similar:

Force, lb = (Pressure, lb/sq in) (Area, sq in)

= 0.866 psi x 48 in x 60 in

= 2494 lb*

The general formula, then, for finding the total force acting on a side wall of a tank is:

$$\boxed{F = 31.2 \times H^2 \times L}$$

F = force in pounds

H = head in feet

L = length of wall in feet

31.2 = constant with units of lbs/cu ft and considers the fact that the force is exerted at H/2 or half the depth of the water.

Example: Find the force acting on a five-foot long wall in a four-foot deep tank.

Force, lb = 31.2 (Head, ft)^2 (Length, ft)

= 31.2 lb/cu ft x (4 ft)^2 x 5 ft

= 2496 lbs

Occasionally an operator is warned: Never empty a tank during periods of high groundwater. Why? The pressure on the bottom of the tank caused by the water surrounding the tank will tend to float the tank like a cork if the upward force of the water is greater than the weight of the tank.

$$\boxed{F = 62.4 \times H \times A}$$

F = upward force in pounds

H = head of water on tank bottom, in feet

A = area of bottom of tank in square feet

62.4 = a constant with units of lbs/cu ft

* Difference in answer due to rounding off of decimal points.

This formula is approximately true if the tank doesn't crack, leak, or start to float.

Example: Find the upward force on the bottom of an empty tank caused by a groundwater depth of 8 feet above the tank bottom. The tank is 20 ft wide and 40 ft long.

Force, lb = 62.4 (Head, ft)(Area, sq ft)

= 62.4 lb/cu ft x 8 ft x 20 ft x 40 ft

= 399,400 lb

15.10 VELOCITY AND RATE OF FLOW

15.100 Velocity

The velocity of a particle or substance is the speed at which it is moving. It is expressed by indicating the length of travel and how long it takes to cover the distance. Velocity can be expressed in almost any distance and time units. For instance, a car may be traveling at a rate of 280 miles per five hours. However, it is normal to express the distance traveled per unit time. The above example would then become:

$$\text{Velocity, mi/hr} = \frac{280 \text{ miles}}{5 \text{ hours}}$$

$$= 56 \text{ miles/hour}$$

The velocity of water in a channel, pipe, or other conduit can be expressed in the same way. If the particle of water travels 600 feet in five minutes, the velocity is:

$$\text{Velocity, ft/min} = \frac{\text{distance, ft}}{\text{time, minutes}}$$

$$= \frac{600 \text{ ft}}{5 \text{ min}}$$

$$= 120 \text{ ft/min}$$

If it is desired to express the velocity in feet per second, multiply by 1 min/60 seconds.

NOTE: $\frac{1 \text{ minute}}{60 \text{ seconds}}$ is like $\frac{1}{1}$ and does not change the relative value of the answer. It only changes the form of the answer.

$$\text{Velocity, ft/sec} = (\text{Velocity, ft/min})(1 \text{ hr/60 sec})$$

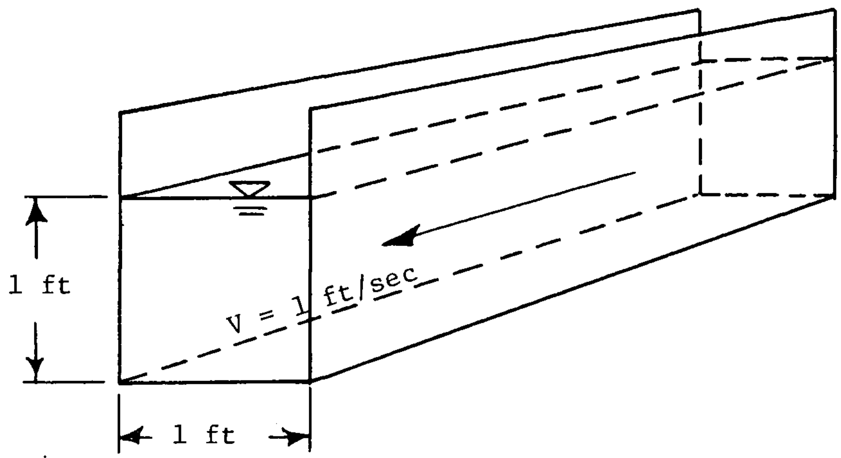
$$= \frac{120 \text{ ft}}{\cancel{\text{min}}} \times \frac{1 \cancel{\text{min}}}{60 \text{ sec}}$$

$$= \frac{120 \text{ ft}}{60 \text{ sec}}$$

$$= 2 \text{ ft/sec}$$

15.101 Rate of Flow

If water in a one-foot wide channel is one foot deep, then the cross sectional area of the channel is 1 ft x 1 ft = 1 sq ft.



If the velocity in this channel is 1 ft per second, then each second a body of water 1 sq ft in area and 1 ft long will pass a given point. The volume of this body of water would be 1 cubic foot. Since one cubic foot of water would pass by every second, the rate of flow would be equal to 1 cubic foot per second, or 1 cfs.

To obtain the rate of flow in the above example the velocity was multiplied by the cross sectional area. This is another important general formula.

$$\boxed{Q = V \times A}$$

Q = rate of flow, cfs or cu ft/sec

V = velocity in ft/sec

A = area, in sq ft

Example: Flow in a 2.5 foot wide channel is 1.4 ft deep and measures 11.2 cfs. What is the average velocity?

In this problem we want to find the velocity. Therefore, we must rearrange the general formula to solve for velocity.

$$V = \frac{Q}{A}$$

$$\text{Velocity, ft/sec} = \frac{\text{Flow Rate, cu ft/sec}}{\text{Area, sq ft}}$$

$$= \frac{11.2 \text{ cu ft/sec}}{2.5 \cancel{\text{ft}} \times 1.4 \cancel{\text{ft}}}$$

$$= \frac{11.2 \text{ ft/sec}}{3.5}$$

$$= 3.2 \text{ ft/sec}$$

Example: Flow in an 8-inch pipe is 500 GPM. What is the average velocity?

$$\text{Area, sq ft} = 0.785 \text{ (Diameter, ft)}^2$$

$$= 0.785 \text{ (8/12 ft)}^2$$

$$= 0.785 \text{ (2/3 ft)}^2$$

$$= 0.785 \text{ (2/3 ft)(2/3 ft)}$$

$$= 0.785 \text{ (4/9 ft}^2\text{)}$$

$$= 0.35 \text{ sq ft}$$

$$\text{Flow, cfs} = \text{Flow, gal/min} \times \frac{\text{cu ft}}{7.48 \text{ gal}} \times \frac{1 \text{ min}}{60 \text{ sec}}$$

$$= \frac{500 \cancel{\text{gal}}}{\cancel{\text{min}}} \times \frac{\text{cu ft}}{7.48 \cancel{\text{gal}}} \times \frac{1 \cancel{\text{min}}}{60 \text{ sec}}$$

$$= \frac{500 \text{ cu ft}}{448.8 \text{ sec}}$$

$$= 1.114 \text{ cfs}$$

$$\text{Velocity, ft/sec} = \frac{\text{Flow, cu ft/sec}}{\text{Area, sq ft}}$$

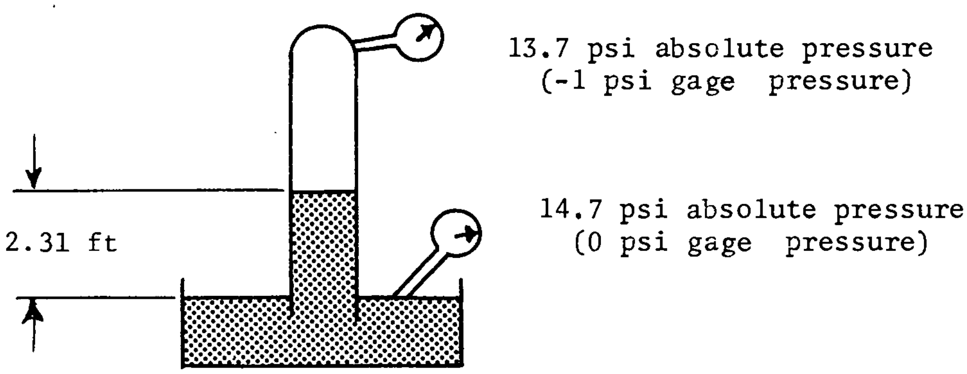
$$= \frac{1.114 \text{ ft}^3\text{/sec}}{0.35 \text{ ft}^2}$$

$$= 3.18 \text{ ft/sec}$$

15.11 PUMPS

15.110 General

Atmospheric pressure at sea level is approximately 14.7 psi. This pressure acts in all directions and on all objects. If a tube is placed upside down in a basin of water and a 1 psi partial vacuum is drawn on the tube, the water in the tube will rise 2.31 feet.



NOTE: 1 ft of water = 0.433 psi; therefore,

$$1 \text{ psi} = \frac{1}{0.433} \text{ ft} = 2.31 \text{ ft of water}$$

The action of the partial vacuum is what gets water out of a sump or well and up to a pump. It is not sucked up, but it is pushed up by atmospheric pressure on the water surface in the sump. If a complete vacuum could be drawn, the water would rise 2.31 x 14.7 = 33.9 feet; but this is impossible to achieve. The practical limit of the suction lift of a positive displacement pump is about 22 feet, and that of a centrifugal pump is 15 feet.

15.111 Work

Work can be expressed as lifting a weight a certain vertical distance. It is usually defined in terms of foot-pounds.

Example: A 165-pound man runs up a flight of stairs 20 feet high. How much work did he do?

$$\text{Work, ft-lb} = \text{Weight, lb} \times \text{Height, ft}$$

$$= 165 \text{ lb} \times 20 \text{ ft}$$

$$= 3300 \text{ ft-lb}$$

15.112 Power

Power is a rate of doing work and is usually expressed in foot-pounds per minute.

Example: If the man in the above example runs up the stairs in three seconds, how much power has he exerted?

$$\text{Power, ft-lbs/sec} = \frac{\text{Work, ft-lb}}{\text{Time, sec}}$$

$$= \frac{3300 \text{ ft-lbs}}{3 \cancel{\text{sec}}} \times \frac{60 \cancel{\text{sec}}}{\text{minute}}$$

$$= 66{,}000 \text{ ft-lb/min}$$

15.113 Horsepower

Horsepower is also a unit of power. One horsepower is defined as 33,000 ft-lbs per minute or 746 watts.

Example: How much horsepower has the man in the previous example exerted as he climbs the stairs?

$$\text{Horsepower, HP} = (\text{Power, ft-lb/min}) \left(\frac{\text{HP}}{33{,}000 \text{ ft-lb/min}}\right)$$

$$= 66{,}000 \text{ ft-lb/min} \times \frac{\text{Horsepower}}{33{,}000 \text{ ft-lb/min}}$$

$$= 2 \text{ HP}$$

Work is also done by lifting water. If the flow from a pump is converted to a weight of water and multiplied by the vertical distance it is lifted, the amount of work or power can be obtained.

$$\text{Horsepower, HP} = \frac{\text{Flow, gal}}{\text{min}} \times \text{Lift, ft} \times \frac{8.34\text{ lb}}{\text{gal}} \times \frac{\text{Horsepower}}{33{,}000\text{ ft-lb/min}}$$

Solving the above relation, the amount of horsepower necessary to lift the water is obtained. This is called water horsepower.

$$\text{Water, HP} = \frac{(\text{Flow, gpm})(\text{H, ft})}{3960^*}$$

However, since pumps are not 100% efficient (they cannot transmit all the power put into them), the horsepower supplied to a pump is greater than the water horsepower. Horsepower supplied to the pump is called brake horsepower.

$$\boxed{\text{Brake, HP} = \frac{\text{Flow, gpm} \times \text{H, ft}}{3960 \times E_p}}$$

E_p = Efficiency of Pump (Usual range 50-85%, depending on type and size of pump)

Motors are also not 100% efficient; therefore, the power supplied to the motor is greater than the motor transmits.

$$\boxed{\text{Motor, HP} = \frac{\text{Flow, gpm} \times \text{H, ft}}{3960 \times E_p \times E_m}}$$

E_m = Efficiency of motor (Usual range 80-95%, depending on type and size of motor)

The above formulas have been developed for the pumping of water and wastewater which have a specific gravity of 1.0. If other liquids are to be pumped, the formulas must be multiplied by the specific gravity of the liquid.

Example: A flow of 500 gpm of water is to be pumped against a total head of 100 feet by a pump with an efficiency of 70%. What is the pump horsepower?

$$^* \quad \frac{8.34\text{ lb}}{\text{gal}} \times \frac{\text{HP}}{33{,}000\text{ ft-lb/min}} = \frac{1}{3960}$$

$$\text{Brake, HP} = \frac{\text{Flow, gpm} \times \text{H, ft}}{3960 \times E_p}$$

$$= \frac{500 \times 100}{3960 \times 0.70}$$

$$= 18 \text{ HP}$$

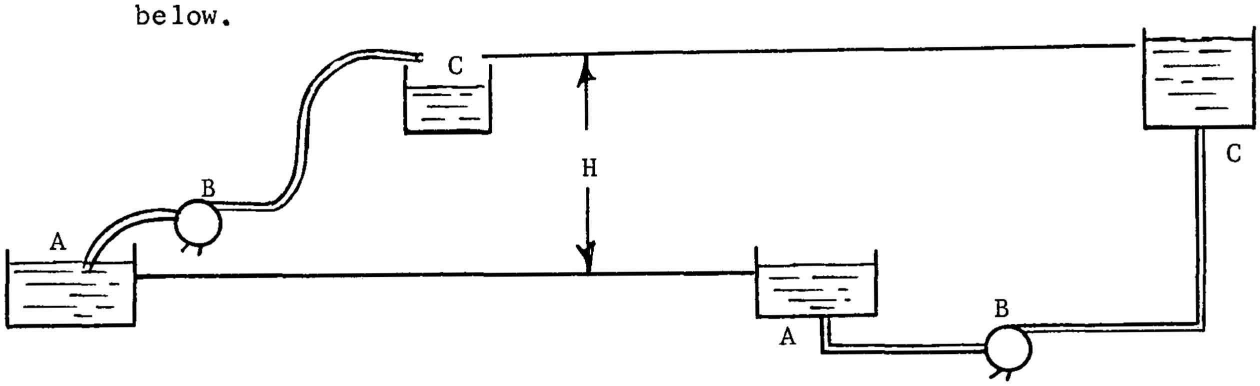
Example: Find the horsepower required to pump gasoline (specific gravity = 0.75) in the above problem.

$$\text{Brake, HP} = \frac{500 \times 100 \times 0.75}{3960 \times 0.70}$$

$$= 13.5 \text{ HP}$$ (gasoline is lighter and requires less horsepower)

15.114 Head

Basically, the head that a pump must work against is determined by measuring the vertical distance between the two water surfaces, or the distance the water must be lifted. This is called the static head. Two typical conditions for lifting water are shown below.



If a pump were designed in the above examples to pump only against head H, the water would never reach the intended point. The reason for this is that the water encounters friction in the pipelines. Friction depends on the roughness and length of pipe, the pipe diameter, and the flow velocity. The turbulence caused at the pipe entrance (point A); the pump (point B); the pipe exit (point C); and at each elbow, bend, or transition also adds to these friction losses. Tables and charts are available for calculation of these friction losses so they may be added to the measured or static head to obtain the total head. For short runs of pipe which do not have high velocities the friction losses are generally less than 10% of the static head.

Example: A pump is to be located eight feet above a wet well and must lift 1.8 MGD another 50 feet to a storage reservoir. If the pump has an efficiency of 75% and the motor an efficiency of 90%, what is the cost of the power consumed if one kilowatt hour costs 1 cent?

Since we are not given the length or size of pipe and the number of elbows or bends, we will assume friction to be 10% of static head.

Static Head, ft = Suction Lift, ft + Discharge Head, ft

= 8 ft + 50 ft

= 58 ft

Friction Losses, ft = 0.1 (Static Head, ft)

= 0.1 (58 ft)

= 5.8 ft

Total Head, ft = Static Head, ft + Friction Losses, ft

= 58 ft + 5.8 ft

= 63.8 ft

$$\text{Flow, gpm} = \frac{1{,}800{,}000 \text{ gal}}{\cancel{\text{day}}} \times \frac{\cancel{\text{day}}}{24 \cancel{\text{hr}}} \times \frac{1 \cancel{\text{hr}}}{60 \text{ min}}$$

= 1250 gpm (assuming pump runs 24 hours per day)

$$\text{Motor, HP} = \frac{\text{Flow, gpm} \times \text{H, ft}}{3960 \times E_p \times E_m}$$

$$= \frac{1250 \times 63.8}{3960 \times 0.75 \times 0.9}$$

$$= 30 \text{ HP}$$

$$\text{Kilowatt-hrs} = 30\ \cancel{HP} \times 24 \text{ hrs/day} \times 0.746 \text{ kw}/\cancel{HP}$$

$$= 537 \text{ kilowatt-hrs/day}$$

$$\text{Cost} = \text{KWH} \times \$0.01/\text{KWH}$$

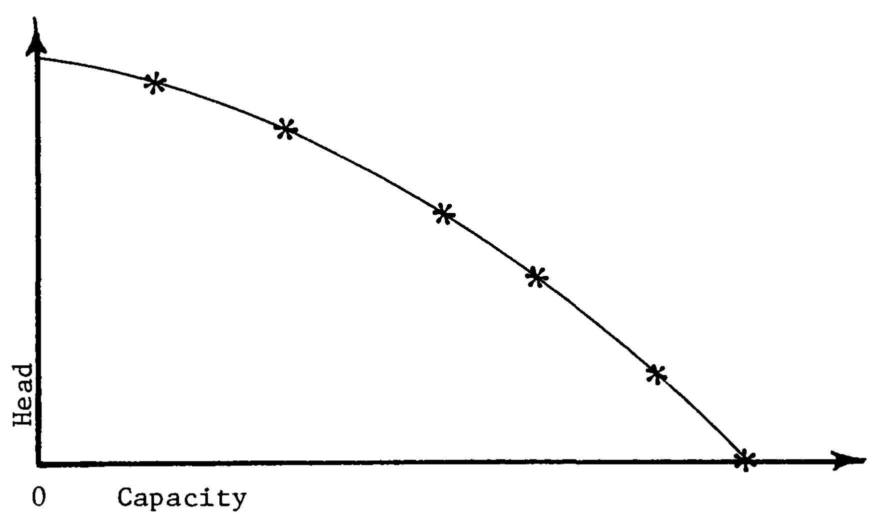
$$= 537 \times 0.01$$

$$= \$5.37/\text{day}$$

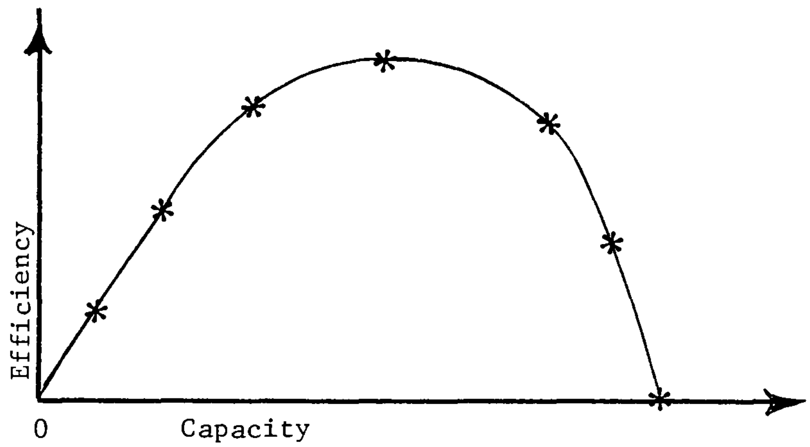
15.115 Pump Characteristics

The discharge of a centrifugal pump, unlike a positive displacement pump, can be made to vary from zero to a maximum capacity which depends on the speed, head, power, and specific impeller design. The interrelation of capacity, efficiency, head, and power is known as the characteristics of the pump.

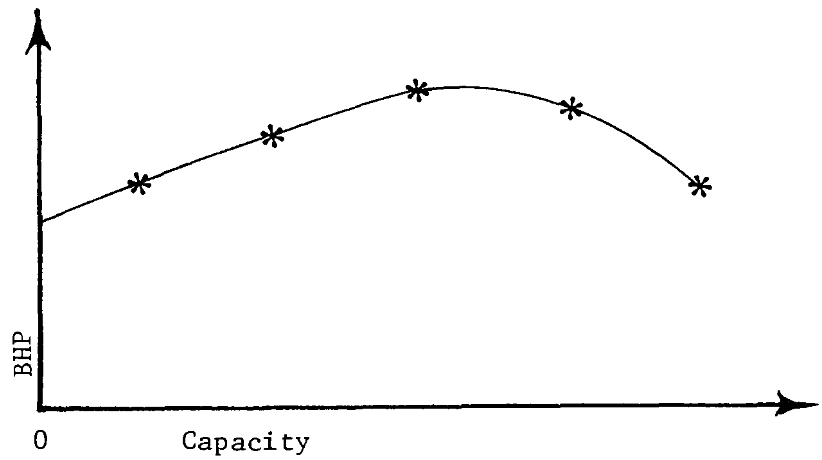
The first relation normally looked at when searching for a pump is the head vs. capacity. The head of a centrifugal pump normally rises as the capacity is reduced. If the values are plotted on a graph they appear as follows:



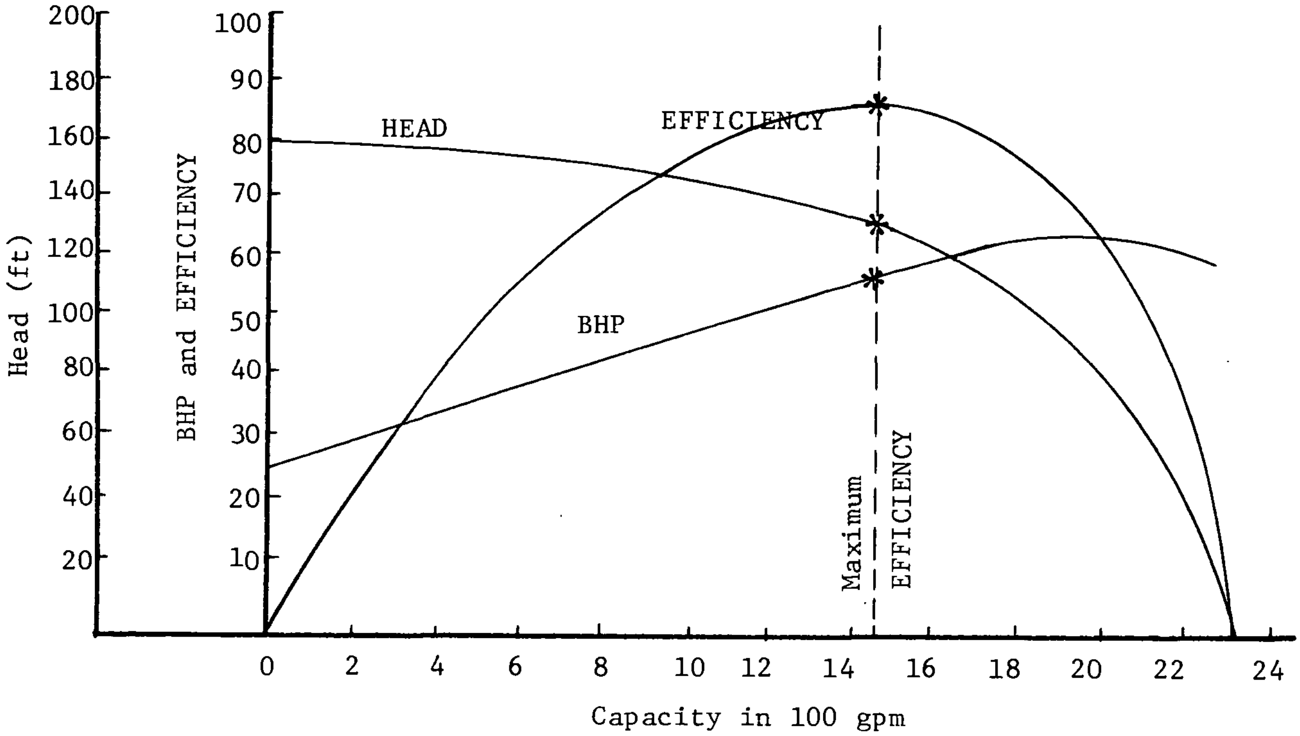
Another important characteristic is the pump efficiency. It begins from zero at no discharge, increases to a maximum, and then drops as the capacity is increased. Following is a graph of efficiency vs. capacity:



The last important characteristic is the brake horsepower or the power input to the pump. The brake horsepower usually increases with increasing capacity until it reaches a maximum, then it normally reduces slightly.



These pump characteristic curves are quite important. Pump sizes are normally picked from these curves rather than calculations. For ease of reading, the three characteristic curves are normally plotted together. A typical graph of pump characteristics is shown as follows:



The curves show that the maximum efficiency for the particular pump in question occurs at approximately 1475 gpm, a head of 132 feet, and a brake horsepower of 58. Operating at this point the pump has an efficiency of approximately 85%. This can be verified by calculation:

$$\text{BHP} = \frac{\text{Flow, gpm} \times \text{H, ft}}{3960 \times \text{E}}$$

As previously explained, a number can be written over one without changing its value:

$$\frac{\text{BHP}}{1} = \frac{\text{gpm} \times \text{H}}{3960 \times \text{E}}$$

Since the formula is now in ratio form, it can be cross multiplied.

$$BHP \times 3960 \times E = gpm \times H \times 1$$

Solving for E,

$$E = \frac{gpm \times H}{3960 \times BHP}$$

$$E = \frac{1475 \text{ gpm} \times 132 \text{ ft}}{3960 \times 58 \text{ HP}}$$

$$= 0.85 \text{ or } 85\% \quad \text{(Check)}$$

The preceding is only a brief description of pumps to familiarize the operator with their characteristics. The operator does not normally specify the type and size of pump needed at his plant. If a pump is needed, the operator should be able to supply the information necessary for a pump supplier to provide the best possible pump for the lowest cost. Some of the information needed includes:

1. Flow range desired
2. Head conditions
    a. Suction head or lift
    b. Pipe and fitting friction head
    c. Discharge head
3. Type of fluid pumped and temperature
4. Pump location

15.116 Evaluation of Pump Performance

1. Capacity

Sometimes it is necessary to determine the capacity of a pump. This can be accomplished by determining the time it takes a pump to fill a portion of a wet well.

Example:

a. Measure the size of the wet well.

Length	=	10 ft	(We will measure the time it takes to fill the well only to a depth of five feet, or the time for water in the well to rise five feet.)
Width	=	10 ft	
Depth	=	5 ft	

$$\text{Volume, cu ft} = \text{L, ft} \times \text{W, ft} \times \text{D, ft}$$

$$= 10 \text{ ft} \times 10 \text{ ft} \times 5 \text{ ft}$$

$$= 500 \text{ cu ft}$$

b. Record time for water to rise five feet in wet well.

Time = 10 minutes 30 seconds

= 10.5 minutes

c. Calculate pumping rate or capacity.

$$\text{Pumping Rate, gpm} = \frac{\text{Volume, gallons}}{\text{Time, minutes}}$$

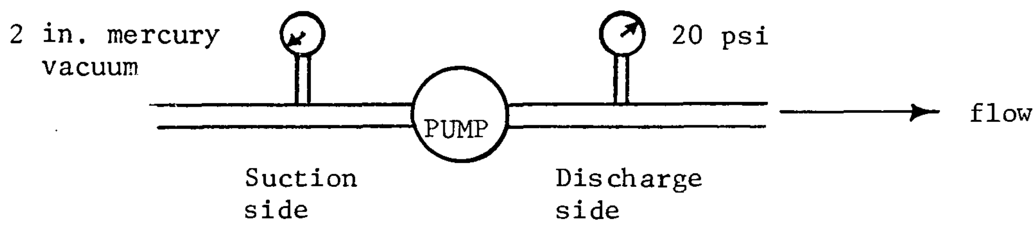
$$= \frac{(500 \text{ cu ft})(7.5 \text{ gal/cu ft})}{10.5 \text{ min}}$$

$$= \frac{3750}{10.5}$$

$$= 357 \text{ gpm}$$

2. Efficiency

To estimate the efficiency of the pump in the previous example, the total head must be known. This head may be estimated by measuring the suction and discharge pressures. Assume these were measured as follows:



No additional information is necessary if we assume the pressure gages are at the same height and the pipe diameters are the same. Both pressure readings must be converted to feet.

$$\text{Suction Head, ft} = 2 \text{ in Mercury} \times \frac{1.133 \text{ ft water}^*}{1 \text{ in Mercury}}$$

$$= 2.27 \text{ ft}$$

$$\text{Discharge Head, ft} = 20 \text{ psi} \times 2.31 \text{ ft/psi}^*$$

$$= 46.20 \text{ ft}$$

$$\text{Total Head, ft} = \text{Suction Head, ft} + \text{Discharge Head, ft}$$

$$= 2.27 \text{ ft} + 46.20 \text{ ft}$$

$$= 48.47 \text{ ft}$$

---

* See Conversion Tables--Section 15.15, Pressure.

Calculate the power output of the pump or water horsepower:

$$\text{Water Horsepower, HP} = \frac{(\text{Flow, gpm})(\text{Head, ft})}{3960}$$

$$= \frac{(357\ \text{gpm})(48.47\ \text{ft})}{3960}$$

$$= 4.4\ \text{HP}$$

To estimate the efficiency of the pump, measure the kilowatts drawn by the pump motor. Assume the meter indicates 8000 watts or 8 kilowatts. The manufacturer claims the electric motor is 80% efficient.

$$\text{Brake Horsepower, HP} = (\text{Power to elec. motor})(\text{motor eff.})$$

$$= \frac{(8\ \text{kw})(0.80)}{0.746\ \text{kw/HP}}$$

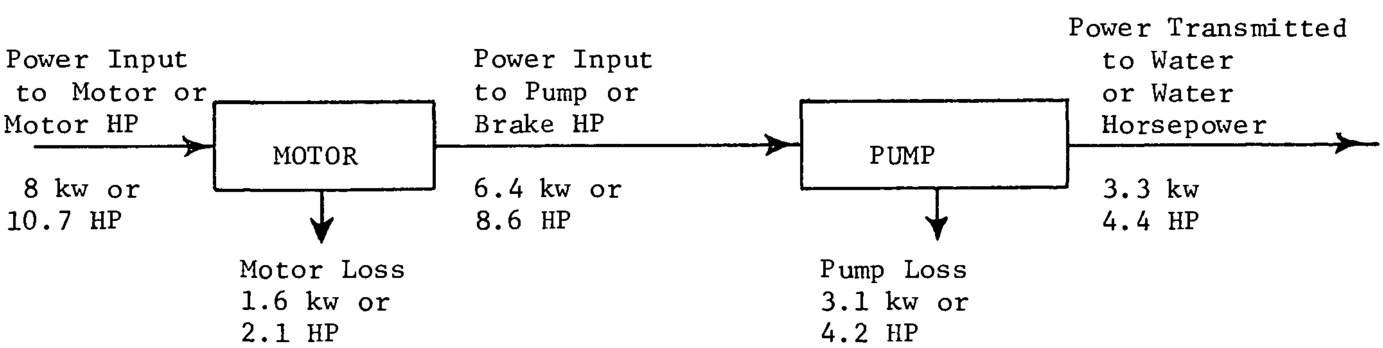
$$= 8.6\ \text{HP}$$

$$\text{Pump Efficiency, \%} = \frac{\text{Water Horsepower, HP} \times 100\%}{\text{Brake Horsepower, HP}}$$

$$= \frac{4.4\ \text{HP} \times 100\%}{8.6\ \text{HP}}$$

$$= 51\%$$

The following diagram may clarify the above problem:



15.117 <u>Pump Speed--Performance Relationships</u>

Changing the velocity of a centrifugal pump will change its operating characteristics. If the speed of a pump is changed, the flow, head developed, and power requirements will change. The operating characteristics of the pump will change with speed approximately as follows:

$$\text{Flow, } Q_n = \left(\frac{N_n}{N_r}\right) Q_r$$

r = rated

n = now

N = pump speed

$$\text{Head, } H_n = \left(\frac{N_n}{N_r}\right)^2 H_r$$

$$\text{Power, } P_n = \left(\frac{N_n}{N_p}\right)^3 P_r$$

Actually, pump efficiency does vary with speed; therefore, these formulas are not quite correct. If speeds do not vary by more than a factor of two (if the speeds are not doubled or cut in half), the results are close enough. Other factors contributing to changes in pump characteristic curves include impeller wear and roughness in pipes.

Example: To illustrate these relationships, assume a pump has a rated capacity of 600 gpm, develops 100 ft of head, and has a power requirement of 15 HP when operating at 1500 rpm. If the efficiency remains constant, what will be the operating characteristics if the speed drops to 1200 rpm?

Calculate new flow rate or capacity:

$$\text{Flow, } Q_n = \left(\frac{N_n}{N_r}\right) Q_r$$

$$= \left(\frac{1200 \text{ rpm}}{1500 \text{ rpm}}\right) 600 \text{ gpm}$$

$$= \left(\frac{4}{5}\right) 600 \text{ gpm}$$

$$= (4)\ (120 \text{ gpm})$$

$$= 480 \text{ gpm}$$

Calculate new head:

$$\text{Head, } H_n = \left(\frac{N_n}{N_r}\right)^2 H_r$$

$$= \left(\frac{1200 \text{ rpm}}{1500 \text{ rpm}}\right)^2 100 \text{ ft}$$

$$= \left(\frac{4}{5}\right)^2 100 \text{ ft}$$

$$= \left(\frac{16}{25}\right) (100 \text{ ft})$$

$$= 16\ (4 \text{ ft})$$

$$= 64 \text{ ft}$$

Calculate new power requirement:

$$\text{Power, } P_n = \left(\frac{N_n}{N_r}\right)^3 P_r$$

$$= \left(\frac{1200 \text{ rpm}}{1500 \text{ rpm}}\right)^3 15 \text{ HP}$$

$$= \left(\frac{4}{5}\right)^3 15 \text{ HP}$$

$$= \left(\frac{64}{125}\right) (15 \text{ HP})$$

$$= \left(\frac{64}{25}\right) (3 \text{ HP})$$

$$= 7.7 \text{ HP}$$

15.12 STEPS IN SOLVING PROBLEMS

15.120 Identify Problem

To solve any problem, you have to identify the problem, determine what kind of answer is needed, and collect the information needed to solve the problem. A good approach to this type of problem is to examine the problem and make a list of known and unknown information.

Example: Find the theoretical detention time in a rectangular sedimentation tank 8 feet deep, 30 feet wide, and 60 feet long when the flow is 1.4 MGD.

Known			Unknown
Depth	=	8 ft	Detention Time, hours
Width	=	30 ft	
Length	=	60 ft	
Flow	=	1.4 MGD	

Sometimes a drawing or sketch will help to illustrate a problem and indicate the knowns, unknowns, and possibly additional information needed.

15.121 Selection of Formula

Most problems involving mathematics in wastewater treatment plant operation can be solved by selecting the proper formula, inserting the known information, and calculating the unknown. In our example, we could look in Chapter 5, Sedimentation and Flotation, or in Section 15.14 of this chapter, Summary of Formulas, to find a formula for calculating detention time. From Section 15.14:

$$\text{Detention Time, hrs} = \frac{(\text{Tank Volume, cu ft})\ (7.5\ \text{gal/cu ft})\ (24\ \text{hr/day})}{\text{Flow, gal/day}}$$

To convert the known information to fit the terms in a formula sometimes requires extra calculations. The next step is to find the values of any terms in the formula that are not in the list of known values.

$$\begin{aligned} \text{Flow, gal/day} &= 1.4\ \text{MGD} \\ &= 1{,}400{,}000\ \text{gal/day} \end{aligned}$$

From Section 15.140:

$$\begin{aligned} \text{Tank Volume, cu ft} &= (\text{Length, ft})\ (\text{Width, ft})\ (\text{Height, ft}) \\ &= 60\ \text{ft} \times 30\ \text{ft} \times 8\ \text{ft} \\ &= 14{,}400\ \text{cu ft} \end{aligned}$$

Solution of Problem:

$$\begin{aligned} \text{Detention Time, hrs} &= \frac{(\text{Tank Volume, cu ft})\ (7.5\ \text{gal/cu ft})\ (24\ \text{hr/day})}{\text{Flow, gal/day}} \\ &= \frac{(14{,}400\ \text{cu ft})\ (7.5\ \text{gal/cu ft})\ (24\ \text{hr/day})}{1{,}400{,}000\ \text{gal/day}} \\ &= 1.9\ \text{hr} \end{aligned}$$

The remainder of this section discusses the details that must be considered in solving this problem.

15.122 Units and Dimensional Analysis

Each term in a formula or mathematical calculation must be of the correct units. The area of a rectangular clarifier (Area, sq ft = Length, ft x Width, ft) can't be calculated in square feet if the width is given as 246 inches or 20 feet 6 inches. The width must be converted to 20.5 feet. In the example problem, if the tank volume were given in gallons, then the 7.5 gal/cu ft would not be needed. The units in a formula must always be checked before any calculations are performed to avoid time-consuming mistakes.

$$\text{Detention Time, hrs} = \frac{(\text{Tank Volume, cu ft})\ (7.5\ \text{gal/cu ft})\ (24\ \text{hr/day})}{\text{Flow, gal/day}}$$

$$= \frac{\cancel{\text{cu ft}}}{} \times \frac{\cancel{\text{gal}}}{\cancel{\text{cu ft}}} \times \frac{\text{hr}}{\cancel{\text{day}}} \times \frac{\cancel{\text{day}}}{\cancel{\text{gal}}}$$

$$= \text{hr} \quad \text{(all other units cancel)}$$

NOTE: We have hours = hr. One should note that the hour unit on both sides of the equation can be cancelled out, and nothing would remain. This is one more check that we have the correct units. By rearranging the detention time formula, other unknowns could be determined.

If the design detention time and design flow were known, the required capacity of the tank could be calculated.

$$\text{Tank Volume, cu ft} = \frac{(\text{Detention Time, hr})\ (\text{Flow, gal/day})}{(7.5\ \text{gal/cu ft})\ (24\ \text{hr/day})}$$

If the tank volume and design detention time were known, the design flow could be calculated.

$$\text{Flow, gal/day} = \frac{(\text{Tank Volume, cu ft})\ (7.5\ \text{gal/cu ft})\ (24\ \text{hr/day})}{\text{Detention Time, hr}}$$

Rearrangement of the detention time formula to find other unknowns illustrates the need to always use the correct units.

15.123 Calculations

Sections 15.12, Multiplication, and 15.13, Division, outline the steps to follow in mathematical calculations. In general, do the calculations inside parentheses ( ) first and brackets [ ] next. Calculations should be done above and below the division line before dividing.

$$\text{Detention Time, hrs} = \frac{(\text{Tank Volume, cu ft})\ (7.5\ \text{gal/cu ft})\ (24\ \text{hr/day})}{\text{Flow, gal day}}$$

$$= \frac{(14{,}400\ \text{cu ft})\ (7.5\ \text{gal/cu ft})\ (24\ \text{hr/day})}{1{,}400{,}000\ \text{gal/day}}$$

```
   24          14400
  7.5            180
  120        1152000
 168           14400
180.0      2,592,000
```

$$= \frac{2{,}592{,}000\ \text{gal-hr/day}}{1{,}400{,}000\ \text{gal/day}}$$

```
          1.85
1400/ 2592
      1400
      11920
      11200
        7200
        7000
```

$= 1.85$, or

$= 1.9$ hr

15.124 Significant Figures

In calculating the detention time in the previous section the answer is given as 1.9 hr. The answer could have been calculated:

$$\text{Detention Time, hrs} = \frac{2{,}592{,}000 \text{ gal-hr/day}}{1{,}400{,}000 \text{ gal/day}}$$

$$= 1.850428571428571428....\text{hours}$$

How does one know when to stop dividing? Common sense and significant figures both help.

First, consider the meaning of detention time and the measurements that were taken to determine the knowns in the formula. Detention time in a tank is a theoretical value and assumes that all particles of water throughout the tank move through the tank at the same velocity. This assumption is not correct; therefore, detention time can only be a representative time for some of the water particles.

Will the flow of 1.4 MGD be constant throughout the 1.9 hours, and is the flow exactly 1.4 MGD, or could it be 1.35 MGD or 1.428 MGD? A carefully calibrated flow meter may give a reading within 2% of the actual flow rate. Flows into a tank fluctuate and flow meters do not measure flows extremely accurately; so the detention time again appears to be a representative or typical detention time.

Tank dimensions are probably satisfactory within 0.1 ft. A flow meter reading of 1.4 MGD is less precise and it could be 1.3 or 1.5 MGD. A 0.1 MGD flow meter error when the flow is 1.4 MGD is (0.1/1.4) x 100% = 7% error. A detention time of 1.9 hours, based on a flow meter reading error of plus or minus 7%, also could have the same error or more, even if the flow was constant. Therefore, the detention time error could be 1.9 hours x 0.07 = ±0.13 hours.

In most of the calculations in the operation of wastewater treatment plants, the operator uses measurements determined in the lab or read from charts, scales, or meters. The accuracy of every measurement depends on the sample being measured, the equipment doing the measuring, and the operator reading or measuring the results. Your estimate is no better than the least precise measurement. Do not retain more than one doubtful number.

To determine how many figures or numbers mean anything in an answer, the approach called "significant figures" is used. In the example the flow was given in two significant figures (1.4 MGD), and the tank dimensions could be considered accurate to the nearest tenth of a foot (depth = 9.0 ft) or two significant figures. Since all measurements and the constants contained two significant figures, the results should be reported as two significant figures or 1.9 hours. The calculations are normally carried out to three significant figures (1.85 hours) and rounded off to two significant figures (1.9 hours).

Decimal points require special attention when determining the number of significant figures in a measurement.

Measurement	Significant Figures
0.00325	3
11.078	5
21,000.	2

Example: The distance between two points was divided into three sections, and each section was measured by a different group. What is the distance between the two points if each group reported the distance it measured as follows:

Group	Distance, ft	Significant Figures
A	11,300.	3
B	2,438.9	5
C	87.62	4
Total Distance	13,826.52	

Group A reported the length of the section it measured to three significant figures; therefore, the distance between the two points should be reported as 13,800 feet (3 significant figures).

When adding, subtracting, multiplying, or dividing, the number of significant figures in the answer should not be more than the term in the calculations with the least number of significant figures.

15.125 Check Your Results

After having completed your calculations, you should carefully examine your calculations and answer. Does the answer seem reasonable? If possible, have another operator check your calculations before making any operational changes.

15.13 TYPICAL TREATMENT PLANT PROBLEMS

15.130 Grit Chambers

1. Grit Chamber Velocity

Example: Estimate the velocity of wastewater flowing through a grit chamber if a stick travels 32 feet in 36 seconds.

Known	Unknown
Distance = 32 ft	Velocity, ft/sec
Time = 36 sec	

$$\text{Velocity, ft/sec} = \frac{\text{Distance Traveled, ft}}{\text{Time, sec}}$$

$$= \frac{32 \text{ ft}}{36 \text{ sec}}$$

$$= 0.89 \text{ ft/sec}$$

2. Volume of Grit Removed

Example: A grit chamber removed 3.2 cu ft of grit during a period when the total flow was 0.8 MG. How many cu ft of grit are removed per MG?

Known	Unknown
Vol. of Grit = 3.2 cu ft	Grit Removed, cu ft/MG
Vol. of Flow = 0.8 MG	

$$\text{Grit Removed, cu ft/MG} = \frac{\text{Volume of Grit, cu ft}}{\text{Volume of Flow, MG}}$$

$$= \frac{3.2 \text{ cu ft}}{0.8 \text{ MG}}$$

$$= 4.0 \text{ cu ft/MG}$$

15.131 Sedimentation Tanks and Clarifiers

Example: A circular clarifier handles a flow of 0.9 MGD. The clarifier is 50 feet in diameter and 8 feet deep. Find the detention time, surface loading rate, and weir overflow rate.

Known		Unknown
Flow	= 0.9 MGD	Detention Time, hours
Diameter	= 50 ft	Surface Loading, gpd/sq ft
Depth	= 8 ft	Weir Overflow, gpd/ft

Detention Time

$$\text{Detention Time, hrs} = \frac{(\text{Tank Volume, cu ft})(7.5\text{ gal/cu ft})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

$$\text{Tank Volume, cu ft} = (\text{Area, sq ft})(\text{Depth, ft})$$

$$\text{Clarifier Area, sq ft} = 0.785\ (\text{Diameter, ft})^2$$

$$\begin{aligned}
\text{Clarifier Area, sq ft} &= 0.785\ (\text{Diameter, ft})^2 \\
&= 0.785\ (50\text{ ft})^2 \\
&= 1962.5\text{ sq ft, or} \\
&= 1960\text{ sq ft}
\end{aligned}$$

$$\begin{aligned}
\text{Tank Volume, cu ft} &= (\text{Area, sq ft})(\text{Depth, ft}) \\
&= (1960\text{ sq ft})(8\text{ ft}) \\
&= 15{,}680\text{ cu ft}
\end{aligned}$$

$$\text{Detention Time, hrs} = \frac{(\text{Tank Volume, cu ft})(7.5 \text{ gal/cu ft})(24 \text{ hr/day})}{\text{Flow, gal/day}}$$

$$= \frac{(15{,}680 \text{ cu ft})(7.5 \text{ gal/cu ft})(24 \text{ hr/day})}{900{,}000 \text{ gal/day}}$$

$$= \frac{2{,}820{,}000}{900{,}000}$$

$$= 3.1 \text{ hr}$$

Surface Loading Rate

$$\text{Surface Loading, gpd/sq ft} = \frac{\text{Flow, gpd}}{\text{Area, sq ft}}$$

$$= \frac{900{,}000 \text{ gpd}}{1960 \text{ sq ft}}$$

$$= 459 \text{ gpd/sq ft}$$

Weir Overflow Rate

$$\text{Weir Overflow, gpd/ft} = \frac{\text{Flow, gpd}}{\text{Length of Weir, ft}}$$

$$\text{Length of Weir, ft} = 3.14 \text{ (Diameter, ft)}$$

$$= 3.14 \text{ (50 ft)}$$

$$= 157 \text{ ft}$$

$$\text{Weir Overflow, gpd/ft} = \frac{\text{Flow, gpd}}{\text{Length of Weir, ft}}$$

$$= \frac{900{,}000 \text{ gpd}}{157 \text{ ft}}$$

$$= 5730 \text{ gpd/ft}$$

15.132 Trickling Filters

Example: A flow of 1.1 MGD is applied to a 50-ft diameter trickling filter which is 4 feet deep. The BOD of the wastewater is 120 mg/l. Calculate the hydraulic and organic loadings on the filter.

Known		Unknown
Flow	= 1.1 MGD	Hydraulic Loading, gpd/sq ft
Diameter	= 50 ft	
Depth	= 4 ft	Organic Loading, $\frac{\text{lbs BOD/day}}{\text{1000 cu ft}}$
BOD	= 120 mg/l	

Hydraulic Loading

$$\text{Hydraulic Loading, gpd/sq ft} = \frac{\text{Flow, gpd}}{\text{Surface Area, sq ft}}$$

$$\begin{aligned}\text{Surface Area, sq ft} &= 0.785\ (\text{Diameter, ft})^2 \\ &= 0.785\ (50\ \text{ft})^2 \\ &= 1960\ \text{sq ft}\end{aligned}$$

$$\begin{aligned}\text{Hydraulic Loading, gpd/sq ft} &= \frac{\text{Flow, gpd}}{\text{Surface Area, sq ft}} \\ &= \frac{1{,}100{,}000\ \text{gpd}}{1960\ \text{sq ft}} \\ &= 561\ \text{gpd/sq ft}\end{aligned}$$

Organic Loading

$$\text{Organic Loading, } \frac{\text{lbs BOD/day}}{\text{1000 cu ft}} = \frac{\text{BOD Applied, lbs/day}}{\text{Volume of Media, 1000 cu ft}}$$

BOD Applied, lbs/day = (BOD, mg/l)(Flow, MGD)(8.34 lb/gal)

Volume of Media, 1000 cu ft = (Surface Area, sq ft)(Depth, ft)

BOD Applied, lbs/day = (BOD, mg/l)(Flow, MGD)(8.34 lb/gal)

= (120 mg/l)(1.1 MGD)(8.34 lb/gal)

= 1100 lbs BOD/day

Volume of Media, 1000 cu ft = (Surface Area, sq ft)(Depth, ft)

= (1960 sq ft)(4 ft)

= 7840 cu ft

= 7.84 - 1000 cu ft

$$\text{Organic Loading, } \frac{\text{lbs BOD/day}}{\text{1000 cu ft}} = \frac{\text{BOD Applied, lbs/day}}{\text{Volume of Media, 1000 cu ft}}$$

$$= \frac{\text{1100 lbs BOD/day}}{\text{7.84 (1000 cu ft)}}$$

= 140 lbs BOD/day/1000 cu ft

15.133 Activated Sludge

Example: Lab results and flow rate for an activated sludge plant are listed below under the known column. Information helpful to the operator in controlling the process is listed in the unknown column. The aerator or aeration tank volume is 0.50 MG.

Known

Mixed Liquor Suspended Solids (MLSS)	=	1800 mg/l
Mixed Liquor Volatile Content	=	76%
Thirty-Minute Settleable Solids Test*	=	360 ml, or 17%
Primary Effluent BOD	=	140 mg/l
Primary Effluent Suspended Solids	=	110 mg/l
Flow Rate	=	2.0 MGD

Unknown

Pounds of Solids in the Aerator

Sludge Volume Index, SVI

Pounds of BOD Applied to Aerator

Sludge Age

Pounds of Solids in Aerator

Aerator Solids, lbs = (MLSS, mg/l)(Tank Vol., MG)(8.34 lbs/gal)

= (1800 mg/l)(0.50 MG)(8.34 lbs/gal)

= 7500 lbs

Sludge Volume Index, SVI

$$\text{SVI} = \frac{(\text{Settleable Solids, \%})(10{,}000)}{\text{MLSS, mg/l}}$$

$$= \frac{(17)(10{,}000)}{1800}$$

$$= 94$$

* Thirty-minute results obtained from 60-minute settleable solids test using 2 liter cylinder.

Pounds of BOD Applied to Aerator

$$\text{Aerator Loading, lbs BOD/day} = (\text{Primary Effluent BOD, mg/l})(\text{Flow, MGD})(8.34\ \text{lbs/gal})$$

$$= (140\ \text{mg/l})(2.0\ \text{MGD})(8.34\ \text{lbs/gal})$$

$$= 2335\ \text{lbs BOD/day Applied to Aerator}$$

Sludge Age

Chapter 7, Activated Sludge, and Chapter 14, Laboratory Procedures and Chemistry, discuss the different methods of calculating sludge age and the meaning of the results.

$$\text{Sludge Age, days} = \frac{(\text{MLSS, mg/l})(\text{Tank Volume, MG})(8.34\ \text{lb/gal})}{(\text{SS in Primary Effl., mg/l})(\text{Flow, MGD})(8.34\ \text{lb/gal})}$$

$$= \frac{\text{Mixed Liquor Solids, lbs}}{\text{Primary Effluent Solids, lbs/day}} \quad \text{(or Aerator Solids, lbs)}$$

$$= \frac{7500\ \text{lbs}}{(110\ \text{mg/l})(2.0\ \text{MGD})(8.34\ \text{lb/gal})}$$

$$= \frac{7500\ \text{lbs}}{1834\ \text{lbs/day}}$$

$$= 4.1\ \text{days}$$

15.134 Sludge Digestion

1. CO_2 in Digester Gas

Example: The total volume of a 100 ml graduate used in the CO_2 test is 127 ml. The volume of gas remaining in the graduate after the CO_2 test was 82 ml. Find the percent CO_2 in the digester gas.

Known			Unknown
Total Volume	=	127 ml	Percent CO_2
Gas Remaining	=	82 ml	

$$\%CO_2 = \frac{(\text{Total Volume, ml} - \text{Gas Remaining, ml})}{\text{Total Volume, ml}} 100\%$$

$$= \frac{(127 \text{ ml} - 82 \text{ ml})}{127 \text{ ml}} 100\%$$

$$= \frac{45 \text{ ml}}{127 \text{ ml}} 100\%$$

$$= 35\%$$

2. Volatile Acid/Alkalinity Relationship

Example: The volatile acids in a digester are 250 mg/1, and the alkalinity is 1750 mg/1. Find the volatile acid/alkalinity relationship.

Known			Unknown
Volatile Acids	=	250 mg/1	Volatile Acid/Alkalinity
Alkalinity	=	1750 mg/1	

$$\text{Volatile Acid/Alkalinity} = \frac{\text{Volatile Acid, mg/1}}{\text{Alkalinity, mg/1}}$$

$$= \frac{250 \text{ mg/1}}{1750 \text{ mg/1}}$$

$$= .14$$

3. Volume Per Stroke of a Piston Pump

Example: Calculate the volume (in gallons) pumped per stroke (revolution) by a piston pump with a bore of 2 5/12 inches and a stroke of 3 inches.

Known		Unknown
Dia. of Piston	= 2 5/12 in	Volume, gallons
Length of Stroke	= 3 in	

$$\text{Cylinder Volume, cu in} = (\text{Area, sq in})\ (\text{Length, in})$$

$$= (0.785)\ (2.417\ \text{in})^2\ (3\text{in})$$

$$= 13.75\ \text{cu in}$$

$$\text{Cylinder Volume, gal} = \frac{13.75\ \text{cu in}}{231\ \text{cu in/gal}}$$

$= 0.06$ gal, or volume pumped per stroke is 0.06 gal.

The actual volume pumped per stroke will be slightly below 0.06 gallon because the system is not 100% efficient.

4. Percent Reduction of Volatile Matter

Example: Find the percent reduction of volatile matter in a digester if the percent volatile matter in the raw sludge was 71 percent and the digested sludge was composed of 53 percent volatile matter.

Known		Unknown
In, % VM in Raw Sludge	= 71%	P, % Reduction of VM
Out, % VM in Dig. Sludge	= 53%	

$$P = \left[\frac{(\text{In} - \text{Out})}{\text{In} - (\text{In} \times \text{Out})}\right] 100\%$$

$$= \left[\frac{(.71 - .53)}{.71 - (.71 \times .53)}\right] 100\%$$

$$= \left[\frac{.18}{.71 - .38}\right] 100\%$$

$$= \frac{.18}{.33} \times 100\%$$

$$= .55 \times 100\%$$

$$= 55\%$$

5. Digester Loading

Example: A digester with a volume of 25,000 cu ft receives 2000 pounds of raw sludge per day with a volatile content of 70%.

Known		Unknown
Digester Volume	= 25,000 cu ft	Digester Loading, lb VM/day/cu ft
Raw Sludge	= 2000 pounds	
Volatile Content	= 70%	

$$\text{Volatile Matter Added, lb/day} = (\text{Raw Sludge, lbs/day})(\text{Volatile, \%})$$

$$= (2000 \text{ lbs/day})(0.70)$$

$$= 1400 \text{ lbs/day}$$

$$\text{Digester Loading, lb VM/day/cu ft} = \frac{\text{Volatile Matter Added, lb/day}}{\text{Digester Volume, cu ft}}$$

$$= \frac{1400 \text{ lbs/day}}{25,000 \text{ cu ft}}$$

$$= 0.056 \text{ lbs VM/day/cu ft}$$

15.135 Ponds

Example: To calculate the different loadings on a pond, the information listed under known must be available.

Known

Ave. Depth	=	4 ft
Ave. Width	=	400 ft
Ave. Length	=	600 ft
Flow	=	0.5 MGD
BOD	=	150 mg/l
Population	=	5000 persons

Unknown

Detention Time, days

Population Loading, persons/acre

Hydraulic Load, in/day

Organic Load, lbs BOD/day/acre

Detention Time

$$\text{Detention Time, days} = \frac{\text{Pond Volume, ac-ft}}{\text{Flow Rate, ac-ft/day}}$$

$$\text{Pond Area, acres} = \frac{(\text{Average Width, ft})(\text{Average Length, ft})}{43{,}560 \text{ sq ft/acre}}$$

$$= \frac{(400 \text{ ft})\ (600 \text{ ft})}{43{,}560 \text{ sq ft/acre}}$$

$$= 5.51 \text{ acres}$$

$$\text{Pond Volume, ac-ft} = (\text{Area, ac})(\text{Depth, ft})$$

$$= (5.51 \text{ acres})(4 \text{ ft})$$

$$= 22.0 \text{ ac-ft}$$

$$\text{Flow Rate, ac-ft/day} = \frac{(500{,}000\ \text{gal/day})}{(7.48\ \text{gal/cu ft})(43{,}560\ \text{sq ft/ac})}$$

$$= 1.53\ \text{ac-ft/day}$$

$$\text{Detention Time, days} = \frac{\text{Pond Volume, ac-ft}}{\text{Flow Rate, ac-ft/day}}$$

$$= \frac{22.0\ \text{ac-ft}}{1.53\ \text{ac-ft/day}}$$

$$= 14.3\ \text{days}$$

Population Loading

$$\text{Population Loading, persons/ac} = \frac{\text{Population Served, persons}}{\text{Pond Area, acres}}$$

$$= \frac{5000\ \text{Persons}}{5.51\ \text{Acres}}$$

$$= 907\ \text{persons/acre}$$

Hydraulic Loading

$$\text{Hydraulic Loading, in/day} = \frac{\text{Depth of Pond, inches}}{\text{Detention Time, days}}$$

$$= \frac{(4\ \text{ft})(12\ \text{in/ft})}{14.3\ \text{days}}$$

$$= 3.36\ \text{in/day}$$

Organic Loading

$$\text{Organic Loading, lb BOD/day/ac} = \frac{(\text{BOD, mg/l})(\text{Flow, MGD})(8.34\ \text{lb/gal})}{\text{Area, ac}}$$

$$= \frac{(150\ \text{mg/l})(0.5\ \text{MGD})(8.34\ \text{lb/gal})}{5.51\ \text{ac}}$$

$$= \frac{625.5\ \text{lb BOD/day}}{5.51\ \text{ac}}$$

$$= 114\ \text{lb BOD/day/ac}$$

15.136 Chlorination

1. Chlorine Demand

Example: Determine the chlorine demand*of an effluent if the chlorine dose is 10.0 mg/l and the chlorine residual is 1.1 mg/l.

Known	Unknown
Chlorine Dose = 10.0 mg/l	Chlorine Demand, mg/l
Chlorine Residual = 1.1 mg/l	

Chlorine Demand, mg/l = Chlor. Dose, mg/l - Chlor. Residual, mg/l

= 10.0 mg/l - 1.1 mg/l

= 8.9 mg/l

2. Chlorine Feed Rate

Example: To maintain a satisfactory chlorine residual in a plant effluent, the chlorine dose must be 10 mg/l when the flow is 0.37 MGD. Determine the chlorinator setting (feed rate) in pounds per day.

Known	Unknown
Dose = 10 mg/l	Chlorinator Setting, lbs/day
Flow = 0.37 MGD	

Chlorine Feed Rate, lbs/day = (Dose, mg/l)(Flow, MGD)(8.34 lb/gal)

= (10 mg/l)(0.37 MGD)(8.34 lb/gal)

= 30.9, or

= 31 lbs/day

*"Standard Methods" uses the term chlorine demand when referring to stabilized water such as a domestic water supply and the term chlorination requirement when referring to wastewater.

15.137 Laboratory Results

1. Dissolved Oxygen (DO) Saturation, Percent

Example: The dissolved oxygen in a receiving water was 10.3 mg/l when the temperature was 50°F (Saturation DO = 11.3 mg/l). Determine the percent DO saturation.

Known		Unknown
DO of Sample	= 10.3 mg/l	DO Saturation, %
DO at 100% Sat.	= 11.3 mg/l	

$$\text{DO Saturation, \%} = \frac{\text{DO of Sample, mg/l}}{\text{DO at 100\% Saturation, mg/l}} \times 100\%$$

$$= \frac{10.3 \text{ mg/l}}{11.3 \text{ mg/l}} \times 100\%$$

$$= 91.2\%$$

2. Biochemical Oxygen Demand (BOD)

Example: Laboratory results are listed under known.

Known		Unknown
BOD Bottle Volume	= 300 ml	BOD, mg/l
Sample Volume	= 12 ml	
Initial DO of Diluted Sample	= 8.0 mg/l	
DO of Sample and Dilution After 5-Day Incubation Period	= 4.0 mg/l	

$$\text{BOD, mg/l} = \left(\text{Initial DO of Diluted Sample, mg/l} - \text{DO of Diluted Sample After 5-Day Incubation, mg/l}\right)\left(\frac{\text{BOD Btl. Vol., ml}}{\text{Sample Vol., ml}}\right)$$

$$= (8.0 \text{ mg/l} - 4.0 \text{ mg/l})\left(\frac{300 \text{ ml}}{12 \text{ ml}}\right)$$

$$= 100 \text{ mg/l}$$

15.138 Efficiency of Plant or Treatment Process

Example: The influent BOD to a treatment plant is 200 mg/l, and the effluent BOD is 20 mg/l. What is the BOD removal efficiency of the plant?

Known		Unknown
Influent BOD	= 200 mg/l	Plant Efficiency, %
Effluent BOD	= 20 mg/l	

$$\text{Efficiency, \%} = \frac{(\text{In} - \text{Out})}{\text{In}} 100\%$$

$$= \frac{(200 \text{ mg/l} - 20 \text{ mg/l})}{200 \text{ mg/l}} 100\%$$

$$= \frac{180 \text{ mg/l}}{200 \text{ mg/l}} 100\%$$

$$= 90\%$$

15.139 Blueprint Reading

Example: A set of blueprints for a treatment plant has a scale of 1/4 inch = 1 foot. On the prints, the laboratory dimensions were measured and found to be 6 inches wide and 9 inches long. What is the floor area of the laboratory?

Known		Unknown
Scale: 1/4 in	= 1 ft	Area, sq ft
Length	= 9 in	
Width	= 6 in	

Area, sq ft = (Length, ft) (Width, ft)

Find actual length and width in feet.

$$\frac{1/4 \text{ in}}{1 \text{ ft}} = \frac{9 \text{ in}}{\text{Length, ft}}$$

$$\text{Length, ft} = (9 \text{ in})\left(\frac{1 \text{ ft}}{1/4 \text{ in}}\right)$$

$$= (9)\ (4)$$

$$= 36 \text{ ft}$$

$$\frac{1/4 \text{ in}}{1 \text{ ft}} = \frac{6 \text{ in}}{\text{Width, ft}}$$

$$\text{Width, ft} = \frac{(6 \text{ in})(1 \text{ ft})}{(1/4 \text{ in})}$$

$$= (6)\ (4)$$

$$= 24 \text{ ft}$$

$$\text{Area, sq ft} = (\text{Length, ft})(\text{Width, ft})$$

$$= (36 \text{ ft})(24 \text{ ft})$$

$$= 864 \text{ sq ft}$$

15.14 SUMMARY OF FORMULAS

15.140 Length

LENGTH OF CLARIFIER WEIR or circumference of a circle:

Length, ft = 3.14 (Diameter, ft)

15.141 Area

RECTANGLE:

Area, sq ft = (Length, ft)(Width, ft)

TRIANGLE:

Area, sq ft = (1/2)(Base, ft)(Height, ft)

CIRCLE:

Area, sq ft = 0.785 $(\text{Diameter, ft})^2$

CYLINDER (wall):

Area, sq ft = 3.14 (Diameter, ft)(Height, ft)

SPHERE:

Area, sq ft = 3.14 $(\text{Diameter, ft})^2$

15.142 Volume

RECTANGLE:

Volume, cu ft = (Length, ft)(Width, ft)(Height, ft)

CYLINDER:

Volume, cu ft = 0.785 $(\text{Diameter, ft})^2$ (Height, ft)

SPHERE:

Volume, cu ft = 0.524 $(\text{Diameter, ft})^3$

15.143 Velocity

$$\text{Velocity, ft/sec} = \frac{\text{Distance Traveled, ft}}{\text{Time, sec}}$$

or

$$\text{Velocity, ft/sec} = \frac{\text{Flow Rate, cu ft/sec}}{\text{Cross-Sectional Area, sq ft}}$$

15.144 Sedimentation Tanks and Clarifiers

$$\text{Detention Time, hrs} = \frac{\text{(Tank Volume, cu ft)(7.5 gal/cu ft)(24 hr/day)}}{\text{Flow, gal/day}}$$

$$\text{Surface Loading Rate, gpd/sq ft} = \frac{\text{Flow, gal/day}}{\text{Area, sq ft}}$$

$$\text{Weir Overflow Rate, gpd/ft} = \frac{\text{Flow, gal/day}}{\text{Length of Weir, ft}}$$

15.145 Trickling Filters

$$\text{Hydraulic Loading, gpd/sq ft} = \frac{\text{Flow, gal/day}}{\text{Surface Area, sq ft}}$$

$$\text{Organic Loading, } \frac{\text{lbs BOD/day}}{\text{1000 cu ft}} = \frac{\text{BOD Applied, lbs/day}}{\text{Volume of Media, 1000 cu ft}}$$

15.146 Activated Sludge

$$\text{Solids in Aerator, lbs} = \text{(MLSS, mg/l)(Tank Vol., MG)(8.34 lb/gal)}$$

where MLSS = Mixed Liquor Suspended Solids

$$\text{Aerator Loading, lbs BOD/day} = \text{(Primary Effl. BOD, mg/l)(Flow, MGD)(8.34 lb/gal)}$$

$$\text{Sludge Volume Index (SVI)} = \frac{(\text{30-Minute Settleable Solids, \%})\ (10{,}000)}{\text{MLSS, mg/l}}$$

$$\text{or} = \frac{\text{30-Minute Settleable Solids, grams}}{\text{100 ml}}$$

$$\text{Sludge Density Index (SDI)} = \frac{100}{\text{SVI}}$$

$$\text{Sludge Age, days} = \frac{(\text{MLSS, mg/l})\ (\text{Tank Vol., MG})\ (\text{8.34 lb/gal})}{(\text{SS in Primary Effl., mg/l})\ (\text{Flow, MGD})\ (\text{8.34 lb/gal})}$$

$$= \frac{\text{Mixed Liquor Solids, lbs, or Solids in Aerator, lbs}}{\text{Primary Effluent Solids, lbs/day}}$$

NOTE: See Chapter 7, Activated Sludge, or Chapter 14, Laboratory Procedures and Chemistry, for other terms used instead of primary effluent solids.

15.147 Sludge Digestion

$$CO_2 \text{ in Digester Gas, \%} = \frac{(\text{Total Volume, ml} - \text{Gas Remaining, ml})}{\text{Total Volume, ml}}\ 100\%$$

$$\text{Reduction of Volatile Matter, \%} = \left[\frac{\text{In} - \text{Out}}{\text{In} - \text{In} \times \text{Out}}\right] 100\%$$

$$\text{Digester Loading, lb VM/day/cu ft} = \frac{\text{Volatile Matter Added, lb/day}}{\text{Digester Volume, cu ft}}$$

15.148 Ponds

$$\text{Detention Time, days} = \frac{\text{Pond Volume, ac-ft}}{\text{Flow Rate, ac-ft/day}}$$

$$\text{Population Loading, persons/ac} = \frac{\text{Population Served, persons}}{\text{Pond Area, acres}}$$

$$\text{Hydraulic Loading, in/day} = \frac{\text{Depth of Pond, inches}}{\text{Detention Time, days}}$$

$$\text{Organic Loading, lb BOD/day/ac} = \frac{(\text{BOD, mg/l})(\text{Flow, MGD})(8.34\ \text{lb/gal})}{\text{Area, acre}}$$

15.149 Other Formulas

15.1490 Chlorination

$$\text{Chlorine Demand, mg/l} = \text{Chlorine Dose, mg/l} - \text{Chlorine Residual, mg/l}$$

$$\text{Chlorine Feed Rate, lbs/day} = (\text{Dose, mg/l})(\text{Flow, MGD})(8.34\ \text{lb/gal})$$

15.1491 Laboratory Results

$$\text{DO Saturation, \%} = \frac{\text{DO of Sample, mg/l} \times 100\%}{\text{DO at 100\% Saturation, mg/l}}$$

$$\text{BOD, mg/l} = \left[\text{Initial DO of Diluted Sample, mg/l} - \text{DO of Diluted Sample After 5-Day Incubation, mg/l}\right]\left[\frac{\text{BOD Bottle Vol., ml}}{\text{Sample Vol., ml}}\right]$$

15.1492 Efficiency of Plant or Treatment Process

$$\text{Efficiency, \%} = \frac{(\text{In} - \text{Out})\ 100\%}{\text{In}}$$

15.1493 Pumps

$$\text{Water, HP} = \frac{(\text{Flow, gpm})(\text{H, ft})}{3960}$$

$$\text{Brake, HP} = \frac{(\text{Flow, gpm})(\text{H, ft})}{(3960)(E_p)}$$

$$\text{Motor, HP} = \frac{(\text{Flow, gpm})(\text{H, ft})}{(3960)(E_p)(E_m)}$$

15.15 CONVERSION TABLES

Tables in this section were taken from Water and Wastewater Engineering, Volume 1, *Water Supply and Wastewater Removal*, by G. M. Fair, J. C. Geyer, and D. A. Okun, John Wiley & Sons, Inc., New York, 1966. Price $13.95. The tables are also found in Volume 2, *Water Purification and Wastewater Treatment and Disposal*, 1968. Price $17.00.

The American and English weights and measures referred to in this book are alike except for the gallon. The United States gallon is employed. The United States billion, which equals 1000 million, is also employed.

LENGTH

Miles	Yards	Feet	Inches	Centimeters
1	1760	5280	--	--
--	1	3	36	91.44
--	--	1	12	30.48
--	--	--	1	2.540

1 m = 100 cm = 3.281 ft = 39.37 in

AREA

Square Miles	Acres	Square Feet	Square Inches	Square Centimeters
1	640	--	--	--
--	1	43,560	--	--
--	--	1	144	929.0
--	--	--	1	6.452

1 sq m = 10.76 sq ft

VOLUME

Cubic Feet	Imperial Gallons	U.S. Gallons	Cubic Inches	Liters
1	6.23	7.481	1728	28.32
--	1	1.2	277.4	4.536
--	--	1	231	3.785
--	--	--	57.75	0.946
--	--	--	61.02	1

1 cu m = 35.31 cu ft = 264.2 gal

1 Imperial (UK) gal weighs 10 lb
1 cu ft of water weighs 62.43 lb
1 cu m = 10^3 l and weighs 1000 kg

1 US gal weighs 8.34 lb
1 cu m weighs 2283 lb

VELOCITY

Miles per Hour	Feet per Second	Inches per Minute	Centimeters per Second	Kilometers per Hour
1	1.467	1056	--	1.609
--	1	720	30.48	--
--	--	1	0.423	--

TIME

Days	Hours	Minutes	Seconds
1	24	1440	86,400
--	1	60	3,600
--	--	1	60

WEIGHT

Tons	Pounds	Grams	Grains	Metric Tons
1	2000	--	--	0.9078
--	1	454	7000	--
--	--	1	15.43	--

1 long ton = 2240 lb

1 ppm = 1 mg/l = 8.34 lb per MG

DISCHARGE

Cubic Feet per Second	Million Gallons Daily	Gallons per Minute
1	0.6463	448.8
1.547	1	694.4

1 in per hour per acre = 1.008 cfs

1 cu m/sec = 22.83 MGD = 35.32 cfs

PRESSURE

Pounds per Square Inch	Feet of Water	Inches of Mercury
1	2.307	2.036
0.4335	1	0.8825
0.4912	1.133	1

1 atm = 14.70 psia = 29.92 in. Hg =

33.93 ft water = 76.0 cm Hg

POWER

Kilowatts	Horsepower	Foot-Pounds per Second	Kilogram-Meters per Second
1	1.341	737.6	102.0
0.7457	1	550	76.04

WORK AND ENERGY

Kilowatt-Hours	Horsepower-Hours	British Thermal Units
1	1.341	3412
0.7457	1	2544

TEMPERATURE

$$\text{Degree Fahrenheit} = 32 + \frac{9}{5} \times \text{Degrees Centigrade}$$

0	5	10	15	20	25	30	35	40	45	50	55	60	C
32	41	50	59	68	77	86	95	104	113	122	131	140	F

DENSITY OF WATER

1 gram/cm^3 = 62.43 lb/cu ft

15.13 ADDITIONAL READING

a. MOP 11.

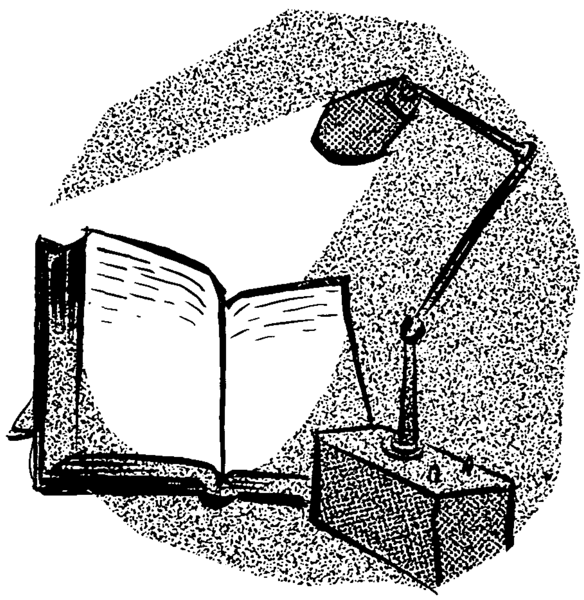
b. New York Manual, pages 183-190 and 215-219.

c. Texas Manual, pages 588-608.

d. <u>Elementary Mathematics and Basic Calculations</u>, Scranton Publishing Company, 35 East Wacker Drive, Chicago, Illinois 60601. Price $1.25.

e. <u>Mathematics for Operators of Water Pollution Control Plants.</u> Obtain from Secretary-Treasurer, California Water Pollution Control Association, P.O. Box 61, Lemon Grove, California 92045. Price $2.35 to members of CWPCA; $3.00 to others.

f. <u>Mathematics Made Simple</u>, A. Sperling and M. Stuart, Doubleday and Company, Inc., Garden City, New York, 1962. Price $1.95.



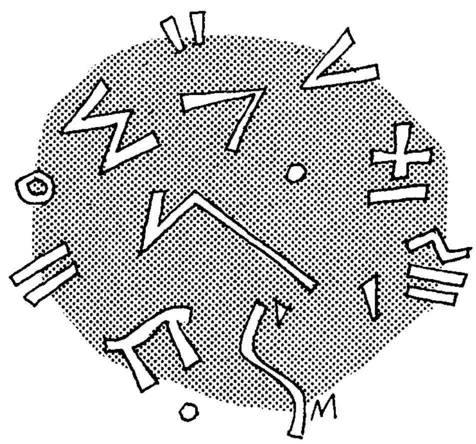
OBJECTIVE TEST PROCEDURE

1. Work the problems in your notebook. Be neat and orderly so that your work may be followed and checked.

2. Mark your answers on the IBM answer sheet.

3. Mail the IBM answer sheet to your Program Director.

You may refer to the chapter for formulas and conversion factors.



OBJECTIVE TEST

Chapter 15. Basic Mathematics and Treatment Plant Problems

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1. There will be only one answer to each question. If necessary, select the closest answer.

A rectangular sedimentation tank is 35 feet wide, 70 feet long, and 9 feet deep. The flow is 1.6 MGD.

1. The detention time is:
   1. 0.5 hr
   2. 1.0 hr
   3. 2.0 hr
   4. 2.5 hr
   5. 3.5 hr

2. The surface loading rate is:
   1. 500 gpd/sq ft
   2. 600 gpd/sq ft
   3. 650 gpd/sq ft
   4. 750 gpd/sq ft
   5. 1000 gpd/sq ft

A 65-ft diameter trickling filter receives a flow of 2.5 MGD with a BOD of 125 mg/l. The filter is 4 feet deep.

3. The hydraulic loading is:
   1. 500 gpd/sq ft
   2. 600 gpd/sq ft
   3. 750 gpd/sq ft
   4. 800 gpd/sq ft
   5. 1000 gpd/sq ft

4. The organic loading is:
   1. 25 lb BOD/day/1000 cu ft
   2. 100 lb BOD/day/1000 cu ft
   3. 150 lb BOD/day/1000 cu ft
   4. 200 lb BOD/day/1000 cu ft
   5. 300 lb BOD/day/1000 cu ft

Information for an activated sludge plant is summarized below.

Mixed Liquor Suspended Solids (MLSS)	=	2100 mg/1
Mixed Liquor Volatile Content	=	73%
Thirty-Minute Settleable Solids Test	=	420 ml* or 21%
Primary Effluent BOD	=	145 mg/1
Primary Effluent Suspended Solids	=	115 mg/1
Flow Rate	=	2.2 MGD
Aeration Tank Volume	=	70,000 cu ft

*2 liter cylinder

5. The pounds of solids in the aeration tank are:

   1. 1,000 lbs
   2. 2,000 lbs
   3. 5,000 lbs
   4. 9,000 lbs
   5. 10,000 lbs

6. The aeration tank loading is:

   1. 1,000 lbs BOD/day
   2. 2,500 lbs BOD/day
   3. 5,000 lbs BOD/day
   4. 7,500 lbs BOD/day
   5. 10,000 lbs BOD/day

7. Raw sludge pumped to a digester was 75 percent volatile matter, and the digested sludge was 55 percent volatile matter. Calculate the percent reduction of volatile matter.

   1. 50%
   2. 55%
   3. 59%
   4. 60%
   5. 61%

A waste treatment pond is 225 ft wide, 310 ft long, and 4.5 ft deep. The inflow is 0.108 MGD, has a BOD of 170 mg/1, and serves a population of 975 people.

8. The detention time of the pond is:

   1. 20 days
   2. 25 days
   3. 30 days
   4. 35 days
   5. 40 days

9. The population loading on the pond is:

   1. 500 persons/acre
   2. 600 persons/acre
   3. 700 persons/acre
   4. 800 persons/acre
   5. 900 persons/acre

10. Hydraulic loading is:

   1. 2.00 in/day
   2. 2.25 in/day
   3. 2.50 in/day
   4. 2.75 in/day
   5. 3.00 in/day

11. Organic loading is:

   1. 80 lb BOD/day/ac
   2. 85 lb BOD/day/ac
   3. 90 lb BOD/day/ac
   4. 95 lb BOD/day/ac
   5. 100 lb BOD/day/ac

12. Determine the chlorine feed rate for a chlorinator when the dose is 12 mg/l and the flow is 0.28 MGD.

   1. 25 lbs/day
   2. 28 lbs/day
   3. 30 lbs/day
   4. 32 lbs/day
   5. 35 lbs/day

13. Calculate the BOD of a 3 ml sample in a 300 ml BOD bottle if the initial DO of diluted sample was 8.3 mg/l and the DO of sample and dilution was 3.4 mg/l after the 5-day incubation period.

   1. 100 mg/l
   2. 200 mg/l
   3. 300 mg/l
   4. 400 mg/l
   5. 500 mg/l

14. The influent suspended solids to an activated sludge plant is 245 mg/l, and the effluent suspended solids is 17 mg/l. The suspended solids removal efficiency for the plant is:

   1. 85%
   2. 90%
   3. 93%
   4. 95%
   5. 98%

15. A pump is capable of delivering 4 horsepower to water being pumped against a 33-ft head. Estimate the flow of water being pumped.

1. 50 gpm
2. 100 gpm
3. 150 gpm
4. 300 gpm
5. 500 gpm

16. The discharge pressure gage on a pump reads 15 psi. This is equivalent to how many feet of water or feet of head?

1. 5 ft
2. 10 ft
3. 25 ft
4. 35 ft
5. 50 ft

17. 100 mg/l is the same as:

1. 100%
2. 10%
3. 1%
4. 0.1%
5. 0.01%

Please write on your IBM answer sheet the total time required to work this chapter.

CHAPTER 16

ANALYSIS AND PRESENTATION OF DATA

by

Kenneth Kerri

TABLE OF CONTENTS

Chapter 16. Analysis and Presentation of Data

PRE-TEST

Chapter 16. Analysis and Presentation of Data

Complete this test before you read Chapter 16. Do not be discouraged if you don't know any of the answers because a lot of the information in this chapter is new to most operators.

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1.

1. Data should be collected and (select best answer):
   1. Filed
   2. Forgotten
   3. Analyzed
   4. Lost
   5. Values placed in all columns on report sheet

2. Laboratory results of influent BOD at a particular plant vary due to:
   1. Nothing--the results should not be different
   2. Differences in the composition of the influent
   3. Operators titrating to different end points
   4. Operators not following the exact same testing procedure every time
   5. Collecting samples in a different manner

3. The characteristics of a sample may change between collection and analysis due to:
   1. Nothing--the characteristics don't change
   2. Temperature changes during transportation to the lab
   3. Chemical changes in the sample
   4. Biological changes in the sample
   5. Changes in the variance

4. A representative sample:
   1. Describes the overall situation
   2. Represents the equipment manufacturers
   3. Represents the people

5. At the beginning of a week a totalizer on the plant inflow read 1,823,471 gallons. Seven days later, the totalizer reads 2,619,582 gallons. The average daily flow during the week was approximately:

   1. 0.01 MGD
   2. 0.11 MGD
   3. 1.11 MGD
   4. 0.10 MGD
   5. 0.13 MGD

6. Bar graphs can be used to show:

   1. Growth
   2. Characteristics of data
   3. Dispersion of data
   4. Your supervisor results of lab tests
   5. How neat you can draw

7. Plotting data on graph paper to show trends may be helpful to:

   1. Justify budget increases
   2. Describe the variance
   3. Predict when expansion will be necessary
   4. Illustrate the need to look for the cause of trend
   5. Illustrate patterns of effluent quality

At 1:30 p.m. every day of the week the dissolved oxygen in the Number 1 pond of a wastewater treatment facility is measured and the results are summarized below in mg/l:

WEEK	DAY				
	M	T	W	T	F
1	9.8	9.5	9.6	9.2	8.9
2	8.1	8.4	8.0	7.6	7.5

8. The average DO in the pond over the two-week period was:

   1. 8.1 mg/l
   2. 8.4 mg/l
   3. 8.5 mg/l
   4. 8.7 mg/l
   5. 8.9 mg/l

9. The range of DO was:

   1. 7.5 to 9.8 mg/l
   2. 9.8 to 7.5 mg/l
   3. 1.3 mg/l
   4. 2.3 mg/l
   5. 0.8 mg/l

10. The median DO was:

    1. 8.0 mg/l
    2. 8.1 mg/l
    3. 8.4 mg/l
    4. 8.6 mg/l
    5. 8.9 mg/l

11. Is there a trend in the DO concentration in the pond?

    1. Yes
    2. No

12. The variance, S^2, in the DO level in $(mg/l)^2$ is:

    1. 0.65
    2. 0.70
    3. 0.72
    4. 0.75
    5. 0.78

13. The standard deviation, S, in the DO level in mg/l is:

    1. 0.70
    2. 0.75
    3. 0.80
    4. 0.85
    5. 0.90

CHAPTER 16. ANALYSIS AND PRESENTATION OF DATA

(Lesson 1 of 2 Lessons)

16.0 INTRODUCTION

Collection of data without analysis, interpretation, and use of results is a waste of time and money. This chapter will attempt to provide you with simple, easy methods to analyze data. To show you how to make the results of your testing meaningful and easily interpreted, a section on Data Presentation also is included. Many times your supervisor can understand what is happening in your plant or why you need a budget increase if you can show him charts indicating trends or changes in plant operation or treatment process efficiencies.

Whether samples are collected, analyzed, interpreted, and used by the same person or a different person performs each task, every job is equally important if the application of results is to be effective. When running lab tests the samples must be representative.[1] Persons reviewing and interpreting lab results assume the tests were performed in a careful, prescribed manner and the results are accurate. Operators applying the interpretation of lab results to operational controls rely on proper interpretation to insure effective adjustments in the treatment processes.

All samples collected and analyzed must be needed by someone. Numbers from test results provide an accurate description or indication of the quantity of work completed or to be completed. Mathematical analysis of data is a means to estimate how well your test results can be repeated on a given sample (quality control) or how much a group of samples vary (another form of quality control). Presentation of data in tables, graphs, or charts makes the information more usable by illustrating trends, variations, and significant changes.

16.1 CAUSES OF VARIATIONS IN RESULTS

When you collect samples of wastewater or receiving water and measure their characteristics (for instance, temperature, pH, BOD), your results will be affected by several factors. Three principal factors which must be taken into account, no matter where the sample

---

[1] Representative Sample. A portion of material or water identical in content to that in the larger body of material or water being sampled.

is taken--influent raw wastewater, treatment process influent or effluent, receiving waters--are:

1. Actual variations in the characteristics of the water or material being examined

2. Sampling procedures

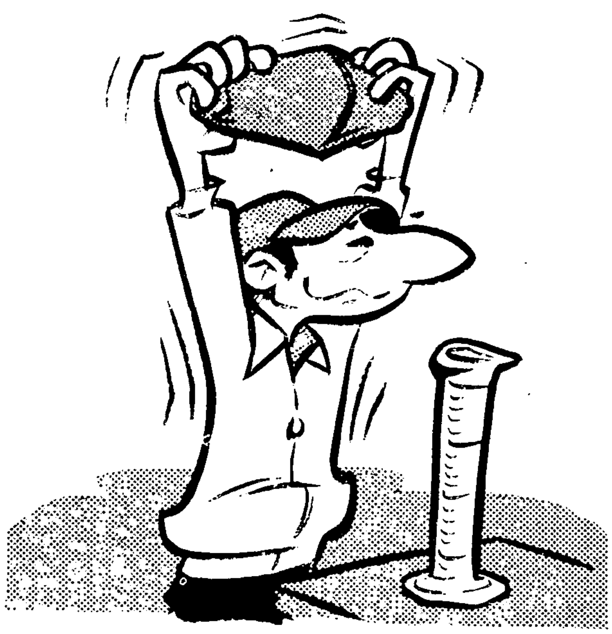
3. Testing or analytical procedures

16.10 Water or Material Being Examined

The properties or characteristics of the wastewater or receiving water are what you are attempting to measure, such as temperature, pH, or BOD. These and many other water quality indicators vary continuously depending on what is being discharged into a wastewater collection system (sewerage system), the effectiveness of treatment processes, and the response of the receiving waters and their changing characteristics. Your objective is to describe the characteristics of the wastewater or receiving water being sampled in terms of average values and also to give an indication of variation or spread of results from the average values.

16.11 Sampling

Characteristics of a sample can vary if you do not always sample at the same location or during the same time of day. If you observe the flow in a wastewater line or influent, you can see the differences in characteristics at various depths, differences between flow in the middle and edge of a pipe or channel, and also differences above or below a bend.



After a sample has been collected in a sampling jar or bottle, heavy material may settle to the bottom, and the jar must be mixed before the sample is tested. Also, if the sample is not analyzed immediately, its characteristics can undergo chemical or biological changes if the sample is not treated and stored properly following collection.

16.12 Testing

The results from two identical samples can differ depending on the analyzing apparatus and the operator conducting the measurement. Fluctuations in voltage can cause changes in instrument readings, and different individuals may titrate to slightly different end points. Using reagents from different bottles, filter paper from different packages, or different pieces of equipment that were not calibrated identically or were not warmed up during the same time period can cause differences in test results. Variations in test results may be caused by omitting a step in the lab procedure, and interfering substances can cause testing errors.

Your objective is to reduce or eliminate sampling and testing errors as much as possible so you can obtain an accurate description of the water being sampled.

QUESTIONS

16.1A What three major factors can cause variations in lab test results?

16.1B Why should most samples be tested immediately by the lab?

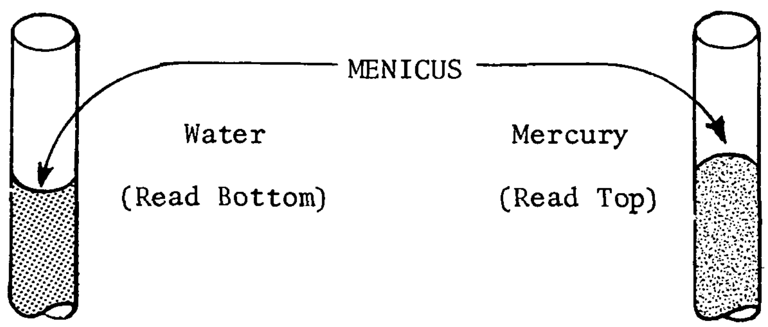
16.2 MANOMETER AND GAGE READING

Manometers and gages are installed in wastewater treatment plants to measure pressures and pressure differences. Both types of instruments should be calibrated and zeroed before using. Calibration and zeroing of any instrument means periodic checking of the instrument against a known standard to be sure the installed instrument reads properly. Manometers and gages can be zeroed in by making sure the instruments read zero when no pressure is being applied to the manometer or gage. If the reading is not zero, then the scales should be adjusted according to manufacturer's recommendations.

To read a manometer, note the scale reading opposite the menicus.[2] This reading may have to be converted from inches of mercury to head in feet of water, pressure in psi, or flow in GPM, depending on the use of the manometer.

---

[2] Menicus. The curved upper surface of a column of liquid (water, oil, mercury) in a small tube. Water will form a valley when the liquid wets the walls of the tube, while mercury will form a hill and the walls of the tube are not wetted.



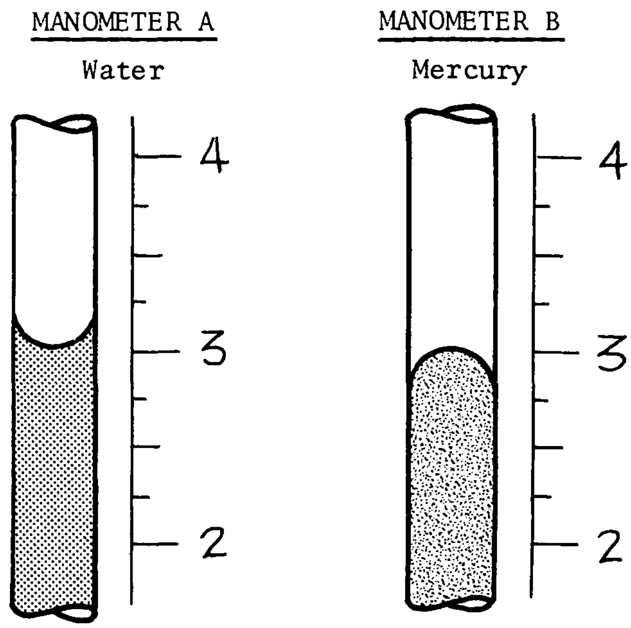
EXAMPLE MANOMETER READINGS

Manometer A

reads 3 inches of water

Manometer B

reads 3 inches of mercury



Gage readings are read directly from a scale behind a gage pointer and the units must be recorded. Sometimes a gage will have two scales and care must be taken to be sure the proper scale reading and units are recorded. Gage readings may have to be converted to more convenient numbers.

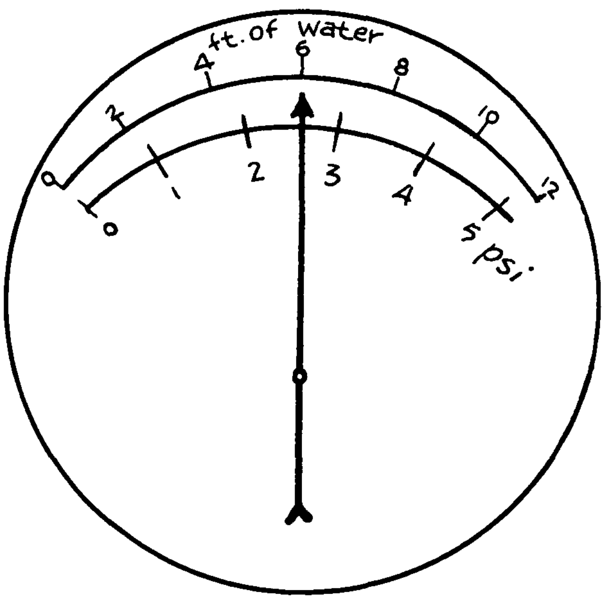
EXAMPLE GAGE READINGS

Gage Reads

6 ft of water

or

2.6 psi



QUESTIONS

16.2A Why must instruments be periodically calibrated and zeroed?

16.2B If the gage shown in this section under EXAMPLE GAGE READINGS indicated a pressure of 2 psi, what would be the pressure head in feet of water?

16.3 CHART READING

Before data can be analyzed and presented, frequently it must be reduced to or tabulated in a usable form. Today, more and more, data are being recorded on a continuous basis on strip charts and circular charts.

For instance, sometimes flow data are recorded in depths of flow in inches or feet through a Parshall flume, and sometimes the recorder will convert the depth to a flow rate, such as MGD. To compile or tabulate data from such continuous charts, select an appropriate time interval, such as a few hours (Fig. 16.1). Prepare a table with a column for (1) the time and (2) the value you read from the chart. A third column (3) may be necessary if you have to convert a depth of flow to a flow rate (MGD). Conversion charts from depth of flow to flow rate in MGD are provided by the manufacturer of a flow meter.

When reading manometers, gages, and charts, care must be taken to be sure the correct number is read and properly recorded.

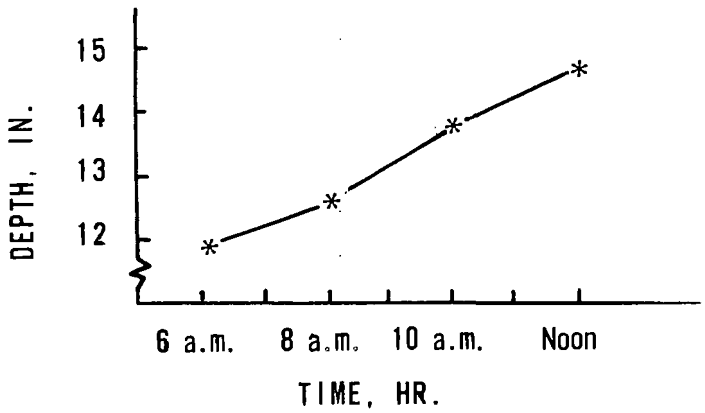


Fig. 16.1 Strip chart flow depth

TABLE 16-1

TABULATION OF DEPTHS AND FLOWS
FROM THE STRIP CHART (FIG. 16.1)

(1) Time	(2) Depth (in.)	(3) Flow[3] (MGD)
6 AM	12	0.61
8 AM	12 1/2	0.65
10 AM	13 1/2	0.74
12 NOON	14 1/2	0.84

16.4 AVERAGE VALUE

When you collect representative samples from a plant influent and measure a particular water quality indicator, such as BOD, the results are not always the same. For example, you might measure the BOD of a trickling filter influent to determine the organic loading and find the BOD varying considerably during a 6-day period. To calculate an expected daily organic loading, the average daily BOD must be calculated.

EXAMPLE 1:

The results of six BOD tests on a trickling filter influent from composite (proportional) samples collected at daily intervals during a 6-day period indicated the BOD to be 150 mg/l, 200 mg/l, 250 mg/l, 200 mg/l, 100 mg/l, and 120 mg/l. What is the average daily BOD?

Procedure:

Add the six measurements and divide by six, the number of measurements.

[3] These figures would be obtained from the manufacturer's "conversion chart" for the particular flume or flow meter.

$$\text{Average BOD, mg/l} = \frac{\text{Sum of All Measurements, mg/l}}{\text{Number of Measurements}}$$

$$= \frac{1020}{6}\text{ mg/l}$$

$$= 170\text{ mg/l}$$

DAY	BOD
1	150
2	200
3	250
4	200
5	100
6	120
Sum =	1020

You have calculated the average BOD by adding all BOD measurements and dividing by the number of measurements.

The average value of any other characteristic is calculated the same way. For example, if you wanted to calculate a month's average daily flow into a plant, you would add up the daily flows for the month and divide by the number of days in the month.

Hint:

Frequently plant flows are recorded on an integrator or totalizer[4] and the flow during a particular time period can be determined by obtaining the difference between the totalizer readings at the beginning and end of the time period.

EXAMPLE 2:

At the beginning of a month a plant totalizer reads 103,628,457 gallons, and 30 days later you record the totalizer value as 114,789,321 gallons. Calculate the average daily flow for the month.

Step 1:

Find the total monthly flow.

Reading at end of time period	=	114,789,321 gals
Reading at start of time period	=	103,628,457 gals
Total flow during month	=	11,160,864 gals

[4] Totalizer. A totalizer continuously sums or adds up the flow into a plant in gallons or million gallons or some other unit of measurement.

Step 2:

Calculate the average daily flow, gal/day:

$$\text{Average Daily Flow, gal/day} = \frac{\text{Sum of Flows, gal}}{\text{Number of Days (measurements)}}$$

$$= \frac{11{,}160{,}864 \text{ gals}}{30 \text{ Days}}$$

$$= 372{,}029 \text{ gals/day}$$

or

$$= \frac{372{,}029 \text{ gals/day}}{1{,}000{,}000 \text{ gals/MG}}$$

$$= 0.372 \text{ MGD}$$

Note:

The average daily flow for the month also could be calculated by adding the 30 daily flows during the month and dividing by 30. This approach can be used to check the results obtained using the difference in the totalizer readings as shown above.

16.5 RANGE OF VALUES

You have seen how to evaluate lab results in terms of average values. This does not give any indication as to whether all of the data were close to the average value or if there was a considerable spread or dispersion of data. A useful method of indicating the spread in results is the range. The range is obtained by subtracting the smallest measurement from the largest one.

$$\text{Range} = \text{Largest Value} - \text{Smallest Value}$$

Procedure:

Step 1: Rank data by arranging observations in ascending (increasing) or descending (decreasing) order, using the data from EXAMPLE 1: 250, 200, 200, 150, 120, 100.

Step 2: Subtract the smallest (100) from the largest (250).

	Largest	250 mg/l
	Smallest	-100 mg/l
Answer:	Range of BOD/mg/l =	150 mg/l

Try another example to review the calculations for the average value and range, then you will be ready to study other ways of describing the dispersion of data and the idea of graphical presentation using this problem.

EXAMPLE 3:

The average daily BOD for two weeks is given below. Calculate the average 2-week BOD and the range for these measurements.

Data: 160, 155, 160, 160, 180, 165, 155, 170, 160, 165, 155, 150, 145, 160.

$$\text{Average BOD, mg/l} = \frac{\text{Sum of All Measurements, mg/l}}{\text{Number of Measurements}}$$

$$= \frac{2240 \text{ mg/l}}{14}$$

$$\begin{array}{r} 160 \\ 14 \overline{)2240} \\ \underline{14} \\ 84 \\ \underline{84} \\ 00 \end{array}$$

$= 160$ mg/l for two weeks

$$\begin{array}{r} 160 \text{ mg/l} \\ 155 \\ 160 \\ 160 \\ 180 \\ 165 \\ 155 \\ 170 \\ 160 \\ 165 \\ 155 \\ 150 \\ 145 \\ \underline{160} \\ 2240 \text{ mg/l} \end{array}$$

Range of BOD, mg/l = Largest BOD, mg/l - Smallest BOD, mg/l

$= 180$ mg/l $- 145$ mg/l

$= 35$ mg/l for two weeks

$$\begin{array}{r} 180 \\ \underline{-145} \\ 35 \end{array}$$

QUESTIONS

Mixed liquor samples were collected at the beginning, middle, and end of an aeration tank and the solids concentrations were 2138 mg/l, 1863 mg/l, and 1921 mg/l.

16.4A Calculate the average mixed liquor concentration.

16.5A What is the range of these measurements?

16.6 MEDIAN, MODE, AND GEOMETRIC MEAN

Sometimes the average value and range calculations are not the best way to describe or analyze data. For example, frequently when running multiple tube coliform bacteria tests you will obtain some extremely high MPNs (most probable number of coliform group bacteria), especially after a rain, equipment failure, or chlorine dosage mishap.

EXAMPLE 4:

Data: MPN/100 ml = 240, 220, 240, 230, 240, 7200, 260, 250, 270, 300, 250. Calculate average MPN.

Procedure:

Determine sum of measurements.

$$\text{Average MPN/100 ml} = \frac{\text{Sum of Measurements, MPN/100 ml}}{\text{Number of Measurements}}$$

$$= \frac{9700}{11}$$

$$= 882$$

$$\begin{array}{r} 882 \\ 11 \overline{)9700} \\ \underline{88} \\ 90 \\ \underline{88} \\ 20 \end{array}$$

$$\begin{array}{r} 240 \\ 220 \\ 240 \\ 230 \\ 240 \\ 7200 \\ 260 \\ 250 \\ 270 \\ 300 \\ \underline{250} \\ \text{Sum} = 9700 \end{array}$$

Average MPN = 882 Coliform Bacteria/100 ml. Note that this value is greater than all of our measurements except the largest one. For this reason, multiple tube coliform results are sometimes reported as a MEDIAN VALUE.

The median is defined as the middle measurement when the measurements are ranked in order of magnitude (size).

Procedure:

Rank data in ascending or descending order.

Measurement:	220	230	240	240	240	250	250	260	270	300	7200
Rank:	1	2	3	4	5	6	7	8	9	10	11
						↑ Median					

Measurement 6 is our middle measurement. Therefore, the MEDIAN MPN/100 ml = 250, which better describes the usual value of the measurements.

If you had only ten measurements (eliminate #11 of 7200), the MEDIAN would fall between measurements 5 and 6 (240 and 250) and would be 245.

Another useful value is the MODE. The mode is the measurement that occurs most frequently. In our example, the measurement 240 occurs three times, which is more than any other. Therefore: MODE MPN/100 ml = 240.

An examination of the data in EXAMPLE 4 indicates that the median and mode do a better job of describing or predicting the MPN value we would expect than the average calculation. For this reason these terms are sometimes used to report data.

QUESTION

16.6A The results of the SVI (Sludge Volume Index) test for an activated sludge plant for one week were as follows: 120, 115, 120, 120, 125, 110, 115. What are the median and mode values for the SVI data?

Geometric Mean:

There are other ways of reporting the results of coliform tests in addition to those mentioned above. The geometric mean is sometimes used because all measurements are used in the calculations, but an extreme value has a lesser influence on the result. The easiest way to find the geometric mean is to plot the results on log probability paper and read the geometric mean on the paper.

To plot data on probability paper, the probability or plotting point of each measurement must be determined. The plotting point is calculated from the following formula:

$$P = \frac{m}{n + 1} \times 100\%$$

where:

- P is the probability (%) the measurement will not be exceeded,
- n is the number or sum of measurements, and
- m is the rank when the measurements are arranged in ascending or increasing order.

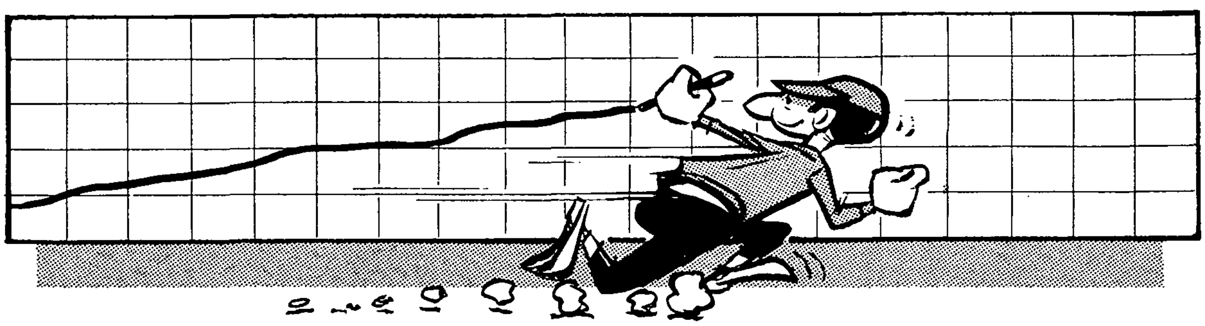
For our example:

Rank m	Measurement MPN/100 ml	Probability %
1	220	8.3
2	230	16.7
3	240	25.0
4	240	33.3
5	240	41.7
6	250	50.0
7	250	58.3
8	260	66.7
9	270	75.0
10	300	83.3
11	7200	91.7

Plot the data as shown on Fig. 16.2.

To estimate the geometric mean from the data plotted on Fig. 16.2:

1. Draw a line of best fit through the data.
2. Draw a vertical line down the 50 percent line to where it intersects with the line of best fit.
3. From the intersection of the 50 percent line and the line of best fit, draw a horizontal line to the scale representing the measurements.
4. Read the Geometric Mean MPN = 265/100 ml.



A problem with plotting data is that different operators will draw different lines of best fit through the data, thus giving different geometric means. This problem can be overcome by calculating the geometric mean. To calculate the geometric mean, all of the measurements must be converted to logarithms, the average of the logs is found, and then this average is converted to the geometric mean.

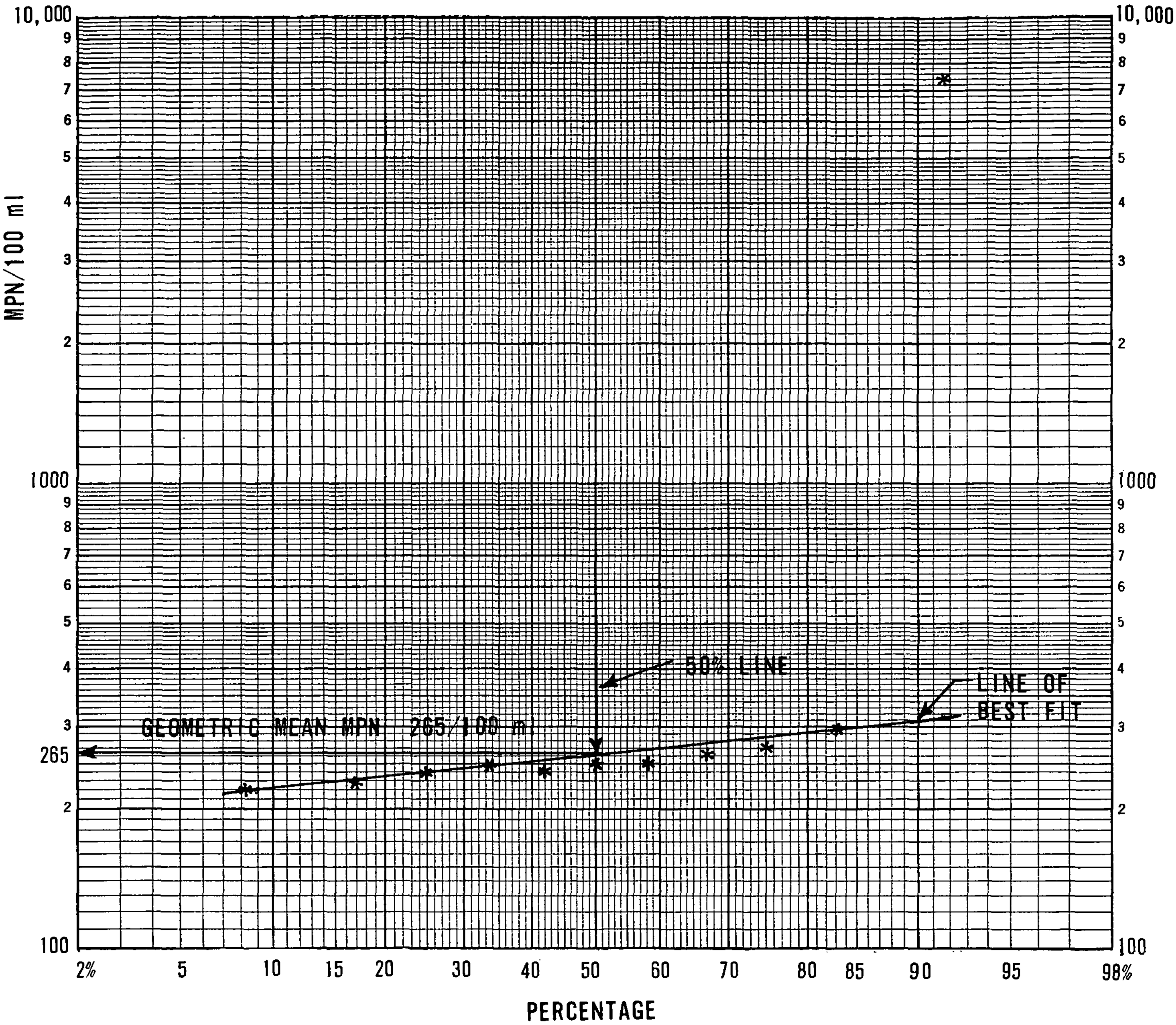


Fig. 16.2 Determination of geometric mean from log probability paper

To find logarithms, the characteristic and the mantissa of a measurement must be determined. The <u>characteristic</u> of a measurement is one less than the number of figures to the left of the decimal point. The <u>mantissa</u> of a number is found by looking in log tables in math books or handbooks and is the same regardless of the location of the decimal point. Looking up the mantissa of 245 in the log table shown below gives 3892.

TABLE OF COMMON LOGARITHMS OF NUMBERS

N	0	1	2	3	4	5	6	7	8	9
22	3424	3444								
23	3617	3636								
24	3802	3820	3838	3856	3874	$\boxed{3892}$	3909	3927	3945	3962
25	3979									

The logarithm of a number is the characteristic plus the mantissa.

<u>EXAMPLES</u>:

Number	Characteristic	Mantissa	Logarithm
24,500	4	.3892	4.3892
2,450	3	.3892	3.3892
245	2	.3892	2.3892
24.5	1	.3892	1.3892
2.45	0	.3892	0.3892
.245	-1	.3892	$\bar{1}.3892$
.0245	-2	.3892	$\bar{2}.3892$
.00245	-3	.3892	$\bar{3}.3892$
.00245	-3	.3892	or 7.3892-10

Note that if the characteristic is negative, the logarithm is written with the minus (-) sign over the characteristic ($\bar{3}.3892$) or the characteristic is subtracted from 10 and a -10 is placed after the mantissa (7.3892-10).

EXAMPLE 5:

Calculate the geometric mean of the data used in the previous problem.

Measurement MPN/100 ml	Characteristic	Mantissa	Logarithm
220	2	.3424	2.3424
230	2	.3617	2.3617
240	2	.3802	2.3802
240	2	.3802	2.3802
240	2	.3802	2.3802
250	2	.3979	2.3979
250	2	.3979	2.3979
260	2	.4150	2.4150
270	2	.4314	2.4314
300	2	.4771	2.4771
7200	3	.8573	3.8573
		Sum of Logarithms =	27.8213

$$\text{Average of Logarithms} = \frac{\text{Sum of Logarithms}}{\text{Number of Measurements}}$$

$$= \frac{27.8213}{11}$$

$$= 2.5292$$

To find the geometric mean, convert the average of the logarithms (2.5292) back to a number. The characteristic is 2 and the mantissa is 5292. First find a mantissa of 5292 in a Table of Common Logarithms of Numbers and determine the closest number as shown below.

TABLE OF COMMON LOGARITHMS OF NUMBERS

N	0	1	2	3	4	5	6	7	8	9
32	5051									
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328								

A mantissa of 5292 falls between 5289 and 5302, but closer to 5289. Therefore the number is 338. Since 338 has a characteristic of 2, the

GEOMETRIC MEAN MPN = 338/100 ml

The geometric mean for this example is greater than all of the other measurements except one. In many calculations of the geometric mean, the results will be closer to the median.

END OF LESSON 1 OF 2 LESSONS

on

ANALYSIS AND PRESENTATION OF DATA

Please answer the discussion and review questions before continuing with Lesson 2.

DISCUSSION AND REVIEW QUESTIONS

Chapter 16. Analysis and Presentation of Data

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook.

1. Collection of data without _______________, _______________, and _______________ of results is a waste of time and money.

2. Whether samples are collected, analyzed, interpreted, and used by the same person or a different person performs each task, every job is equally important if the application of results is to be effective. True or False?

3. What are the three principal factors that can cause variations in test results?

4. How could errors occur when reading charts and gages?

The solids concentrations of sludge withdrawn from a primary clarifier during the past seven days are given below:

Day:	1	2	3	4	5	6	7
Solids, %:	6.0	6.5	6.0	5.0	6.5	7.5	8.0

5. What is the average solids concentration?

6. What is the range of solids concentration?

7. What is the median solids concentration?

8. What is the mode solids concentration?

CHAPTER 16. ANALYSIS AND PRESENTATION OF DATA

(Lesson 2 of 2 Lessons)

16.7 GRAPHS

16.70 Bar Graphs

Sometimes results can be illustrated by graphs to show the characteristics (average value and dispersion) of data. Many people, especially supervisors, can easily interpret data presented graphically and appreciate this approach.

PROCEDURE:

Step 1. Group the data from EXAMPLE 3 into class intervals of equal width (say 5 mg/l) and range of interval (for instance, 177.5 - 182.5 mg/l). See (a) below. The length or size of class width (5, 10, or 20) is usually constant. Width of class interval depends on spread of data (wide range, wide interval) and is selected in order that all or most of the data can be placed in 5 to 10 intervals. (There are eight intervals in this example.)

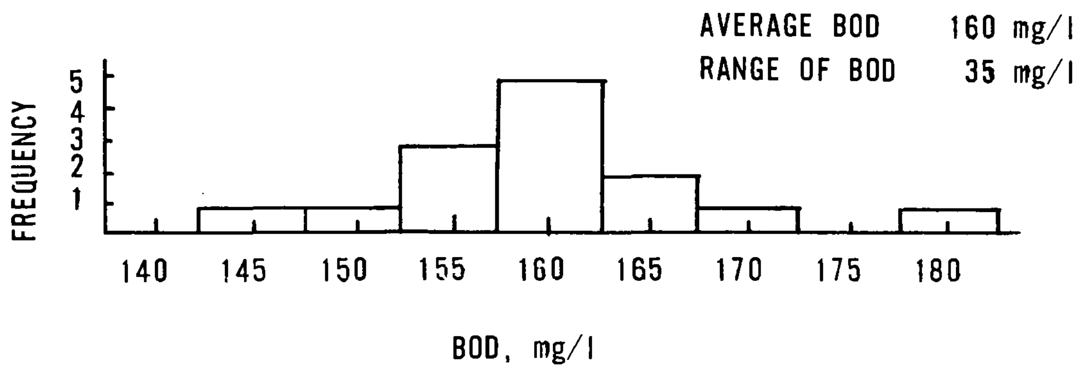
Step 2. Determine class midpoints--180 mg/l, 175, 170, etc. See (b) below. Class midpoints are always numbers that are easy to plot or work with (for instance: 2, 4, 6, 8, 10; or 5, 10, 15, 20, 25; or 10, 20, 30, 40, 50; or 25, 50, 75, 100, 125).

Step 3. Determine frequency. Count the number of measurements (in this case, from EXAMPLE 3) that were recorded in each class interval. This is usually accomplished by systematically going through your list of measurements, placing a check or 1 (column c below) opposite the appropriate class midpoint or class interval, and then adding up the checks or 1's to obtain the frequency (d).

Step 4. Plot results.

Class Interval	Class Midpoint	Number of Measurements	Frequency
(a)	(b)	(c)	(d)
182.5 - 177.5	180	1	1
177.5 - 172.5	175		0
172.5 - 167.5	170	1	1
167.5 - 162.5	165	11	2
162.5 - 157.5	160	~~1111~~	5
157.5 - 152.5	155	111	3
152.5 - 147.5	150	1	1
147.5 - 142.5	145	1	1

BAR GRAPH SHOWING DISTRIBUTION OF BOD



Sometimes the plotting points on a bar graph are connected to form a smooth curve. The resulting curve describes either a normal or a skewed distribution of the data, depending on the shape of the curve. If the distribution is normal, the average, median, and mode values will be approximately the same. In skewed distributions the average, median, and mode are different (Fig. 16.3).

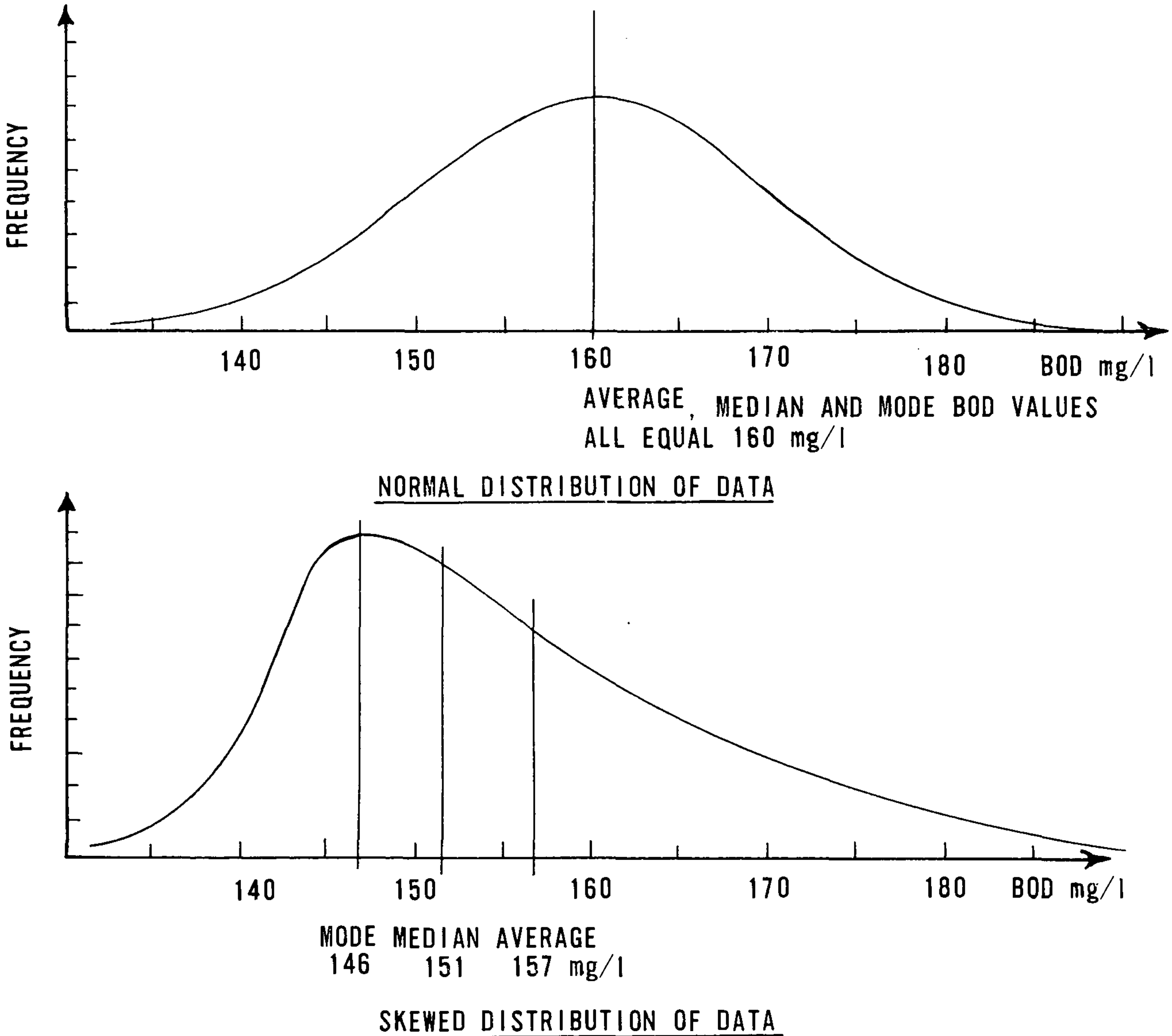


Fig. 16.3 Normal and skewed distribution of data

QUESTION

16.7A The results of the SVI (Sludge Volume Index) test for an activated sludge plant for one week were as follows: 120, 115, 120, 120, 125, 110, 115.

a. Calculate the average SVI.

b. What is the range?

c. Draw a bar graph showing the distribution (spread) of SVI.

16.71 Trends

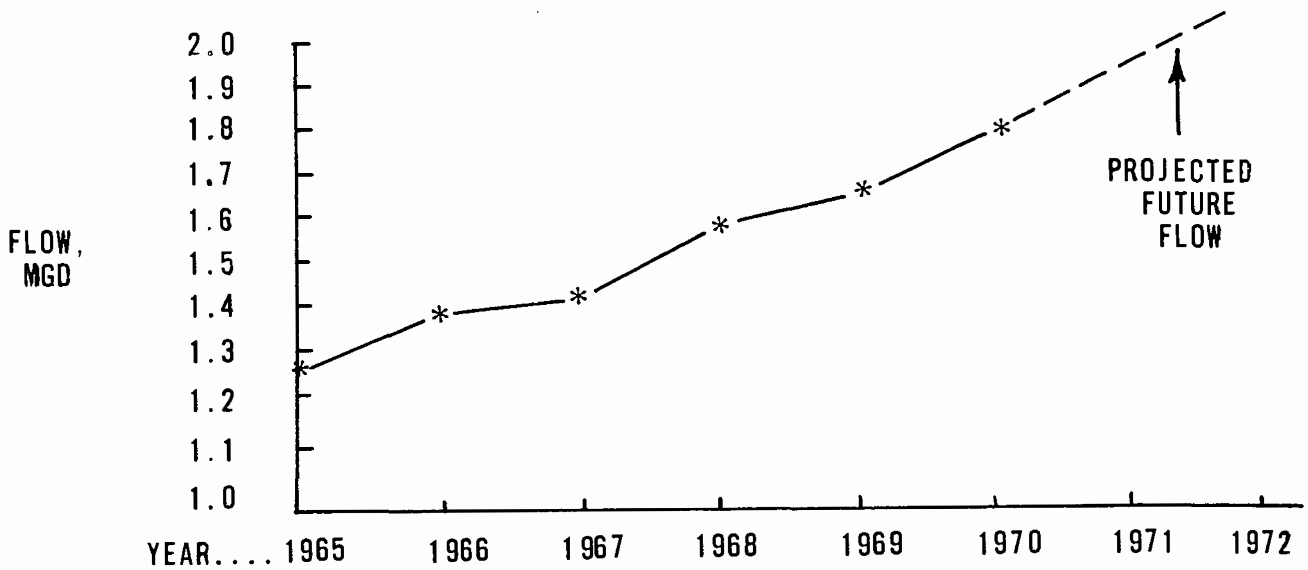
Plotting data on graphs[5] is very helpful to illustrate trends in the operation of your plant. Occasionally plotting data will reveal unexpected trends. This approach could be used to indicate to supervisors or the public the increase in plant inflow or decrease in the quality of plant effluent to justify increases in budgets or plant expansion. To look for or show a trend, plot the value you are interested in (for instance, flow, MGD, or effluent BOD, mg/l) against time (day, week, month, year).

EXAMPLE 6:

Analysis of flow data (totalizer readings) provides the following annual information:

Year:	1965	1966	1967	1968	1969	1970
Average Daily Flow, MGD:	1.25	1.38	1.42	1.58	1.65	1.81

Plot the data:



[5] Graph paper may be obtained at most stationery stores. See graph paper at end of this chapter.

Interpretation of Data:

The graph shows a continuously increasing average daily flow. If your plant has a capacity of 2 MGD, the graph would clearly show the need for expansion in the near future if past trends in population growth or any industrial expansion continue. You could extend the trend (dashed line) to project future flows and predict when you expect to reach plant capacity (1971-1972).

Applications:

Plotting data and looking for trends may be helpful to indicate broken pipes and illegal connections or discharges. You should always attempt to identify the cause of a trend. An industry may clean up on Friday afternoon and dump a slug of waste into the collection system that may reach your plant Friday night. If you plot your data and note a reduction in the quality of your effluent every Friday night or Saturday, you might start looking for the cause of the problem.

Some operators record flows continuously on daily circular charts. Every year they change the color of the ink, but use the same chart on the same day for several years. This is a good way to identify trends, too.

16.72 Summary

Two methods have been given in this section to present data:

1. Bar Graphs
2. Line Graphs

How does the operator determine which method to use? Bar graphs are used to summarize data and indicate number of times or frequency a given value was measured. Line graphs illustrate trends by showing how a particular measurement changes with time.

QUESTION

16.7B Weekly alkalinity tests on digester sludge are given below:

Week	1	2	3	4	5	6	7	8	9	10
Alkalinity, mg/l	1730	1670	1690	1680	1630	1620	1590	1530	1480	1420

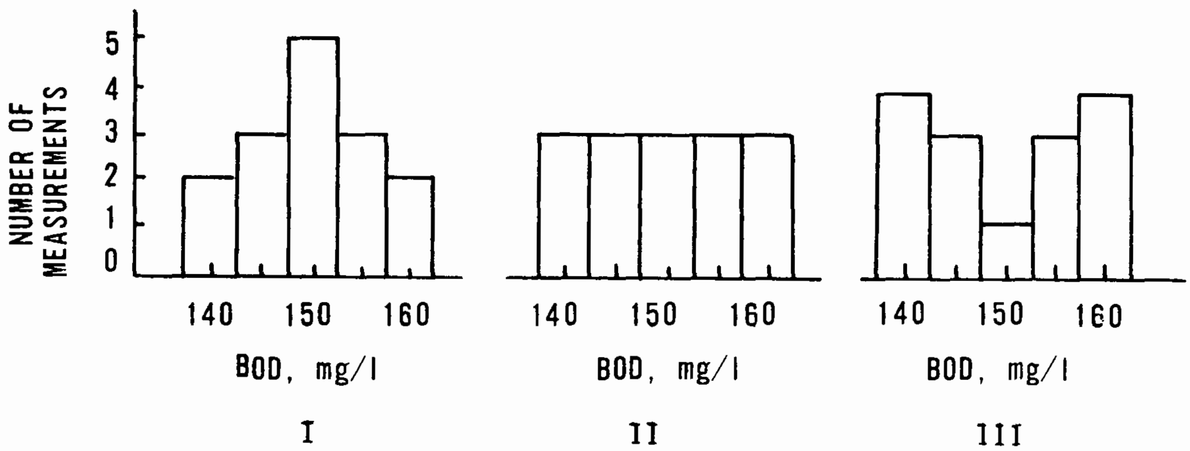
a. Is a trend apparent?

b. Should any action be taken by the operator?

16.8 VARIANCE AND STANDARD DEVIATION

Variance and standard deviation are terms frequently used in professional journals that report the results of research findings. Knowledge of this material is important in the field of quality control because these terms describe the spread of measurements or results.

In previous discussions, results have been described in terms of an average value and a range. The bar graphs below show the results of three different tests, but they all have the same average value and range.



For all three cases, the average value is 150 mg/l and the range is 20 mg/l (160-140), using the midpoints for our calculations.

Another term (parameter) to describe the above results is the variance, S^2 , a measure of the dispersion or spread of the results. The variance is calculated by taking the difference between each measurement, X, and the average value of all the measurements, $\bar{X}$, squaring it, summing up the squared differences, and dividing by the total number of differences, n, minus one, as shown in the following formula.

Variance, S^2	=	$\frac{\Sigma (X-\bar{X})^2}{n-1}$
X	=	Each Measurement
Average Value, $\bar{X}$	=	$\frac{\Sigma X}{n}$
n	=	Number of Measurements
Σ	=	Summation of All Values

In the denominator, one is subtracted from n, because $\bar{X}$ in the numerator is calculated from n measurements. $\bar{X}$ is influenced by all of our measurements. By dividing by n-1 we obtain a more conservative description of the actual dispersion. The larger n becomes, the more insignificant becomes the "minus one" term. When analyzing plant data, the number of measurements is usually small; therefore, the "minus one" term is important.

Step 1. Calculate the variance for the results shown in Bar Graph I.

Measurement X, mg/1	$X-\bar{X}$	$(X-\bar{X})^2$	Freq.	$(X-\bar{X})^2$ Freq.
140	140-150 = -10	(-10)(-10) = 100	2	(100)(2) = 200**
145	145-150 = - 5	(- 5)(- 5) = 25	3	(25)(3) = 75
150	150-150 = 0	(0)(0) = 0	5	(0)(5) = 0
155	155-150 = 5	(5)(5) = 25	3	(25)(3) = 75
160	160-150 = 10	(10)(10) = 100	2	(100)(2) = 200
		TOTAL	n = 15	$\Sigma (X-\bar{X})^2$ = 550 $(mg/1)^2$ *

$$S^2 = \frac{\Sigma (X-\bar{X})^2}{n-1}$$

$$= \frac{550}{15-1} (mg/1)^2$$

$$= \frac{550}{14}$$

$$= 39.3 \ (mg/1)^2$$

```
      39.28
14 ⟌ 550
     42
     130
     126
       4 0
       2 8
       1 20
       1 12
```

* Units should be $(mg/1)^2$. The term is meaningless, but is included to maintain the proper units. For the first row, X is 140 mg/1; $X-\bar{X}$ is 140 mg/1-150 mg/1 = -10 mg/1; $(X-\bar{X})^2$ is (-10 mg/1)(-10 mg/1) = 100 $(mg/1)^2$; and $(X-\bar{X})^2$ Freq. is (100 [mg/1]^2)(2) = 200 $(mg/1)^2$.

** Instead of writing 140 twice, subtracting 140-150 twice, and squaring (-10)(-10) twice, we performed our calculations once on one line and then multiplied by the frequency, 2. We did the same for the other measurements, X.

Step 2.

Calculate the variance for the results shown in Bar Graph II.

Measurement, X	$X-\overline{X}$	$(X-\overline{X})^2$	Freq.	$(X-\overline{X})^2$ Freq.
140	-10	100	3	300
145	- 5	25	3	75
150	0	0	3	0
155	5	25	3	75
160	10	100	3	300
	TOTAL		n = 15	$\Sigma (X-\overline{X})^2 = 750$

$$S^2 = \frac{\Sigma (X-\overline{X})^2}{n-1}$$

$$= \frac{750}{15-1}$$

$$= 53.6 \ (mg/1)^2$$

```
     53.57
14 / 750
     70
      50
      42
       8 0
       7 0
       1 00
         98
```

Step 3.

Calculate the variance for the results shown in Bar Graph III.

Measurement, X	$X-\overline{X}$	$(X-\overline{X})^2$	Freq.	$(X-\overline{X})^2$ Freq.
140	-10	100	4	400
145	- 5	25	3	75
150	0	0	1	0
155	5	25	3	75
160	10	100	4	400
	TOTAL		n = 15	$\Sigma (X-\overline{X})^2 = 950$

$$S^2 = \frac{\Sigma (X-\overline{X})^2}{n-1}$$

$$= \frac{950}{15-1}$$

$$= 67.9 \ (mg/1)^2$$

```
     67.85
14 | 950
     84
     110
      98
      12 0
      11 2
         80
         70
```

In comparing the variance of the three bar graphs, note that as more and more measurements shift away from the average value, the value of the variance increases, thus indicating an increase in the dispersion of our results.

The dispersion is frequently described in terms of S, the standard deviation, which has the same units as the average value, mg/l. The standard deviation, S, is the square root of the variance, S^2. The square root of a number is one of two equal numbers that when multiplied together give that number.

EXAMPLES:

The square root of 9 = 3	or $\sqrt{9}$	= 3	and (3)(3) = 9
16 = 4	or $\sqrt{16}$	= 4	and (4)(4) = 16
25 = 5	or $\sqrt{25}$	= 5	etc.
4 = 2	or $\sqrt{4}$	= 2	
1 = 1	or $\sqrt{1}$	= 1	
S^2 = S	or $\sqrt{S^2}$	= S	
1.44 = 1.2	or $\sqrt{1.44}$	= 1.2	
$(mg/l)^2$ = mg/l	or $\sqrt{(mg/l)^2}$	= mg/l	

To obtain the square root of a number there are several potential methods listed below in order of ease of use.

1. Look up the values in a table in a math book or handbook.
2. Use a slide rule.
3. Attempt a trial and error approach by multiplying a number by itself.
4. By direct calculation.

EXAMPLE 7:

Find the standard deviation, S, of the variance $S^2 = 39.3\ (mg/l)^2$.

Use of a math book or handbook, or a slide rule are the quickest and easiest ways to find the square root of a number. If these sources are not available, the square root may be calculated.

Trial and Error:

First try Step 3, multiplying a number by itself.

Trial:	I	II	III	IV
	6.0	6.5	6.3	6.2
	6.0	6.5	6.3	6.2
	36.00	325	189	124
		390	378	372
		42.25	39.69	38.44
	Less than 39.3, too small	Greater than 39.3, too large	Greater than 39.3, too large	Less than 39.3, too small

Trial III is closest to 39.3. Therefore S = 6.3 mg/l.

Direct Calculation:

To calculate the square root directly, the following steps are used.

1. Begin at the decimal point and separate the number in groups of two, to the left, or right, or in both directions, depending on the number, as shown below.

   $\sqrt{39.30\ 00}$

   Other Examples[6]:

   $\sqrt{128.}$ $\quad$ $\sqrt{0.66\ 20}$ $\quad$ $\sqrt{0.04\ 31}$

2. Select the largest number which, when squared, is equal to or less than the number contained in the first number or pair of numbers on the left.

   $$\begin{array}{l} \ \ 6. \\ \sqrt{39.30} \end{array}$$

   Other Examples:

   $$\begin{array}{l} \ \ 1 \\ \sqrt{128.} \end{array} \qquad \begin{array}{l} \ \ .\ 8 \\ \sqrt{0.66\ 20} \end{array} \qquad \begin{array}{l} \ \ .\ 2 \\ \sqrt{0.04\ 31} \end{array}$$

[6] These other examples are provided to indicate how to determine the square root of other numbers.

3. Square this number, subtract it from the first number or pair of numbers, and bring down the next pair of numbers.

```
      6.
   √ 39.30
     36.
      3.30
```

4. Double the 6, obtain 12, and estimate how many twelves will go into 33. The answer is 2. Place 2 over 30 and to the right of 12, obtaining 122. Multiply 122 by 2 to get 244. Subtract 330-244 = 86 and bring down the next pair of numbers (00).

```
      6. 2
   √ 39.30 00

     36.
122 √ 3.30
      2.44
        86 00
```

5. Double 62, obtain 124, and estimate how many times 124 goes into 860. Try 7. Place 7 over 00 and to the right of 124 to obtain 1247. Multiply 1247 by 7 to get 8729. This is larger than 8600. Reduce 7 to 6. Multiply 1246 by 6 to get 7476. Subtract, 8600-7476 = 1124, and bring down the next pair of numbers.

```
      6. 2  6
   √ 39.30 00          Therefore,  S = 6.26

     36
122 √ 3 20                    or   S = 6.3 mg/1

     2 44
1246 √ 86 00                              Checks
        74 76
```

<u>QUESTION</u>

16.8A Calculate the variance and standard deviation of the SVI data given in Question 16.7A. SVI = 120, 115, 120, 120, 125, 110, 115.

$$S^2 = \frac{\Sigma\,(X-\bar{X})^2}{n-1}$$

16.9 SUMMARY

1. <u>Average or Mean Value</u>

$$\bar{X} = \frac{\text{Sum of All Measurements}}{\text{Number of Measurements}} = \frac{\Sigma X}{n}$$

where X is each measurement or test result, and n is the number of measurements or observations.

2. <u>Range</u>

Range = Largest X - Smallest X

3. <u>Median</u>

Median = Middle measurement when measurements are ranked in order of magnitude (may fall between two measurements)

4. <u>Mode</u>

Mode = Measurement that occurs most frequently (may be more than one mode)

5. <u>Variance and Standard Deviation</u>

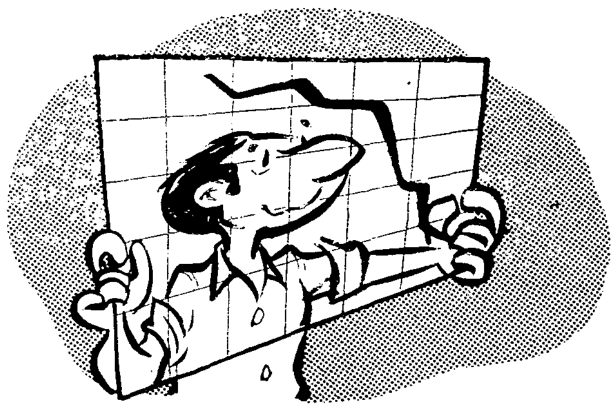
$$\text{Variance, } S^2 = \frac{\Sigma (X-\bar{X})^2}{n-1}$$

$$\text{Standard Deviation, } S = \sqrt{\frac{\Sigma (X-\bar{X})^2}{n-1}} = \sqrt{S^2}$$

16.10 ADDITIONAL READING

a. "Graphical Approach to Statistics", Water and Sewage Works Magazine, Scranton Publishing Company, Inc., 35 East Wacker Drive, Chicago, Illinois 60601. $1.25.

b. "Basic Statistical Methods for Engineers and Scientists", by A.M. Neville and J.B. Kennedy, International Textbook Company, Scranton, Pennsylvania 18515. $8.50.



END OF LESSON 2 OF 2 LESSONS

on

ANALYSIS AND PRESENTATION OF DATA

DISCUSSION AND REVIEW QUESTIONS

Chapter 16. Analysis and Presentation of Data

(Lesson 2 of 2 Lessons)

Work these questions before continuing. Write your answers in your notebook. The problem numbering continues from Lesson 1.

The solids concentrations of sludge withdrawn from a primary clarifier during the past seven days are given below:

Day:	1	2	3	4	5	6	7
Solids, %:	6.0	6.5	6.0	5.0	6.5	7.5	8.0

9. Draw a bar graph showing the distribution of data.

10. Draw a line graph to illustrate if any trend is developing.

11. Is a trend apparent?

12. Calculate the variance, S^2, for the solids data.

13. Determine the standard deviation, S, for the solids data using any method you prefer.

SUGGESTED ANSWERS

Chapter 16. Analysis and Presentation of Data

16.1A Variations in test results may be caused by:

1. Water or material (sludge) being examined
2. Sampling
3. Testing (analyst, procedure, reagents, equipment)

Many factors in each of these three categories also can cause changes. For example, in sampling, variations could be caused by changing the location where the sample was obtained and when the sample was obtained.

16.1B Samples should be tested immediately by the lab because sometimes the items (BOD, DO) we wish to measure will change with time due to biological or chemical reactions taking place in the sample container.

16.2A Instruments must be periodically calibrated and zeroed before using to insure accurate results.

16.2B A gage reading of 2 psi also would give a reading of 4.6 feet of water.

16.4A Calculate the average mixed liquor concentration in mg/l.

$$\text{Average Concentration, mg/l} = \frac{\text{Sum of All Measurements, mg/l}}{\text{Number of Measurements}} \qquad \begin{array}{r} 2138 \\ 1863 \\ \underline{1921} \\ 5922 \end{array}$$

$$= \frac{5922 \text{ mg/l}}{3}$$

$$= 1974 \text{ mg/l}$$

16.5A Range of measurements.

$$\text{Range, mg/l} = \text{Largest Value} - \text{Smallest Value}$$

$$= 2138 \text{ mg/l} - 1863 \text{ mg/l} \qquad \begin{array}{r} 2138 \\ \underline{-1863} \\ 275 \end{array}$$

$$= 275 \text{ mg/l}$$

16.6A

Rank	SVI	Freq.
1	125	1
2	120	
3	120	3
4	120	
5	115	2
6	115	
7	110	1

Median SVI = 120 Half of the values are larger and half are smaller.

Mode SVI = 120 Value that occurs most frequently (three times).

16.7A

SVI	Freq.	SVI x Freq.	or	Sum of SVI
125	1	125		125 120
120	3	360		120 120
115	2	230		115 115
110	1	110		110
SUMS	7	825		825

a. $$\text{Average SVI} = \frac{\text{Sum of SVI}}{\text{Number of SVI}} = \frac{825}{7} = 118$$

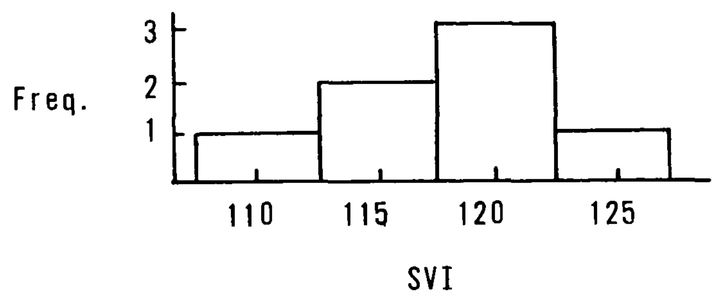
$$\begin{array}{r} 117.8 \\ 7\overline{)\,825} \\ \underline{7} \\ 12 \\ \underline{7} \\ 55 \\ \underline{49} \\ 60 \\ 56 \end{array}$$

b. Range of SVI = Largest SVI - Smallest SVI

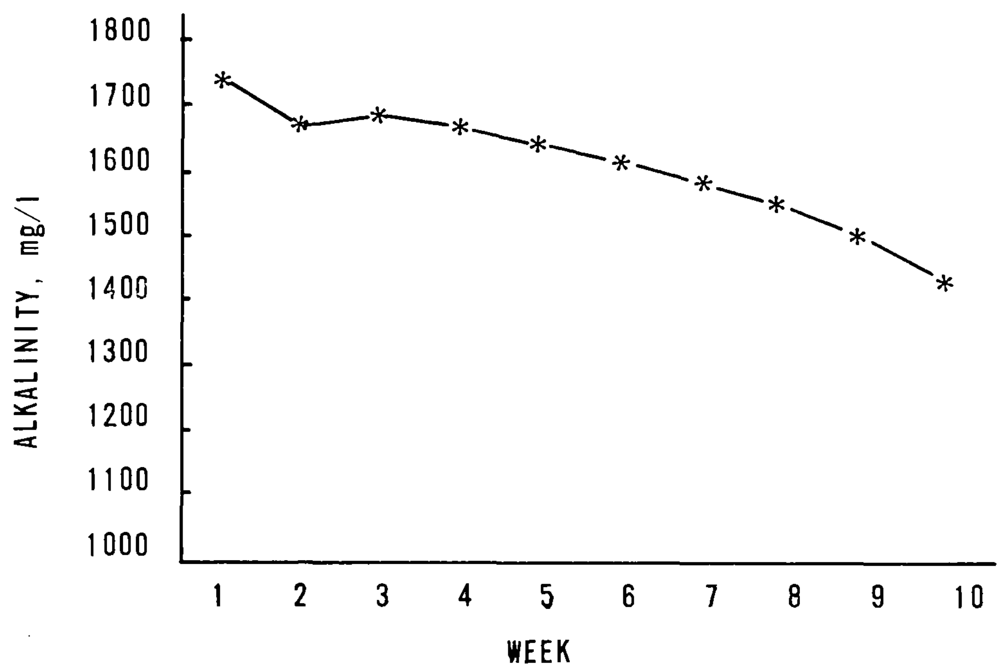
= 125 - 110

= 15

16.7A c. Bar Graph.



16.7B



a. Yes, a trend is apparent.

b. Corrective action should be taken to prevent the continued drop of alkalinity. See Chapter 8 on Sludge Digestion and Handling.

16.8A

STEP:		(1)	(2)	(3)	(4)
X	Freq.	X Freq.	$X-\bar{X}$	$(X-\bar{X})^2$	$(X-\bar{X})^2$ F.
125	1	125	125-118 = 7	49	49
120	3	360	120-118 = 2	4	12
115	2	230	115-118 = -3	9	18
110	1	110	110-118 = -8	64	64
SUM	7	825			143

1. Calculate average SVI, $\bar{X}$.

$$\bar{X} = \frac{\text{Sum Measurements}}{\text{Sum Freq.}} = \frac{825}{7} = 118$$

$$7 \overline{)825} = 117.8$$

7
12
7
55
49
60
56

2. Determine $X - \bar{X} = X - 118 = 125 - 118 = 7$

3. Determine $(X-\bar{X})^2 = (7)^2 = 49$

4. Determine $(X-\bar{X})^2$ (Freq.) $= 49 \times 1 = 49$

5. Calculate variance, S^2.

$$S^2 = \frac{\Sigma\,(X-\bar{X})^2}{n-1} = \frac{143}{7-1} = 24$$

$$6 \overline{)143} = 23.8$$

12
23
18
50
48

6. Calculate standard deviation, S.

$$S = \sqrt{S^2} = \sqrt{24} = 4.9$$

$$\begin{array}{r l} & 4.9 \\ & \sqrt{24.} \\ & 16 \\ 89 & \overline{|\ 8\ 00} \\ & \ 8\ 01 \end{array}$$

Close enough...

OBJECTIVE TEST

Chapter 16. Analysis and Presentation of Data

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1.

1. Data should be collected and (select best answer):
    1. Filed
    2. Forgotten
    3. Analyzed
    4. Lost
    5. Values placed in all columns on report sheet

2. Laboratory results of influent BOD at a particular plant vary due to:
    1. Nothing--the results should not be different
    2. Differences in the composition of the influent
    3. Operators titrating to different end points
    4. Operators not following the exact same testing procedure every time
    5. Collecting samples in a different manner

3. The characteristics of a sample may change between collection and analysis due to:
    1. Nothing--the characteristics don't change
    2. Temperature changes during transportation to the lab
    3. Chemical changes in the sample
    4. Biological changes in the sample
    5. Changes in the variance

4. A representative sample:
    1. Describes the overall situation
    2. Represents the equipment manufacturers
    3. Represents the people

5. At the beginning of a week a totalizer on the plant inflow read 1,823,471 gallons. Seven days later, the totalizer reads 2,619,582 gallons. The average daily flow during the week was approximately:
    1. 0.01 MGD
    2. 0.11 MGD
    3. 1.11 MGD
    4. 0.10 MGD
    5. 0.13 MGD

6. Bar graphs can be used to show:

    1. Growth
    2. Characteristics of data
    3. Dispersion of data
    4. Your supervisor results of lab tests
    5. How neat you can draw

7. Plotting data on graph paper to show trends may be helpful to:

    1. Justify budget increases
    2. Describe the variance
    3. Predict when expansion will be necessary
    4. Illustrate the need to look for the cause of trend
    5. Illustrate patterns of effluent quality

At 1:30 PM every day of the week the dissolved oxygen in the Number 1 pond of a wastewater treatment facility is measured and the results are summarized below in mg/l:

WEEK	DAY				
	M	T	W	T	F
1	9.8	9.5	9.6	9.2	8.9
2	8.1	8.4	8.0	7.6	7.5

8. The average DO in the pond over the two-week period was:

    1. 8.1 mg/l
    2. 8.4 mg/l
    3. 8.5 mg/l
    4. 8.7 mg/l
    5. 8.9 mg/l

9. The range of DO was:

    1. 7.5 to 9.8 mg/l
    2. 9.8 to 7.5 mg/l
    3. 1.3 mg/l
    4. 2.3 mg/l
    5. 0.8 mg/l

10. The median DO was:

    1. 8.0 mg/l
    2. 8.1 mg/l
    3. 8.4 mg/l
    4. 8.6 mg/l
    5. 8.9 mg/l

11. Is there a trend in the DO concentration in the pond?

    1. Yes
    2. No

12. The variance, S^2, in the DO level in $(mg/l)^2$ is:

    1. 0.65
    2. 0.70
    3. 0.72
    4. 0.75
    5. 0.78

13. The standard deviation, S, in the DO level in mg/l is:

    1. 0.70
    2. 0.75
    3. 0.80
    4. 0.85
    5. 0.90

Review Questions:

Ponds receiving 0.2 MGD have overall dimensions of 400 ft by 500 ft with an average influent BOD of 160 mg/l. The average water depth is 4.5 ft. Select the closest answer.

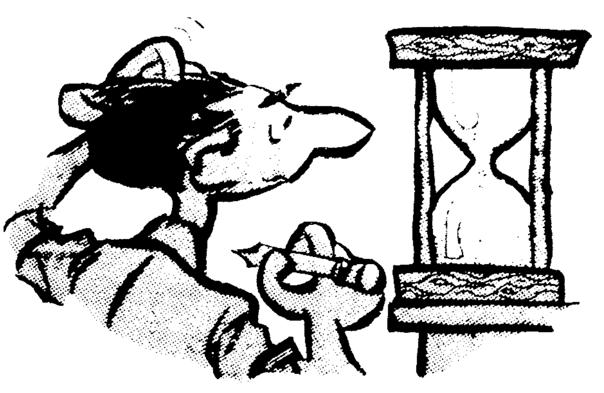
14. The theoretical detention time in the ponds is:

    1. 25 days
    2. 35 days
    3. 50 days
    4. 65 days
    5. 75 days

15. The organic loading is:

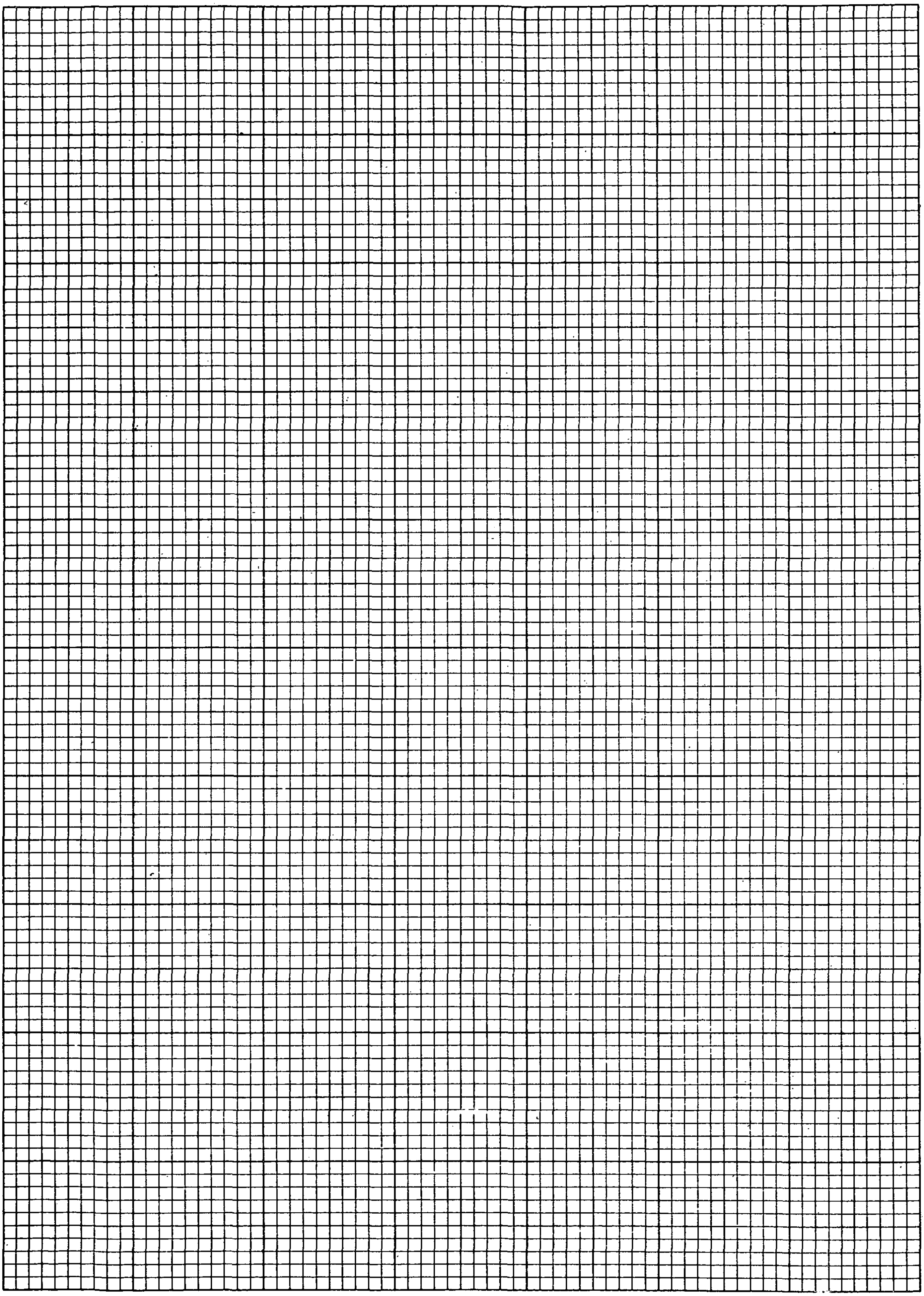
    1. 20 lb BOD/day/ac
    2. 30 lb BOD/day/ac
    3. 40 lb BOD/day/ac
    4. 50 lb BOD/day/ac
    5. 60 lb BOD/day/ac

Please write on your IBM answer sheet the total time required to work both lessons and this Objective Test.



GRAPH PAPER

See Next Sheet



CHAPTER 17

RECORDS AND REPORT WRITING

by

George Gribkoff

(with a supplement by John Brady)

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Chapter 17. Records and Report Writing

NO PRE-TEST

for

Chapter 17. Records and Report Writing

CHAPTER 17. RECORDS AND REPORT WRITING

17.0 INTRODUCTION

Most books on plant operation discuss record keeping adequately but are very sketchy on their treatment of report writing. However, report writing is the main means by which those who have information communicate with those who need it. Operators must communicate effectively with management and the general public on the operation of their plant and on requests for additional funds for improvements and personnel.

Any business transaction or operation requires records for efficient management; this is also true for operation of waste treatment facilities.

17.1 RECORDS

The administrator, superintendent, and operators of a wastewater treatment facility should know the cost and efficiency of their plant. Well-kept records will make the task of writing treatment plant cost and efficiency reports much easier.

17.10 Importance of and Need for Records

Records are needed for the following reasons:

A. Plant Operation. Review of operating records can indicate the efficiency of the plant and its treatment units and past and future problems.

B. Records are needed to show type and frequency of maintenance of operating units and evaluation of effectiveness of maintenance programs. (See Chapter 11, Maintenance.)

C. Records can provide data upon which to base recommendations for modifying plant operation and facilities.

D. Records of past performance and operational procedures are invaluable tools for the engineer in the evaluation of present performance and serve as a basis for the design of future treatment units.

E. Records are used to support budget requests for personnel, additional facilities, or equipment.

F. Records may be needed in damage suits brought against your district or municipality. They can be especially helpful to the operator if an accident occurs. As soon as possible after an accident someone should record the chain of events leading to the accident, exactly what happened, and any preventive or corrective action.

G. Records for water pollution and public health aspects may be required by regulatory agencies.

H. Records provide the actual data for the preparation of weekly, monthly, or annual reports to administrative officials, the public, and regulatory agencies.

Records must be permanent, complete, and accurate. Write entries on data sheets in ink or with an indelible pencil. A lead pencil should never be used because notations can smudge and be altered or erased. False and misleading records may actually do more harm than lack of records.

Record keeping costs time and money, and only useful records should be kept. Periodically records no longer useful should be discarded. Lab analyses of receiving water quality should be kept indefinitely. Some compromise is necessary between collecting useless records and avoiding the frustrations of not finding needed information. Keep your records neat and organized. A record misfiled is a record lost, and a lost record is worthless.

17.11 Type of Records

The type of records to be kept will depend on the size and type of plant. A small primary plant may not require the number or the variety of records required of large secondary or advanced wastewater treatment plants.

The specific records required will be determined by the size and type of treatment processes in the plant and are discussed more fully under respective chapters dealing with plant processes. Typical data sheets are included at the ends of chapters on Sedimentation and Flotation (Primary Plant), Trickling Filters, Activated Sludge, Sludge Digestion and Handling, and Ponds.

Records are generally separated into five classifications:

1. Operation and performance records
2. Descriptive and inventory records of the physical plant and stock
3. Maintenance records
4. Financial or cost records
5. Personnel

17.110 Operation Records

The minimum amount of record keeping that may be required is as follows:

1. Daily records of flows into the plant.
2. Chemical, physical, and bacteriological characteristics of influent and effluent.
3. Amount of electrical power consumed.
4. Amount of chlorine used.
5. Unusual happenings such as bypasses, floods, storms, complaints, and other significant events. Any other unusual event should be recorded if there is any possibility that a record of these events may be needed in the future, either for legal or administrative purposes. The main idea to keep in mind is to record <u>only</u> that data which may eventually be used.

17.111 Physical Plant and Stock Inventory

As a minimum, the following records are essential for proper evaluation of plant facilities and for making future recommended modifications or additions.

1. Contract and "as built" plans and specifications of waste treatment facility. This includes detailed piping and wiring of plant.

2. Plans and operating instructions for plant equipment.

3. Costs of major equipment and unit items.

4. A complete record and identification card for all major equipment. The card should include name of manufacturer and identifying code number.

5. Lists of tools, materials, chemicals, lab reagents and supplies, and office supplies.

6. A record card for each industrial waste discharger containing information on type, quantity, characteristics, and times of expected waste discharges.

17.112 Maintenance Records

See Chapter 11, Maintenance.

17.113 Financial or Cost Records

Keep lists of purchases and expenses to date during fiscal year. Comparisons should be made with budget allocation to avoid excess purchases.

17.114 Personnel

Employee personnel records, including annual performance ratings, should be maintained for each of the plant employees.

17.12 Frequency of Records

Records at most waste treatment facilities are kept daily and on a monthly basis.

17.120 Daily Records

Data to be recorded will depend upon the type and size of the plant. Specific record forms are contained at the end of chapters pertaining to a particular type of treatment plant. One of the most important daily records is a day-by-day diary or log of events and operations during the day. A daily diary or log should be maintained in every plant, and in large plants at each section (such as lab, maintenance). The log may be a spiral notebook or a standard daily diary made for that purpose.

The information entered in the plant log should be pertinent only to plant functions. Log entries should include at the top of the page the day of the week, the date, and the year. The names of the operators working at the plant, and their arrival and departure times, should also be included. Log entries should be made during the day of various activities and problems as they develop. Do not wait until the end of the day to write up the log as some items may be overlooked. If the operator will take a few minutes to make log entries in the morning and afternoon, he will develop a good log. Logs are beneficial to the operator and to people who replace the operator during vacations, illnesses, or leaves of absence. A well-kept log may prove very helpful to the operating agency as legal evidence in certain court cases. An example of one day's log entries in a small trickling filter plant is outlined below:

Tuesday, June 10, 1969

J. Doakes, Operator. A. Smith, Assistant Operator.
G. Doe, Maintenance Helper.

8:20 AM	Made plant checkout, changed flow charts, No. 2 supernatant tube plugged on No. 2 digester, cleared tube.
9 AM	Started drawing sludge from bottom of No. 2 digester to No. 1 sand bed.
9:15 AM	Smith and Doe completed daily lubrication and maintenance, put No. 2 filter recirculation pump on, took No. 1 pump off.

10 AM Received three tons of chlorine, containers Nos. 1583, 1296, 495; returned two empty containers Nos. 1891 and 1344. Replaced bad flex connector on No. 2 chlorine manifold header valve, and connected container No. 495 on standby.

10:30 AM Collected and analyzed daily lab samples.

1:15 PM Pumped scum pit, 628 gallons to No. 1 digester.

1:30 PM Restored sludge pump No. 2 by removing plastic bottle cap from discharge ball check; pump back in operation.

2:45 PM Smith and Doe hosed down filter distributor arms and cleaned orifices. Doe smashed finger when closing one of the end gates on filter arm. Sent Doe to Dr. Jones, filled out accident report, and notified Mr. Sharp of accident.

3:10 PM Stopped drawing sludge to No. 1 bed. Drew 18,000 gallons of sludge; sample in refrigerator to be analyzed Wednesday.

3:20 PM Electrician from Delta Voltage Company in with repaired motor for No. 2 effluent pump, Invoice No. A-1824, motor installed and pump OK.

4:10 PM Doe back from doctor, stated he will lose fingernail, and required three stitches and tetanus shot. Must go back next Thursday.

4:30 PM Plant checkout for tonight, put No. 2 chlorine container on line, in case No. 1 should run empty during the night.

Helpful Tip:

Many operators carry a pencil and pocket notebook with them at all times on the job. During the day they record all events and items of importance and write the information in the plant diary at the end of the day.

As an example, the minimum daily records kept at a fairly large size treatment plant with digester tanks may include the following items:

1. Precipitation and weather temperature
2. Raw wastewater flow (MGD from totalizer)
3. Influent and effluent temperatures
4. pH of influent and effluent
5. Grit (cu ft/mil gal)
6. Chlorine use (lbs)
7. Influent and effluent (5-day BOD, mg/l)
8. Influent and effluent (suspended solids, mg/l)
9. Influent and effluent (settleable solids, mg/l)
10. Raw sludge (gal)

    pH
    Total solids, %
    Volatile solids, %

11. Digested bottom sludge

    Total solids, %
    Volatile solids, %
    pH
    Volatile acids and alkalinity, mg/l
    Temperature

12. Gas produced (cu ft)

13. Effluent chlorine residual (mg/l) and coliform count, MPN

14. Any unusual influent characteristics such as appearance or odors

17.121 Monthly Records

Monthly records should reflect the totals and averages of the values recorded daily or at some other frequency and in some cases should give maximum and minimum daily results, such as maximum and minimum daily flows.

17.13 Keeping and Maintaining Monthly Records

Daily recorded data are usually written on monthly data sheets. The monthly data sheet is designed to meet the reporting needs of a particular plant and should have all important data recorded that may be used later for preparation of monthly or annual reports.

MONTHLY DATA SHEET (See Appendix)

The monthly data sheet may be a single 8-1/2 x 11" sheet for a small primary plant, or it may be a number of sheets pertinent to various treatment units in a secondary or advanced waste treatment plant.

Normally every plant operator makes up a monthly data sheet for his plant to record daily information. These sheets are numbered down the left hand side to 31 to cover 31 days in a month. Then from left to right across the sheet are marked off different columns to record daily information. These columns should contain the day of the week, weather conditions, plant flow, influent and effluent temperature, pH, settleable solids, BOD, raw sludge pumped, digester sludge drawn, gas production, DO, and other pertinent information. A space for remarks is helpful to record and explain unusual events.

Sometimes the operator may use two or three different sheets to collect pertinent data. Since each plant is different, the operator prepares his plant data sheet to record the data he needs for proper plant operation and for the requirements of his agency and the regulatory agencies.

In addition to routine daily operation, maintenance and wastewater characteristics, the monthly data sheet should contain any unusual happenings that may affect interpretation of results and preparation of a monthly report such as unusual weather, floods, bypasses, breakdowns, or changes in operations or maintenance procedures.

A typical monthly data sheet (Appendix) and monthly report (Section 17.3) for an activated sludge plant are at the end of this chapter.

17.14 Evaluation of Records

Records are not useful unless they are evaluated and used as indicators of plant operation and maintenance. Records are also useful as sources for reports to management or the public.

The recorded data should enable the operator to determine operation and maintenance of his plant. The information shown by the records should also indicate to him and his supervisor the efficiency of each unit in the plant. Records kept on the quality of the effluent and the receiving waters should be analyzed for the discharge's effect on the receiving waters. The importance of looking at and analyzing records frequently cannot be overemphasized.

Records should not only be analyzed as a single piece of data, but any one variation should be looked upon for its relation to another source of data. For example, a sudden drop in temperature of the influent might be accompanied by greatly increased flows. This could indicate storm water inflows or infiltration of sewer lines. Infiltration by storm waters also could influence the BOD and suspended solids concentrations in the plant influent. Or one might observe a sudden increase in 5-day BOD concentrations in the plant effluent. This may indicate a seasonal increase due to beginning of cannery operations, or it may indicate a breakdown of industrial treatment facilities discharging untreated wastes into the wastewater collection system.

Before any meaningful interpretation can be made of any sudden variation in data, an expected range of values has to be determined for the particular treatment unit under consideration based upon expected or past performance.

For example, if average daily flows during weekdays were around two million gallons per day and suddenly a flow of 1.5 million gallons per day was recorded, this may indicate malfunctioning of metering equipment or a break in sewer lines or a bypass ahead of the plant. Conversely, unusually high flows may indicate storm water infiltration, surface water runoff flowing into the system through manholes, or an unusual dump of wastewater.

An excellent way to facilitate review of daily records and detect sudden changes or trends is a prepared chart showing values plotted against days. Unless results are plotted, slight changes and trends can go undetected. The deviation from the expected values may have been caused by unusual circumstances or an error in observation or analysis. Procedures for plotting and interpreting data are provided in Chapter 16, Analysis and Presentation of Data.

QUESTIONS

17.1A Why is it important to keep records of plant operation?

17.1B Why should unusual happenings be recorded and described?

17.1C Why do many operators carry a pencil and pocket notebook on the job?

17.1D Why should records frequently be reviewed and analyzed?

17.2 REPORT WRITING

This section will cover the major principles and mechanics of report writing, the type of report usually required of a plant operator, and a discussion and example of effective writing.

To many, the thought of writing a report represents a task that is to be approached with fear and with a sense of inadequacy. This need not be the case. Anyone who can read and is willing to put forth the effort can prepare an adequate report. The typical treatment plant operator may regard the writing of reports as an unwelcome chore and thus may approach the subject with a natural resistance.

You should approach the task of report writing as if your next pay raise depended on a neat, organized, and brief report. One operator's annual report was so well written that a local newspaper used the report to develop a six-article series on his treatment plant. The newspaper stories explained the operation of the plant and its effectiveness in protecting the fish life, water supplies, and recreational uses of the receiving waters. Shortly after the articles appeared in the newspaper the operator received a substantial increase in salary.

17.20 Importance of Reports

A report serves many purposes. It can serve as the basis of a request for additional budget and personnel, plant additions, or changes in plant operation. A report also is a means by which your ability, actions, and knowledge are communicated to management and your supervisor. It should be visualized as an opportunity to tell your story to your supervisor, management, or the general public. Your ability to prepare and submit effective reports is one factor considered for advancement in your profession.

Furthermore, you and your plant operation are partially judged by the information contained in your report, its style, and its appearance. A poorly prepared report may result in an impression that the plant is not operating efficiently; or, still worse, it can result in little action on or rejection of recommendations or requests.

It is not enough that you operate a plant efficiently; you must demonstrate this to your supervisors, administrators, and regulatory agencies in a clearly understandable and well-prepared report.

The narrative type of report writing will be discussed first because it is the non-routine part of a typical monthly, quarterly, or annual report.

17.21 Major Principles of Report Writing

Whatever the report or its size, there are some basic principles common to good report writing:

1. Know the purpose and objective of your report.
2. Tailor your report to the person or persons to whom it is directed.
3. Know your subject.
4. Organize the report to present order of ideas in a logical manner.
5. Use language in the report that will be understood by the reader.
6. Use facts and figures.
7. Be as exact and brief as possible.
8. Write effectively.

In starting to prepare a narrative report, the most important questions are what is the purpose of this report and for whom is it written? The next important step is the organization of the ideas and subject matter in a logical order.

17.22 Organization of the Report

There is no single way to organize a formal report. It is important to remember that a written report does not necessarily organize and present the material in the same order in which the information was gathered. Organization means simply that the topics in the report are set forth in logical sequence to tell the story effectively.

Some reports may follow a general format such as:

A. Brief statement of problem

B. Summary

C. Conclusions and recommendations

D. Body of report

   1. Technical and administrative background

   2. Investigation details

   3. Any necessary supporting material to back up conclusions and recommendations

   4. Appendix (if necessary) including detailed data and tables to support body of report

The conclusion and recommendation section of a report should receive the most attention and review. It is important that these be stated clearly and briefly and in language that will be understood by your readers. It also is important to make certain that your conclusions and recommendations are supported in the body of the report.

A memorandum to a supervisor or a narrative portion in a report should be checked for organization and content as follows:

1. Is the material presented in an organized way?

2. Is there duplication?

3. Is there omission of an important item?

4. Is the material presented really necessary to make your point and support your conclusions or recommendations?

Unnecessary material in a communication or report only serves to weaken your case by clouding the main issues.

The above list applies to almost any written communication and can be summarized by the four Cs of good report writing:

Conciseness
Clearness
Completeness
Candor

17.23 Mechanics of Writing a Report

In the previous section examples were given on organizational plans for formal reports; but what are the mechanics of writing a memorandum, a short report, or a section in a larger report?

Following are some guidelines for preparing a report:

A. List ideas and topics you plan to cover in a report.

B. Arrange ideas in logical sequence.

C. Gather supporting material needed to support the ideas to be presented in the report.

D. BEGIN WRITING--this is most important! Prepare a rough draft of the report based on listed ideas and their organization. At this stage of preparation, writing without undue concern about sentence structure or grammar is suggested. It is more important at this stage to record your ideas. It is much easier in a later rewriting of the preliminary draft to eliminate unnecessary material than it is to add to the report.

E. Prepare conclusions and recommendations, if any, after writing the main body of the report.

F. Review preliminary draft for content, logical presentation and organization, and eliminate any unnecessary information. It is at this stage that you can reorganize your order of presentation for a more effective report and check for simplicity and understandability.

G. Review report for sentence sense, spelling, grammar, and briefness.

H. Make another draft (if necessary).

I. Have a colleague or supervisor review the draft if possible.

J. Finally, check your report for overall effectiveness:

    1. Will your initial statements create interest in the contents of the report?

    2. Will the reader understand it?

    3. Is the presentation of ideas in logical order?

    4. Are major points emphasized?

5. Has all irrelevant material been eliminated?

6. Are the sentences direct and effective?

7. Is the report neat and attractive?

8. Does the report support your conclusions and recommendations?

A report does not have to be a literary masterpiece. The more factual and brief it is, the more likely it is to be favorably considered.

17.24 Effective Writing

While the organization of a report and presentation of ideas in a logical manner are the chief components of a good report, effective writing is also necessary.

Effective writing is simply the putting together of words in a gramatically correct and brief manner, eliminating needless words, expressions, and repetitions. A good technical report impresses no one favorably if it is full of flowery and confusing language.

Fortunately, there is an excellent self-tutor publication available entitled, "Effective Writing" (A Tutor Text), by Kellog Smith and Jane Stapleford, published by Doubleday and Company, Inc. The "Tutor Text" teaches and reviews, by means of multiple choice questions and answers, the basic grammar necessary for effective writing. Anyone who can read can improve his writing by utilizing this book and answering the multiple choice questions in the text.

The book covers such important subjects on effective writing as: subject-verb agreement, reference pronouns, placement of modifiers, parallel sentence structure, subordination and presentation of ideas, and most important, concise writing.

The next few paragraphs are provided to show you examples of different styles of writing. More details may be found in the reference by Smith and Stapleford, "Effective Writing" (A Tutor Text).

Following are some examples of direct versus indirect writing and use of active voice as contrasted to the passive voice:

> Indirect: This report which you requested in your letter of December 15, 1968, on the efficiency of the trickling filter units is submitted for your approval. It is concerned with removal of organic material and future operation using different size of filter media.

> Direct: As requested in your letter of December 15, 1968, the report on trickling filter efficiency for removal of organic material and possible filter media size changes is submitted for your approval.

Besides being more direct, we have used eleven words less, or cut the sentence by 25%. Whenever possible, use active sentence construction rather than passive.

> Passive: It is recommended that the monitoring of the effluent be started immediately.

> Active: Monitoring of the effluent should start immediately.

Parallel sentence construction will make your sentence clearer.

> Non-Parallel: The supervisor pointed out how Brown opposed progress, how he encouraged the men to slow down, that he never showed initiative, and that he could not maintain the machines.

> Parallel: The supervisor pointed out that Brown opposed progress, that he encouraged the men to slow down, that he never showed initiative, and that he could not maintain the machines.

17.25 Types of Reports

There are many types of reports ranging all the way from a memorandum to an annual report to management.

Specifically, it may be (1) a monthly plant operation report, (2) a report to a regulatory agency, such as a health department, or (3) a quarterly or annual report to management or the public.

17.250 Monthly Reports (See Section 17.3)

The monthly reports are used in the preparation of the annual report. Preparation of the monthly report consists of the following preliminary activities:

1. Gathering daily records

2. Reviewing daily log sheets for any significant or unusual events during the month

3. Jotting down ideas that one wishes to include in the narrative section of the report

In small plants, a monthly report may consist mainly of data sheets giving the pertinent facts on:

1. Laboratory analyses and effectiveness of plant treatment and its various units

2. Cost data on labor, chemicals, and maintenance

3. Maintenance records

4. Remarks stating unusual significant events during the month

5. Effect on receiving waters

6. Conclusions and recommendations

In some larger plants a monthly report may be required in addition to the monthly data sheets.

The monthly report is a brief summary of combined information from the monthly data sheets and daily logs. The report is put together in outline form with a dozen or so subheadings required for a secondary plant. The reports are useful to the operator and his supervisor to keep them informed of plant functions and problem areas.

The subheadings may be labeled as to flow pattern through the plant and generally describe in narrative form the physical characteristics, maintenance and operation problems, and unusual events during the month.

MONTHLY REPORT

A. Flow

1. Total amount of flow passed through the plant for month
2. Maximum daily flow
3. Minimum daily flow
4. Average daily flow
5. Flow meter problems

B. Headworks

1. Screening: shredding device, operation and maintenance problems
2. Screen material removed, cu ft/MG
3. Grit removed, cu ft/MG
4. Unusual material in the wastewater, such as oil, silt, odors

C. Primary clarifiers

1. Operation or maintenance problems
2. Scum removal, note plugged scum lines
3. Sludge pumped, solids concentration
4. Effluent characteristics

D. Secondary treatment system

1. Trickling filter

    a. Loading rates, average
    b. Recirculation rates, average
    c. Maintenance problems

2. Activated sludge

    a. Loading rates, average
    b. Mixed liquor concentration, average
    c. Mixed liquor DO level

E. Secondary clarifiers

1. Operation or maintenance
2. Sludge pumped, solids concentration

F. Chlorination

1. Pounds of chlorine used/month
2. Pounds of chlorine used/day, average
3. Chlorine residuals
4. Chlorinator problems

G. Outfall

    1. Effluent characteristics
    2. General appearance and condition around plant discharge
    3. Condition of receiving system

H. Raw sludge pumps

    1. Problems and maintenance

I. Digesters

    1. Gallons of raw sludge pumped to digesters
    2. Gas production
    3. Temperature, pH, volatile acids, alkalinity
    4. Operation problems and maintenance performed

J. Sludge drying beds

    1. Gallons of sludge drawn
    2. Yards of dry cake removed
    3. Moisture content of cake or pounds of dry solids
    4. Maintenance or cleaning problems

K. Gas system and boilers

    1. Operation and maintenance

L. General

    1. Power failures
    2. Accidents
    3. Visitors
    4. Grounds and building maintenance
    5. Plant cost

        a. Man-hours worked
        b. Equipment parts
        c. Power and fuel
        d. Chemicals
        e. Miscellaneous

17.251 Annual Reports

The annual report receives wider distribution and is the report more likely to be reviewed by the public, management, and other governmental agencies.

The annual report is, in part, a compilation of data obtained in the monthly reports. It summarizes the plant's yearly efficiency, cost data, and analysis of plant operation costs, and contains recommendations for next year's operations.

In addition, an annual report should contain a short introduction to provide a background to the reader, giving a brief history and reason for the report.

The body of the report should contain schematic drawings, pictures, and other attractive graphs whenever possible, and should include at least the following items:

a. A letter of transmittal

b. Conclusions and recommendations

c. A brief description and schematic diagram of the system

d. An organization chart showing the various functional divisions and their chiefs

e. A statistical summary of general plant data such as:

    (1) Population served

    (2) Wastewater flows (maximum, average, minimum)

    (3) Plant unit data, percent removal and efficiency of various units

f. Body of report which includes a brief description and supporting tables, graphs, or charts needed to back up final recommended actions or requests on such topics as:

    (1) Wastewater quality

    (2) Chlorination

    (3) Screening

    (4) Pumping

    (5) Sludge digestion

    (6) Receiving water quality (maps--summary data)

    (7) Maintenance and repair

    (8) Financial data such as assets, liabilities, revenue

g. Appendix which includes summary data by month for the annual report year, giving minimum, maximum, and average values for:

    (1) General plant data

    (2) Treatment unit data

    (3) Loadings and efficiency of treatment

    (4) Chemical, physical, and bacteriological data on influent and effluent

    (5) Chemical, physical, and bacteriological data on receiving waters

Report writing, especially for an operator not experienced in report writing, can seem like a formidable task. But with provided guidelines, a review of effective writing, and some real effort, anyone who can read can produce an effective report.

17.26 Obtain Reports by Other Operators

A very helpful guide to writing a report is to obtain a report written by another operator. Usually a report may be obtained by writing a nearby city or operator and asking for a copy. If you explain that you are an operator and would appreciate a copy of their report, your request will probably be granted. A representative of a regulatory agency should be able to recommend to you examples of well-written reports.

QUESTIONS

17.2A What is the purpose of writing monthly and annual reports?

17.2B How could you obtain a copy from another plant?

17.3 TYPICAL MONTHLY REPORT

CLEANWATER TREATMENT PLANT
MONTHLY REPORT FOR JUNE 1969

by John Brady

Flow: Cleanwater treated a total raw wastewater flow of 68.497 million gallons this month, with a daily average of 2.283 MG. There were no unusual flow conditions during the month.

Grit Chamber: The grit chamber was cleaned on 6/23, with 1.5 cubic yards of grit removed, consisting mainly of eggshells and sand.

Screening: The top bearing of barminutor No. 1 travel motor was replaced on 6/4 and a spring on the micro switch was also replaced. A broken comb was replaced on the No. 2 barminutor on 6/15 and all combs on that unit were reset to 0.006 inch clearance.

Raw Wastewater Pumps: No problems with No. 1 and No. 3 pumps. No. 2 pump was repacked on 6/9.

Primary Clarifiers: On 6/21 the No. 2 primary clarifier was dewatered for annual inspection. The mechanism was in good condition and only required resetting the clearance of the brass plow squeegees to their original 1/8 inch. The tank weirs and scum baffle were wire brushed and repainted with 395-A. The tank was returned to service on 6/26. While the No. 2 primary was out of service, the No. 1 primary carried the full plant load without any detrimental effect on the efficiency of the plant.

Aerator: No problems. The aerator loading was maintained at 25 pounds of BOD per 100 pounds of mixed liquor suspended solids, and a constant return sludge rate of 30%.

Final Clarifier and Return Sludge Pumps: No operational problems with the final clarifier. The No. 2 return sludge pump was returned from J & M Machine Shop on 6/1 and re-installed. J & M replaced the shaft sleeve and both shaft bearings at a cost of $182.36 (Invoice No. 34475). However, the pump was not ready for service until 6/2 as J & M had packed the pump bearings with an all-purpose medium industrial lubricant rather than the F.M. oil film low temperature grease of -65° to 100°F, as specified.

Chlorination: No problems. Used 9950 pounds of chlorine at an average rate of 335 pounds per day. One hundred twenty-five pounds per day were used for post-chlorination maintaining an average chlorine residual of 4.4 mg/l. Two hundred ten pounds per day were used for pre-chlorination for odor control.

Outfall: Other than the foam build-up around the outfall and the foam drift downstream for approximately 500 yards, the receiving stream was in good condition. The stream sampling below the outfall remained at 8.9 mg/l DO, 2.0 mg/l BOD, and average temperature of 58°F.

Raw Sludge Pump: On 6/9 and 6/30, the raw sludge pump was plugged with a piece of plastic and a wooden stick under the discharge ball check. In each case the pump was restored to service during the 8 AM shift.

Digesters: Digester No. 1 was operated as the primary and No. 2 as the secondary. The temperature in the No. 1 tank was raised from 91°F to 94°F. During the month the tank was continuously mixed. The recirculated sludge contained an average volatile acids content of 150 mg/l, with the alkalinity at 2550 mg/l (volatile acid/alkalinity relationship of 0.06).

Sludge Drying: Supernatant from the No. 2 digester became heavy on 6/12 with the settleable solids ranging from 9 to 15% by volume. On 6/17, 28,000 gallons of digested sludge was drawn from the No. 2 digester to the No. 3 drying bed to reduce supernatant load. The drawn sludge contained 8.3% solids with a volatile content of 52.6%.

The No. 1 and No. 4 drying beds were cleaned, yielding a total of 63 cubic yards of dry sludge.

Gas System and Boiler: On 6/7 it was found that low gas production was recorded for 6/6. The No. 2 digester pressure relief was found to be venting at various times. The entire gas system piping units were cleaned and inspected with the problem location found on 6/13 in the gas meter itself. The condensate and residue had gummed up the gear train from the bellows slide arms. The unit was cleaned with kerosene, relubricated with molly cote, and returned to service with no further problems.

Power Supply: There were two power outages this month, on 6/24 and 6/27, with the plant being out of service 40 to 45 minutes each time. The cause of the outages was due to a service fuse dropping on one phase at the utility pole by the main gate, leaving only the two phases from which to operate.

Each time the main power board was shut down to protect plant equipment.

General:

6/3 Replaced broken hinge on main gate.

6/6 Mosquito abatement personnel moved their oil storage tank from the plant grounds.

6/15 Left main gate barricade chopped down by vandals.

6/17 Replaced left main gate barricade.

6/19 State Water Pollution Control engineer visited plant and collected effluent samples.

6/24 Received 400 return sludge meter charts (Invoice No. 111323).

6/25 Flame-Out Fire Equipment Supply Company representative in and made yearly check on plant fire extinguishers.

Submitted: *[/s/ John J. Smith]*
Chief Operator

17.4 ADDITIONAL READING

1. MOP 11, pages 147-153.
2. New York Manual, pages 119-156.
3. Olman, J.N., Jr., "Technical Reporting", Henry Holt and Company, New York (1952), 289 p. illus. 25 cm. Price $8.50.
4. Smith, K., and Stapleford, J., "Effective Writing", Doubleday and Company, Inc., Garden City, New York. 481 p. (A Tutor Text). Price $6.50.
5. Souther, J.W., "Technical Report Writing", John Wiley & Sons, Inc., New York (1957), 70 p. Price $3.95.

SUGGESTED ANSWERS

Chapter 17. Records and Report Writing

17.1A Records are important to:

a. Document plant performance, efficiency, and problems

b. Justify budget requests

c. Provide design criteria for remodeling, expansion, and new processes

d. Verify observations of plant operation

e. Help if legal action is threatened

f. Document quality of receiving waters

g. Report preparation for supervisors and regulatory agencies

h. Identify significant departures from normal values and take corrective action

i. Show type and frequency of maintenance of operating units

If you recognized the importance of keeping records to document plant performance and justify budgets, you have identified the important concepts. See Section 17.10, Importance of and Need for Records.

17.1B Unusual happenings should be recorded and described because they have an important influence on the interpretation of laboratory analyses describing the operation and efficiency of your plant and the condition of the receiving water. Also they could prove very helpful to the operator in case of an accident. See Section 17.11, Type of Records.

17.1C Many operators carry a pencil and pocket notebook on the job to record all important events as they occur during the day. See Section 17.12, Frequency of Records.

17.1D Records should frequently be evaluated to determine if your plant is operating properly and to identify any developing difficulties before they can become serious problems. See Section 17.14, Evaluation of Records.

17.2A The purpose of monthly and annual reports is to provide a brief description of the operation of your plant for the benefit of management and regulatory agencies. See Section 17.20, Importance of Records.

17.2B Write a letter to another operator or city and ask for a copy of one of their reports. See Section 17.26, Obtain Reports by Other Operators.

OBJECTIVE TEST

(No Discussion and Review Questions)

Chapter 17. Records and Report Writing

Please write your name and mark the correct answers on the IBM answer sheet as directed at the end of Chapter 1.

1. Well-written plant reports are important because they:
    1. Look nice
    2. Communicate to management the accomplishments of you and your plant
    3. Can serve to justify a plant budget
    4. Keep the operator from maintaining his equipment
    5. Explain to the public the operation and function of your plant

2. Plant records are important because they:
    1. Provide essential information when a plant is modified or expanded
    2. Show type and frequency of maintenance of operating units
    3. Make pleasant music
    4. Fill up storage space so the public won't think there is any wasted space around the plant
    5. Provide data required by regulatory agencies

3. What types of records should be kept by an operator?
    1. Operation
    2. Inventory
    3. Complaints
    4. Music
    5. Maintenance

4. Which of the following entries should be made in the plant log?
    1. Jones won the football pool.
    2. Smith cleaned clarifier weirs today.
    3. Switched chlorine feed from No. 2 cylinder to No. 1.
    4. Heavy thunderstorm hit north end of town around 3 PM and lasted for approximately 15 minutes.
    5. Mayor Charles visited plant and discussed some recent odor complaints by plant neighbors.

5. Records are not useful unless they are:

   1. Evaluated
   2. Used to fill bookcases
   3. Used to prop up slide projectors
   4. Used as indicators of plant operation and maintenance
   5. Burned for heat

6. A poorly prepared report may:

   1. Prevent the operator from getting a pay raise
   2. Indicate to management that the operator doesn't know what he is doing
   3. Indicate to the regulatory agency that the plant is not operating efficiently
   4. Convince the public that they shouldn't spend any more money on the plant
   5. Indicate that the operator doesn't care about his job

7. Some of the basic principles of good report writing include:

   1. A college degree
   2. Knowledge of the subject
   3. A good typewriter
   4. Organizing the report to present ideas in a logical fashion
   5. Using facts and figures

8. Effective writing means:

   1. Use of correct grammar
   2. Elimination of needless words
   3. Putting words together in a brief manner
   4. Determining the effectiveness of your plant
   5. Avoiding repetitive statements

9. Reports written by other operators are very helpful in preparing a report. These reports may be obtained:

   1. By asking another operator for a copy of one of his reports
   2. By buying one
   3. By asking your plant consulting engineer to help you find a report
   4. By requesting a representative from a regulatory agency to assist in finding a report
   5. From an effective writing textbook

10. Books on report writing may be:

    1. Obtained from a library
    2. Found in most treatment plants
    3. Obtained by writing the publisher
    4. Found in most homes
    5. Of no use to an operator

11. Well-kept records will make the task of writing reports much easier.

    1. True
    2. False

12. Entries on data sheets should be written in ink, because lead pencil entries may smudge and can be altered or erased.

    1. True
    2. False

Review Questions:

13. Estimate the pounds of solids in a 350,000-gallon aeration tank if the suspended solids concentration is 1400 mg/l.

    1. 3500
    2. 3900
    3. 4000
    4. 4100
    5. 4500

14. Calculate the percent reduction in volatile matter during digestion if the raw sludge was 72% volatile matter and the digested sludge is 51%.

    1. 50%
    2. 55%
    3. 60%
    4. 65%
    5. 70%

15. Determine the organic loading on a pond in pounds of BOD per acre per day if the inflow is 1.5 MGD with a BOD of 145 mg/l and the pond area is 30 acres.

    1. 50 lbs BOD/ac/day
    2. 55 lbs BOD/ac/day
    3. 60 lbs BOD/ac/day
    4. 65 lbs BOD/ac/day
    5. 70 lbs BOD/ac/day

16. Lab tests indicate a chlorine dose of 10 mg/l is necessary for adequate disinfection of the plant effluent for a flow of 1.2 MGD. What should be the feed setting on the chlorinator?

    1. 10 lbs/24 hr
    2. 50 lbs/24 hr
    3. 100 lbs/24 hr
    4. 200 lbs/24 hr
    5. 500 lbs/24 hr

Please write on your IBM answer sheet the total time required to work this chapter.

C O N G R A T U L A T I O N S

You've worked hard and completed a very difficult program.

APPENDIX

(Monthly Data Sheet)

CLEANWATER, U.S.A.

WATER POLLUTION CONTROL PLANT

MONTHLY RECORD ________ 19__ OPERATOR: ____________

DATE	DAY	WEATHER	FLOW — MGD	RAW WASTEWATER TEMP.	pH	SETT. SOLIDS	B.O.D.	SUSP. SOLIDS	PRIM. EFF. B.O.D.	SUSP. SOLIDS	D.O.	FINAL EFFLUENT pH	B.O.D.	SUSP. SOLIDS	D.O.	CL_2 RES.	AERATION SYSTEM LBS. VOL. SOLIDS	SUSP. SOLIDS	% VOL.	30 MIN. SETT.	S.V.I.	D.O.	RETURN SUSP. SOLIDS	RETURN-MGD	WASTE GAL. X 1000	WASTE LBS./DAY
1	S	CLEAR	1.782	75	7.2	14			118	84	0.6	6.9	19	18	0.9	2.7	6746	2036	78.9	150	73	2.5	5961	0.702	70	3480
2	M	CLEAR	2.347	74	7.3	13	218	150	156	84	0.3	6.8	19	15	1.0	2.8	6859	2078	78.6	150	72	1.4	4683	0.711	72	2812
3	T	CLEAR	2.165	74	7.3	8			109	66	0.8	6.8	14	9	1.2	8.8	7224	2211	77.8	170	76	2.1	6625	0.708	71	3922
4	W	CLEAR	2.012	74	7.3	12			135	74	0.5	6.8	16	14	0.8	4.4	7305	2213	78.6	180	81	2.0	6641	0.712	70	3877
5	T	CLEAR	2.483	74	7.2	13	189	138	134	62	0.3	6.8	9	11	1.7	5.2	7014	2106	79.3	170	80	2.6	6098	0.722	78	3966
6	F	CLEAR	2.386	74	7.2	13			112	60	0.4	6.8	18	6	2.6	6.0	6754	2069	79.0	160	77	3.5	5862	0.700	80	3911
7	S	CLEAR	2.131	75	7.3	13			89	66	0.7	6.9	14	7	1.2	4.4	6296	1905	78.7	150	78	2.6	5564	0.706	80	3712
8	S	CLEAR	1.867	76	7.4	12	174	134	84	74	0.9	6.9	9	15	0.8	4.2	7057	2138	78.6	180	84	0.9	6758	0.703	72	4058
9	M	CLEAR	2.634	75	7.3	14			117	68	0.3	6.9	11	11	1.6	3.5	6767	2097	79.1	160	78	2.5	6022	0.712	70	3515
10	T	CLEAR	2.307	76	7.3	18			120	66	0.3	7.1	8	8	1.5	6.6	6119	1861	78.3	170	91	2.8	6135	0.705	64	3274
11	W	CLEAR	2.198	76	7.3	18	192	142	111	68	0.4	7.0	9	10	1.1	6.6	7035	2123	78.9	200	94	1.7	6183	0.700	70	3609
12	T	CLEAR	2.202	76	7.3	11			99	72	0.4	7.0	11	9	2.0	3.8	6352	1954	77.4	190	97	3.0	6027	0.704	70	3518
13	F	CLEAR	2.178	77	7.3	11			81	58	0.6	7.0	15	18	3.5	4.0	6313	1937	77.6	170	87	4.8	5542	0.689	72	3327
14	S	CLEAR	2.008	78	7.3	12	155	156	105	76	0.3	6.9	12	8	3.1	3.8	6335	1929	78.2	160	82	4.3	4856	0.703	70	2834
15	S	CLEAR	1.942	78	7.2	12			113	74	0.4	6.9	9	9	1.3	4.4	6873	2090	78.3	180	86	2.2	5753	0.711	73	3502
16	M	CLEAR	2.464	78	7.2	11			128	74	0.3	6.9	10	10	1.8	3.0	7082	2162	78.0	200	92	2.5	6852	0.723	76	4343
17	T	CLEAR	2.321	78	7.1	8	168	144	110	64	0.4	6.8	10	11	1.9	6.6	6215	1937	76.4	190	98	2.8	6654	0.698	74	4106
18	W	CLEAR	2.611	78	7.3	15			105	64	0.2	6.9	11	7	2.2	4.4	6227	1923	77.1	190	98	3.3	5767	0.717	83	3992
19	T	CLEAR	2.457	78	7.3	12			87	72	0.5	6.9	10	7	2.9	6.2	4844	1534	75.2	170	110	4.5	4762	0.721	25	992
20	F	CLEAR	2.498	79	7.3	11	193	118	105	66	0.7	6.9	18	12	3.1	4.4	5846	1822	76.4	190	104	4.1	5123	0.719	0	0
21	S	CLEAR	2.213	76	7.1	12			109	76	0.6	7.1	10	9	1.2	4.2	6892	2096	78.3	200	95	2.6	5928	0.706	35	1730
22	S	CLEAR	1.878	76	7.3	12			131	78	0.4	6.9	14	10	0.5	4.2	7518	2263	79.1	260	114	1.8	3894	0.703	35	1136
23	M	CLEAR	2.901	77	7.3	12	187	142	133	89	0.2	6.9	13	13	0.3	2.5	8388	2541	78.6	310	121	1.9	8396	0.741	70	4901
24	T	N.M. CLEAR	2.346	78	7.3	13			114	56	0.3	6.9	14	10	2.2	4.2	7962	2409	78.7	230	95	3.6	8824	0.700	71	5225
25	W	CLEAR	2.421	78	7.3	13			89	56	0.4	7.0	12	8	2.8	4.0	7688	2332	78.5	230	98	4.1	7382	0.713	72	4432
26	T	CLEAR	2.562	79	7.3	12	212	170	143	87	0.6	7.0	10	6	1.7	4.3	6697	2047	77.9	210	102	2.6	6867	0.698	70	4008
27	F	CLEAR	2.428	79	7.3	10			128	84	0.5	6.8	15	10	0.5	3.8	6923	2103	78.2	200	94	1.2	7436	0.702	64	3969
28	S	CLEAR	2.149	78	7.3	12			84	66	0.9	6.9	16	5	0.6	3.5	7169	2180	78.3	200	91	1.7	8412	0.706	68	4770
29	S	CLEAR	1.862	79	7.3	7	176	102	117	60	0.5	6.9	14	8	0.5	3.9	7852	2397	78.0	230	95	1.0	7117	0.700	66	3917
30	M	CLEAR	2.746	79	7.3	13			107	73	0.2	6.8	8	8	1.6	3.5	7688	2335	78.4	220	94	2.9	7735	0.713	70	4515
31																										
MAX			2.901	79	7.4	18	218	170	156	89	0.9	7.1	19	18	3.5	8.8	8388	2541	79.3	310	121	4.8	8824	0.741	83	5225
MIN			1.782	74	7.1	7	155	102	84	56	0.2	6.8	8	5	0.5	2.5	4844	1534	76.4	150	72	0.9	4683	0.698	0	0
AVG			2.283	77	7.3	12	186	139	112	70		6.9	12	10	1.6	4.4	6868	2092	78.1	192	91	2.6	6328	0.708	65	3511

SUMMARY DATA

% REMOVAL	B.O.D.	S.S.
INF — PRI	39.7	49.6
INF — EFF	93.5	92.8

SLUDGE DATA

% SOLIDS — AVG.	5.6
LBS. DRY SOLIDS / DAY	5579
% VOL. SOLIDS — AVG.	79.8
LBS. VOL. SOLIDS / DAY	4452
LBS. VOL. SOL./1000 FT^3/DAY	67.5
GALS. SLUDGE TO BEDS	28,000
CU. YDS. CAKE REMOVED	63
FT^3 GAS / LB. VOL. SOLIDS	6.8
FT^3 GAS / LB. MG FLOW	14,286

COST DATA

MAN DAYS 63 PAYROLL	2,325.78
POWER PURCHASED	520.32
OTHER UTILITIES (GAS, H_2O)	NONE
GASOLINE, OIL, GREASE	108.56
CHEMICALS AND SUPPLIES	547.25
MAINTENANCE	238.48
VEHICLE COSTS	NONE
OTHER	NONE
TOTAL	$ 3,740.39
OPER. COST/MG TREATED	$ 54.62
OPER. COST/CAPITA/MO.	$ 0.158

FLOW METER:
LAST 222046
1st 153549
TOTAL 68.497 MG

ELECTRIC METER:
LAST 7838
1st 5670
TOTAL 2168
MULT 40 X 2168 = 86,720 KWH

RAW SLUDGE:
LAST 798324
1st 432984
STROKES 365340
TOTAL 365340 X 1.0 = 365,340 GALS

GAS METER:
LAST 2181110
1st 1265230
TOTAL 915880 FT^3

RETURN SLUDGE:
LAST 67635048
1st 67613800
TOTAL 21.248 MG

WASTE SLUDGE:
LAST 134251
1st 132560
TOTAL 1961 x 1000 MG

GLOSSARY

A Summary of All the Words Defined

in

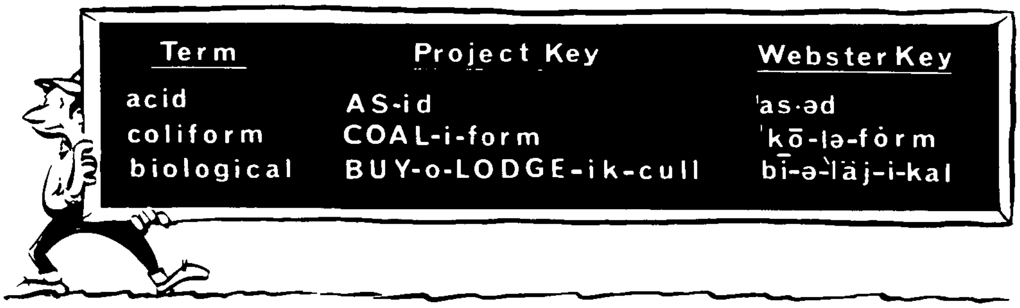
OPERATION OF WASTEWATER TREATMENT PLANTS

Project Pronunciation Key

by Warren L. Prentice

The Project Pronunciation Key is designed to aid you in the pronunciation of new words. While this key is based primarily on familiar sounds, it does not attempt to follow any particular pronunciation guide. This key is designed solely to aid operators in this program.

You may find it helpful to refer to other available sources for pronunciation help. Each current standard dictionary contains a guide to its own pronunciation key. Each key will be different from each other and from this key. Examples of the difference between the key used in this program and the Webster's New World Dictionary Key, College Edition, 1968[1] are shown below:



Term	Project Key	Webster Key
acid	AS-id	'as·əd
coliform	COAL-i-form	'kō-lə-fôrm
biological	BUY-o-LODGE-ik-cull	bī-ə-'läj-i-kal

In using this key, you should accent (say louder) the syllable which appears in capital letters. The following chart is presented to give examples of how to pronounce words using the Project Key.

	SYLLABLE				
WORD	1st	2nd	3rd	4th	5th
acid	AS	id			
coagulant	co	AGG	you	lent	
biological	BUY	o	LODGE	ik	cull

The first word, <u>acid</u>, has its first syllable accented. The second word, <u>coagulant</u>, has its second syllable accented. The third word, <u>biological</u>, has its first and third syllables accented.

We hope you will find the key useful in unlocking the pronunciation of any new word.

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[1] The Webster's New World Dictionary, College Edition, 1968, was chosen rather than an unabridged dictionary because of its availability to the operator.

GLOSSARY

Absorption (ab-SORP-shun): Taking in or reception of one substance into the body of another by molecular or chemical action, and distributed throughout the absorber.

Activated Sludge (ACK-ta-VA-ted sluj): Sludge particles produced in raw or settled wastewater (primary effluent) by the growth of organisms (including zoogleal bacteria) in aeration tanks in the presence of dissolved oxygen. The term "activated" comes from the fact that the particles are teaming with bacteria, fungi, and protozoa.

Activated Sludge Process (ACK-ta-VATE-ed sluj): A biological wastewater treatment process in which a mixture of wastewater and activated sludge is aerated and agitated. The activated sludge is subsequently separated from the treated wastewater (mixed liquor) by sedimentation, and wasted or returned to the process as needed.

Adsorption (add-SORP-shun): To gather (a gas, liquid, or dissolved substance) on the surface or interface zone of another substance.

Advanced Waste Treatment: Any process of water renovation that upgrades water quality to meet specific reuse requirements. May include general cleanup of water or removal of specific parts of wastes insufficiently removed by conventional treatment processes.

Aeration Bay (air-A-shun): The same as aeration tank or aerator. The tank where raw or settled wastewater is mixed with return sludge and aerated.

Aeration Liquor: Mixed liquor. The contents of the aeration tank, which is composed of living organisms plus material carried into the tank by the untreated wastewater or primary effluent.

Aerobic (AIR-O-bick): A condition in which "free" or dissolved oxygen is present in the aquatic environment.

Aerobic Bacteria (AIR-O-bick back-TEAR-e-ah): Bacteria which live and reproduce only in an environment containing oxygen which is available for their respiration (breathing), such as atmospheric oxygen or oxygen dissolved in water. Oxygen combined chemically, such as in water molecules, H_2O, cannot be used for respiration by aerobic bacteria.

Aerobic Decomposition (AIR-O-bick): Decomposition and decay of organic material in the presence of "free" or dissolved oxygen.

Aerobic Process (AIR-O-bick): A waste treatment process conducted under aerobic (in the presence of "free" or dissolved oxygen) conditions.

Agglomeration (a-GLOM-er-A-shun): The growing or coming together of dispersed suspended matter into larger flocs or particles which settle rapidly.

Aliquot (AL-li-kwot): Portion of a sample.

Ambient Temperature (AM-bee-ent): Temperature of the surroundings.

Amperometric (am-PURR-o-MET-rick): A method of measurement that records electric current flowing or generated, rather than recording voltage. Amperometric titration is an electrometric means of measuring concentrations of substances in water.

Anaerobic (AN-air-O-bick): A condition in which "free" or dissolved oxygen is not present in the aquatic environment.

Anaerobic Bacteria (AN-air-O-bick back-TEAR-e-ah): Bacteria that live and reproduce in an environment containing no "free" or dissolved oxygen. Anaerobic bacteria obtain their oxygen supply by breaking down chemical compounds which contain oxygen, such as sulfates (SO_4).

Anaerobic Decomposition (AN-air-O-bick): Decomposition and decay of organic material in an environment containing no "free" or dissolved oxygen.

Anaerobic Digestion (AN-air-O-bick): Wastewater solids and water (about 5% solids, 95% water) are placed in a large tank where bacteria decompose the solids in the absence of dissolved oxygen. At least two general groups of bacteria act in balance: (1) Saprophytic bacteria break down complex solids to volatile acids, and (2) Methane Fermenters break down the acids to methane, carbon dioxide, and water.

BOD (BEE-OH-DEE): See Biochemical Oxygen Demand.

BTU (BEE-TEA-YOU): British Thermal Unit. The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Bacteria (back-TEAR-e-ah): Bacteria are living organisms, microscopic in size, which consist of a single cell. Most bacteria utilize organic matter for their food and produce waste products as the result of their life processes.

Bacterial Culture (back-TEAR-e-al): In the case of activated sludge, the bacterial culture refers to the group of bacteria classed as Aerobes, and facultative organisms, which covers a wide range of organisms. Most treatment processes in the United States grow facultative organisms which utilize the carbonaceous (carbon compounds) BOD. Facultative organisms can live when oxygen resources are low. When "nitrification" is required, the nitrifying organisms are Obligate Aerobes (require oxygen) and must have at least 0.8 mg/l of dissolved oxygen throughout the whole system to function properly.

Batch Process: A batch process is a treatment process in which a tank or reactor is filled, the water is treated, and the tank contents are released. The tank may then be filled and the process repeated.

Biochemical Oxygen Demand or BOD: The BOD indicates the rate of oxygen utilized by wastewater under controlled conditions of temperature and time.

Bioassay (BUY-o-ass-SAY): (1) an assay method using a change in biological activity as a qualitative or quantitative means of analyzing a material's response to biological treatment. or (2) A method of determining toxic effects of industrial wastes or other wastes by using live organisms such as fish for test organisms.

Biodegradation (BUY-o-de-grah-DAY-shun): The breakdown of organic matter by bacteria to more stable forms which will not create a nuisance or give off foul odors.

Bioflocculation (BUY-o-flock-u-LAY-shun): A condition whereby organic materials tend to be transferred from the dispersed form in wastewater to settleable material by mechanical entrapment and assimilation.

Blank: A bottle containing dilution water or distilled water, but the sample being tested is not added. Tests are frequently run on a sample and a blank and the differences compared.

Buffer: A measure of the ability or capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water or wastewater for offering a resistance to changes in the pH.

Bulking (BULK-ing): Bulking occurs in activated sludge plants when the sludge becomes too light and will not settle properly.

Cathodic Protection (ca-THOD-ick): An electrical system for prevention of rust, corrosion, and pitting of steel and iron surfaces in contact with water and wastewater.

Chloramines (KLOR-a-means): Chloramines are compounds formed by the reaction of chlorine with ammonia.

Chlorine Demand: Chlorine demand is the difference between the amount of chlorine added to wastewater and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, nature, and amount of the impurities in the water.

Chlorine Requirement: The amount of chlorine which must be added to produce the desired result under stated conditions. The result (the purpose of chlorination) may be based on any number of criteria, such as a stipulated coliform density, a specified residual chlorine concentration, the destruction of a chemical constituent, or others. In each case a definite chlorine dosage will be necessary. This dosage is the chlorine requirement.

Chlororganic (chlor-or-GAN-nick): Chlororganic compounds are organic compounds combined with chlorine. These compounds generally originate from or are associated with living or dead organic materials.

Clarifier (KLAIR-i-fire): Settling Tank, Sedimentation Basin. A tank or basin in which wastewater is held for a period of time, during which the heavier solids settle to the bottom and the lighter material will float to the water surface.

Coagulants (co-AGG-you-lents): Chemicals added to destabilize, aggregate and bind together colloids and emulsions to improve settleability, filterability, or drainability.

Coliform (COAL-i-form): The coliform group of organisms is a bacterial indicator of contamination. This group has as one of its primary habitats the intestinal tract of human beings. Coliforms also may be found in the intestinal tract of warm-blooded animals, and in plants, soil, air, and the aquatic environment.

Colloids (KOL-loids): Very small solids (particulate or insoluble material) in a finely divided form that remain dispersed in a liquid for a long time due to their small size and electrical charge.

Colorimetric: A means of measuring unknown concentrations of water quality indicators in a sample by comparing the sample's color, after the addition of specific reagents, with the color of known concentrations.

Combined Sewer: A sewer designed to carry both sanitary wastewaters and storm or surface water runoff.

Comminution (com-min-OO-shun): A mechanical treatment process which cuts large pieces of wastes into smaller pieces so they won't plug pipes or damage equipment (shredding).

Comminutor (com-min-OO-ter): A device used to reduce the size of the solid chunks in wastewater by shredding (comminuting). The shredding action can be visualized if you imagine many scissors cutting or hammering to shreds all the large influent solids material.

Composite (Proportional) Samples (com-POZ-it): Samples collected at regular intervals in proportion to the existing flow and then combined to form a sample representative of the entire period of flow over a given period of time.

Coning (CONE-ing): A condition that may be established in a sludge hopper during sludge withdrawal when part of the sludge moves toward the outlet while the remainder tends to stay in place. Development of a cone or channel of moving liquid surrounded by relatively stationary sludge.

Conventional Treatment: The pretreatment, sedimentation, flotation, trickling filter and activated sludge wastewater treatment processes.

Cross-Connection: A connection where wastewater or water from a pump seal could enter a drinking water supply.

DO (DEE-OH): Abbreviation of Dissolved Oxygen. DO is the atmospheric oxygen dissolved in water or wastewater.

Dateometer (date-O-meter): A small calendar disc attached to motors and equipment to indicate the year in which the last maintenance service was performed.

Decomposition, Decay: Generally aerobic processes that convert unstable materials into more stable forms by chemical or biological action. Waste treatment encourages decay in a controlled situation in order that the material may be disposed of in a stable form. When organic matter decays under anaerobic conditions (putrefaction), undesirable odors are produced. In aerobic processes, the odors are much less objectionable than those produced by anaerobic decomposition.

Degradation (de-grah-DAY-shun): The conversion of a substance to simpler compounds.

Density (DEN-sit-tee): The weight per unit volume of any substance. The density of water (at 4°C) is 1.0 gram per cubic centimeter (gms/cc) or about 62.4 lbs per cubic foot.

Detention Time: The time required to fill a tank at a given flow or the theoretical time required for a given flow of wastewater to pass through a tank.

Detritus (de-TRI-tus): The heavy, coarse material carried by wastewater.

Dewaterable: A material is considered dewaterable if water will readily drain from it. Generally raw sludge dewatering is more difficult than water removal from digested sludge.

Diffused Air Aeration: A diffused air activated sludge plant takes air, compresses it, and then discharges the air below the water surface of the aerator through some type of air diffusion device.

Diffuser: A diffuser is a device (porous plate, tube, bag) used to break the air stream from the blower system into fine bubbles in the mixed liquor.

Digester (die-JEST-er): A tank in which sludge is placed to allow sludge digestion to occur. Digestion may occur under anaerobic (more common) or aerobic conditions.

Disinfection (DIS-in-feck-shun): The process by which pathogenic (disease) organisms are killed. There are several ways to disinfect, but chlorination is the most frequently used method in water and wastewater treatment.

Dissolved Oxygen: Atmospheric oxygen dissolved in water or wastewater, usually abbreviated DO.

Distillate: In the distillation of a sample, a portion is evaporated; the part that is condensed afterwards is the distillate.

Distributor: The rotating mechanism that distributes the wastewater evenly over the surface of a trickling filter or other process unit. Also see Fixed Spray Nozzle.

Effluent (EF-lu-ent): Wastewater or other liquid--raw, partially or completely treated--flowing from a basin, treatment process, or treatment plant.

Elutriation (e-LOO-tree-a-shun): The washing of digested sludge in plant effluent with a suitable ratio of sludge to effluent. The objective is to remove (wash out) fine particulates or certain soluble components in sludge.

Emulsion (e-MULL-shun): A liquid mixture of two or more liquid substances not normally dissolved in one another, but one liquid held in suspension in the other.

End Point: Samples are titrated to the end point. This means that a chemical is added, drop by drop, to a sample until a certain color change (blue to clear, for example) occurs which is called the end point of the titration. In addition to a color change, an end point may be reached by the formation of a precipitate or the reaching of a specified pH. An end point may be detected by the use of an electronic device such as a pH meter.

Endogenous (en-DODGE-en-us): A diminished level of respiration in which materials previously stored by the cell are oxidized.

Enteric: Intestinal.

Enzymes (EN-zimes): Enzymes are substances produced by living organisms that speed up chemical changes.

Estuaries (ES-chew-wer-eez): Bodies of water at the lower end of a river that are subject to tidal fluctuations.

Facultative (FACK-ul-tay-tive): Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food materials. In other words, facultative bacteria can live under aerobic or anaerobic conditions.

Facultative Pond (FACK-ul-tay-tive): The most common type of pond in current use. The upper portion (supernatant) is aerobic, while the bottom layer is anaerobic. Algae supply most of the oxygen to the supernatant.

Filamentous Bacteria (FILL-a-men-tuss): Organisms that grow in a thread or filamentous form.

Fixed: A sample is "fixed" in the field by adding chemicals that prevent the water quality of the sample from changing before final measurements are performed later in the lab.

Fixed Spray Nozzle: Cone-shaped spray nozzle used to distribute wastewater over the filter media, similar to a lawn sprinkling system. A deflector or steel ball is mounted within the cone to spread the flow of wastewater through the cone, causing a spraying action. Also see Distributor.

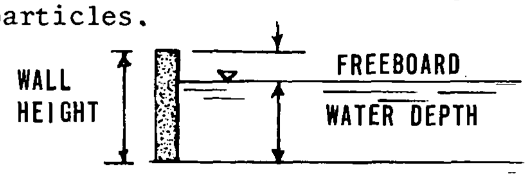
Flame Polished: Sharp or broken edges of glass (such as the end of a glass tube) are flame polished by placing the edge in a flame and rotating it. By allowing the edge to melt slightly, it will become smooth.

Flights: Scraper boards, made from redwood or other rot-resistant woods, used to collect and move settled sludge or floating scum.

Floc: Groups or "clumps" of bacteria that have come together and formed a cluster. Found in aeration tanks and secondary clarifiers.

Flocculated (FLOCK-you-lay-ted): An action resulting in the gathering of fine particles to form larger particles.

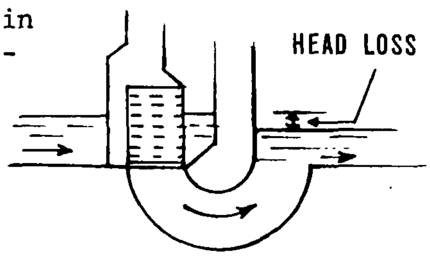
Freeboard: The vertical distance from the normal water surface to the top of the confining wall.



Grit: The heavy mineral material present in wastewater such as sand, eggshells, gravel, and cinders.

Grit Removal: Grit removal is accomplished by providing an enlarged channel which causes the flow velocity to be reduced and allows the heavier grit to settle to the bottom of the channel where it can be removed.

Head Loss: "Head" is a common term used in discussing pumps. It is a way of expressing pressure in terms of the height of a vertical column of water. In the sketch, the head loss is the height to which the water must build up until there is sufficient pressure to force that particular amount of water through the slots in the comminutor drum.



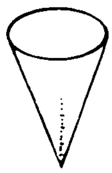
Hepatitis: Hepatitis is an acute viral infection of the liver (yellow jaundice).

Hydrolysis (hi-DROL-e-sis): The addition of water to the molecule to break down complex substances into simpler ones.

Hypochlorinators (hi-po-KLOR-i-NAY-tors): Hypochlorinators are devices that are used to feed calcium, sodium, or lithium hypochlorite as the disinfecting agent.

Hypochlorites (hi-po-KLOR-ites): Hypochlorites are compounds containing chlorine that are used for disinfection. They are available as liquids or solids (powder, granules, and pellets) in barrels, drums, and cans.

Imhoff Cone: A clear, cone-shaped container marked with graduations used to measure the volumetric concentration of settleable solids in wastewater.



Infiltration (IN-fill-TRAY-shun): Groundwater that seeps into pipes through cracks, joints, or breaks.

Influent (IN-flu-ent): Wastewater or other liquid--raw or partially treated--flowing into a reservoir, basin, treatment process, or treatment plant.

Inoculate (in-NOCK-you-LATE): To introduce a seed culture into a system.

Inorganic Waste: Waste material such as sand, salt, iron, calcium, and other mineral materials which are not converted in large quantities by organism action. Inorganic wastes are chemical substances of mineral origin and may contain carbon and oxygen, whereas organic wastes are chemical substances of animal or vegetable origin and contain mainly carbon and hydrogen along with other elements.

Launders (LAWN-ders): Sedimentation tank effluent troughs.

Lineal (LIN-e-al): The length in one direction of a line. For example, a board 12 feet long has 12 lineal feet in its length.

Liquefaction (LICK-we-FACK-shun): Liquefaction as applied to sludge digestion means the transformation of large solid particles of sludge into either a soluble or a finely dispersed state.

Loading: Quantity of material applied to a device at one time.

M or Molar: A molar solution consists of one gram molecular weight of a compound dissolved in enough water to make one liter of solution. A gram molecular weight is the molecular weight of a compound in grams. For example, the molecular weight of sulfuric acid (H_2SO_4) is 98. A 1 M solution of sulfuric acid would consist of 98 grams of H_2SO_4 dissolved in enough distilled water to make one liter of solution.

MPN (EM-PEA-EN): MPN is the Most Probable Number of coliform group organisms per unit volume expressed as a density of organisms per 100 ml.

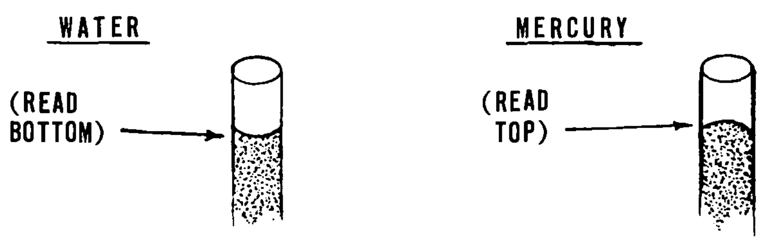
Manometer (man-NOM-meet-her): Usually a glass tube filled with a liquid and used to measure the difference in pressure across a flow measuring device such as an orifice or venturi meter.

Masking Agents: Liquids which are dripped into the wastewater, sprayed into the air, or evaporated (using heat) with the "fumes" or odors discharged into the air by blowers to make an undesirable odor less noticeable.

Mechanical Aeration: The surface of the aeration tank is agitated to cause spray and waves by a paddle wheel, mixers, rotating brushes, pumps discharging water into the air like a fountain or discharging the water down a series of steps creating falls or some other method of splashing water into the air or air into the water where the oxygen can be absorbed.

Media: The material in a trickling filter over which settled wastewater is sprinkled and then flows over and around during treatment. Slime organisms grow on the surface of the media and treat the wastewater.

Meniscus: The curved top of a column of liquid (water, oil, mercury) in a small tube. Water will form a valley when the liquid wets the walls of the tube, while mercury will form a hill and the walls of the tube are not wetted.



Mesophilic Bacteria (mess-O-FILL-lick): Medium temperature: A group of bacteria that thrive in a temperature range between 68°F and 113°F.

Microorganisms (micro-ORGAN-is-zums): Very small organisms that can be seen only through a microscope. Some microorganisms use the wastes in wastewater for food and thus remove or alter much of the undesirable matter.

Milligrams Per Liter, mg/l (MILL-i-GRAMS per LEET-er): A measure of the concentration by weight of a substance per unit volume. For practical purposes, one mg/l is equal to one part per million parts (ppm). Thus a liter of water with a specific gravity of 1.0 weighs one million milligrams and if it contains 10 milligrams of dissolved oxygen, the concentration is 10 milligrams per million milligrams, or 10 milligrams per liter (10 mg/l), or 10 parts of oxygen per million parts of water, or 10 parts per million (10 ppm).

Millimicron (MILL-e-MY-cron): One thousandth of a micron or a millionth of a millimeter.

Mixed Liquor: When the activated sludge in an aeration tank is mixed with primary effluent or the raw wastewater and return sludge, this mixture is then referred to as mixed liquor as long as it is in the aeration tank. When the mixed liquor flows from the aeration tank it goes into the secondary clarifiers or final sedimentation tank. Mixed liquor also may refer to the contents of mixed aerobic or anaerobic digesters.

Molecular Weight: The molecular weight of a compound in grams is the sum of the atomic weights of the elements in the compound. The molecular weight of sulfuric acid (H_2SO_4) in grams is 98.

ELEMENT	ATOMIC WEIGHT	NUMBER OF ATOMS	MOLECULAR WEIGHT
H	1	2	2
S	32	1	32
O	16	4	64
			98

Molecule (MOLL-ee-kule): The smallest portion of an element or compound retaining or exhibiting all the properties of the substance.

Motile (MO-till): Motile organisms exhibit or are capable of movement.

Muffle Furnace: A small oven capable of temperatures up to 600°C and used in laboratories for burning or incinerating samples to determine their loss on ignition (volatile) or fixed solids (ash) content.

Multi-Stage Pump: A pump that has more than one impeller. A single-stage pump has one impeller.

N or Normal: A normal solution contains one gram equivalent weight or a reactant (compound) per liter of solution. The equivalent weight of an acid is that weight of which contains one gram atom of ionizable hydrogen or its chemical equivalent. For example, the equivalent weight of sulfuric acid (H_2SO_4) is 49 (98 divided by 2 because there are two replaceable hydrogen ions). A 1 N solution of sulfuric acid would consist of 49 grams of H_2SO_4 dissolved in enough water to make one liter of solution.

Nitrification: The biochemical conversion of unoxidized nitrogenous matter (ammonia and organic nitrogen) to oxidized nitrogen (usually nitrate). The second-stage BOD is sometimes referred to as the nitrification stage (first-stage BOD is called the carbonaceous stage--carbon compounds oxidized to CO_2).

Nomogram: A chart or diagram containing three or more scales used to solve problems with three or more variables instead of using mathematical formulas.

Nonsparking Tools: These tools will not produce a spark during use.

Nutrients: Substances which are required to support living plants and organisms. Major nutrients are carbon, hydrogen, oxygen, sulfur, nitrogen and phosphorus. Nitrogen and phosphorus are difficult to remove from wastewater by conventional treatment processes because they are water soluble and tend to recycle.

Obligate Aerobes: Bacteria that must have molecular (dissolved) oxygen (DO) to survive.

Organic Waste: Waste material which comes from animal or vegetable sources. Organic waste generally can be consumed by bacteria and other small organisms. Inorganic wastes are chemical substances of mineral origin and may contain carbon and oxygen, whereas organic wastes contain mainly carbon and hydrogen along with other elements.

Orifice (OR-i-fiss): An opening in a plate, wall, or partition . In a trickling filter distributor the wastewater passes through an orifice to the surface of the filter media. An orifice flange set in a pipe consists of a slot or hole smaller than the pipe diameter. The difference in pressure in the pipe above and below the orifice may be related to flow in the pipe.

Orthotolidine (or-tho-TOL-i-dine): Orthotolidine is a colorimetric indicator of chlorine residual in which a yellow-colored compound is produced.

Oxidation (ox-i-DAY-shun): Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In wastewater treatment organic matter is oxidized to more stable substances.

Parasitic Bacteria (PARA-SIT-tick): Parasitic bacteria are those bacteria which normally live off another living organism, known as the host.

Pathogenic Organisms (path-o-JEN-nick OR-gan-iz-ums): Bacteria or viruses which can cause disease (typhoid, cholera, dysentery). There are many types of bacteria which do not cause disease and which are not called pathogenic. Many beneficial bacteria are found in wastewater treatment processes actively cleaning up organic wastes.

Percent Saturation: Liquids can contain in solution limited amounts of compounds and elements. 100% saturation is the maximum theoretical amount that can be dissolved in the solution. If more than the maximum theoretical amount is present, the solution is supersaturated.

$$\text{Percent Saturation} = \frac{\text{Amount in Solution}}{\text{Maximum Theoretical Amount in Solution}} \times 100\%$$

pH (PEA-A-ch): pH is an expression of the intensity of the alkaline or acidic strength of a water. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion concentration.

$$\text{pH} = \text{Log}\,\frac{1}{(H^+)}$$

The pH may range from 0 to 14, where 0 is most acid, 14 most alkaline, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5

Photosynthesis (foto-SIN-the-sis): A process in which organisms with the aid of chlorophyll (green plant enzyme) convert carbon dioxide and inorganic substances to oxygen and additional plant material, utilizing sunlight for energy. Land plants grow by the same process.

Physical Waste Treatment Processes: Racks, screens, comminutors, sedimentation, and flotation. Chemical or biological reactions are not an important part of the process.

Pollution: Any interference with beneficial reuse of water or failure to meet quality requirements.

Ponding: A condition occurring on trickling filters when the voids become plugged to the extent that water passage through the filter is inadequate. Ponding may be the result of excessive slime growths, trash, or media breakdown.

Population Equivalent: A means of expressing the strength of organic material in wastewater. Domestic wastewater consumes, on an average, approximately 0.2 lb of oxygen per person per day, as measured by the standard BOD test.

Postchlorination: Chlorination of the plant discharge or effluent following plant treatment.

Preaeration: A preparatory treatment of wastewater consisting of aeration to freshen the wastewater, remove gases, add oxygen, promote flotation of grease, and aid coagulation.

Prechlorination: Chlorination at the headworks of the plant; influent chlorination prior to plant treatment.

Pretreatment: Use of racks, screens, comminutors, and grit removal devices to remove metal, rocks, sand, eggshells, and similar materials which may hinder operation of a treatment plant.

Primary Treatment: A wastewater treatment process consisting of a rectangular or circular tank which allows those substances in wastewater that readily settle or float to be separated from the water being treated.

Protozoa (pro-toe-ZOE-ah): A group of microscopic animals, principally of one cell, that sometimes cluster into colonies.

Prussian Blue: A paste or liquid used to show a contact area.

Psychrophilic Bacteria (sy-kro-FILL-ik): Cold Temperature: A group of bacteria that thrive in temperatures below 68°F.

Putrefaction (PU-tree-FACK-shun): Biological decomposition of organic matter with the production of ill-smelling products associated with anaerobic conditions.

Putrescible (pu-TRES-sib-bull): Putrescible material will decompose under anaerobic conditions and produce nuisance odors.

Rack: Parallel metal bars or rods evenly spaced and placed at an angle in the influent channel that remove rags, rocks, and cans from wastewater.

Raw Wastewater: Plant influent or wastewater before any treatment.

Reagent (re-A-gent): A substance which takes part in a chemical reaction that is used to measure, detect, or examine other substances.

Receiving Water: A stream, river, lake, or ocean into which treated or untreated wastewater is discharged.

Recirculation: The return of part of the effluent from a treatment process to the incoming flow.

Reliquifaction (re-LICK-we-FACK-shun): The return of a gas to a liquid. For example, a condensation of chlorine gas returning to the liquid form.

Representative Sample: A portion of material or water identical in content to that in the larger body of material or water being sampled.

Residual Chlorine: Residual chlorine is the amount of chlorine remaining after a given contact time and under specified conditions.

Respiration: The physical and chemical processes by which an organism supplies its cells and tissues with oxygen needed for metabolism and relieves them of carbon dioxide formed in energy-producing reactions.

Rising Sludge: Rising sludge occurs in the secondary clarifiers of activated sludge plants when the sludge settles to the bottom of the clarifier, is compacted, and then starts to rise to the surface.

Sanitary Sewer (SAN-eh-tare-ee SUE-er): A sewer intended to carry wastewater from homes, business, and industries. Storm water runoff sometimes is collected and transported in a separate system of pipes.

Saprophytic Organisms (SAP-pro-FIT-tik): Organisms living on dead or decaying organic matter. They help natural decomposition of the organic solids in wastewater.

Screen: A device with openings generally uniformly sized to retain or remove suspended or floating objects in wastewater larger than the openings. A screen may consist of bars, rods, wires, gratings, wire mesh, or perforated plates.

Secondary Treatment: A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated.

Septic (SEP-tick): A condition produced by the growth of anaerobic organisms. If severe, the wastewater turns black, giving off foul odors and creating a heavy oxygen demand.

Septicity (sep-TIS-it-tee): Septicity is the condition in which organic matter decomposes to form foul-smelling products associated with the absence of free oxygen.

Sewage: The used water and solids from homes that flow to a treatment plant. The preferred term is wastewater.

Shock Load: The arrival at a plant of a waste which is toxic to organisms in sufficient quantity or strength to cause operating problems, such as odors or sloughing off of the growth or slime on the trickling filter media. Organic or hydraulic overloads also can cause a shock load.

Shredding: A mechanical treatment process which cuts large pieces of wastes into smaller pieces so they won't plug pipes or damage equipment (comminution).

Sloughings (SLUFF-ings): Trickling filter slimes that have been washed off the filter media. They are generally quite high in BOD and will degrade effluent quality unless removed.

Sludge (sluj): The settleable solids separated from liquids during processing or deposits on bottoms of streams or other bodies of water.

Sludge Digestion: A process by which organic matter in sludge is gasified, liquefied, mineralized, or converted to a more stable form by anaerobic (more common) or aerobic organisms.

Sludge Gasification: A process in which soluble and suspended organic matter are converted into gas. Sludge gasification will form bubbles of gas in the sludge and cause large clumps of sludge to rise and float on the water surface.

Specific Gravity: Weight of a particle or substance in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (or 39°F). Wastewater particles usually have a specific gravity of 0.8 to 2.6.

Stabilize: To convert to a form that resists change. Organic material is stabilized by bacteria which convert the material to gases and other relatively inert substances. Stabilized organic material generally will not give off obnoxious odors.

Stabilized Waste: A waste that has been treated or decomposed to the extent that, if discharged or released, its rate and state of decomposition would be such that the waste would not cause a nuisance or odors.

Stasis (STAY-sis): Stagnation or inactivity of the life processes within organisms.

Stethoscope: An instrument used to magnify sounds and convey them to the ear.

Storm Sewer: A separate sewer that carries runoff from storms, surface drainage, and street wash, but excludes domestic and industrial wastes.

Stuck: A stuck digester does not decompose organic matter properly. It is characterized by low gas production, high volatile acid to alkalinity relationship, and poor liquid-solids separation. A digester in a stuck condition is sometimes called a "sour" digester.

Supernatant (sue-per-NAY-tent): Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the scum on the surface of an anaerobic digester. This liquid is usually returned to the influent wet well or the primary clarifier.

Tertiary Treatment (TER-she-AIR-ee): See Advanced Waste Treatment.

Thermophilic Bacteria (thermo-FILL-lik): Hot temperature: A group of bacteria that thrive in temperatures above 113°F.

Thief Hole: A digester sampling well.

Titrate: To titrate a sample, a chemical solution of known strength is added on a drop-by-drop basis until a color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical solution to completion of the reaction as signaled by the end point.

Totalizer: A totalizer continuously sums or adds up the flow into a plant in gallons or million gallons or some other unit of measurement.

Toxicity (tocks-IS-it-tee): A condition that may exist in wastes that will inhibit or destroy the growth or function of any organism.

Trickling Filter: A treatment process in which the wastewater trickles over media that provide the opportunity for the formation of slimes which clarify and oxidize the wastewater.

Trickling Filter Media: Rocks or other durable materials that make up the body of the filter. Synthetic (manufactured) media have been used successfully.

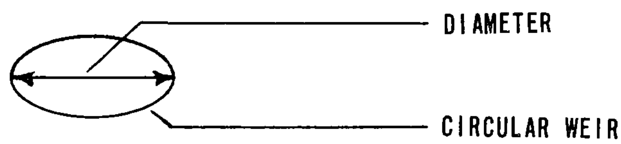
Two-Stage Filters: Two filters are used. Effluent from the first filter goes to the second filter, either directly or with a clarifier between the two filters.

Volute (vol-LOOT): The spiral-shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

Wastewater: The used water and solids from a community that flow to a treatment plant. Storm water, surface water, and groundwater infiltration also may be included in the wastewater that enters a plant. The term sewage usually refers to household wastes, but this word is being replaced by the term wastewater.

Weir (weer): A vertical obstruction, such as a wall, or plate, placed in an open channel and calibrated in order that a depth of flow over the weir can easily be converted to a flow rate in MGD (million gallons per day).

Weir Diameter (weer): Circular clarifiers have a circular weir within the outside edge of the clarifier, and all of the water leaving the clarifier flows over this weir. This diameter is the length of a line from one edge of a weir to the opposite edge and passing through the center of the circle formed by the weir.



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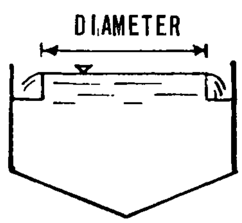

SECTION

Weir, Proportional (weer): A specially shaped weir in which the flow through the weir is directly proportional to the head.

Wet Oxidation: Any process in which substances are converted to a higher oxidation state in a water media, such as activated sludge, trickling filters, ponds, or digesters.

Zoogleal Film (ZOE-glee-al): A complex population of organisms that form a slime growth on the trickling filter media and break down the organic matter in wastewater. These slimes consist of living organisms feeding on the wastes in wastewater, dead organisms, silt, and other debris. Slime growth is a more common word.

Zoogleal Mass (ZOE-glee-al): Jelly-like masses of bacteria found in both the trickling filter and activated sludge processes. These masses may be formed for or function as the protection against predators and for storage of food supplies.