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FIELD MANUAL FOR PERFORMANCE EVALUATION AND TROUBLESHOOTING AT MUNICIPAL WASTEWATER TREATMENT FACILITIES

by

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Although many references were used for the preparation of this manual, the principal references include the following:

1. EPA Training Course 179.2, "Troubleshooting Municipal Wastewater Treatment Plants," Course Manual.

2. "Operation of Wastewater Treatment Plants," Manual of Practice No. 11, Water Pollution Control Federation, 1976.

3. "Process Control Manual for Aerobic Biological Wastewater Treatment Facilities," EPA Municipal Operations Branch, EPA-430/9-77-0066, March 1977.

4. "Operations Manual, Anaerobic Sludge Digestion," EPA-430/9-76-001, February, 1976.

5. "Orange County Water District Operation & Maintenance Manual for Water Factory 21," Culp/Wesner/Culp - Clean Water Consultants, 1974.

6. "Operation & Maintenance Manual for Metropolitan Denver Sewage Disposal District", Culp/Wesner/Culp - Clean Water Consultants, 1977.

7. "Manual of Wastewater Operations," Texas Water Utilities Association, 1976.

8. Manufacturer's O&M data on specific equipment.

SECTION 1

INTRODUCTION

PURPOSE AND SCOPE OF MANUAL

The purpose of this manual is to provide a technical field guide or reference document for use in improving the performance of municipal wastewater treatment plants. The main purpose of the manual is to provide a troubleshooting guide for:

- identifying problems
- analyzing problems
- solving problems

Another purpose of the manual is its use in EPA and State training courses for plant inspectors and performance evaluators. Consulting engineers, designers, plant operators, educators, and students may also find the manual useful.

The manual describes general procedures for evaluating the performance of treatment processes and equipment commonly used in municipal wastewater facilities. The procedures also cover other items related to the effective operation of municipal wastewater treatment plants.

Troubleshooting and performance evaluation material is provided for each unit process commonly used in wastewater treatment facilities.

MANUAL FORMAT

It is assumed that the manual user has a general understanding of both typical wastewater treatment plant design and operation. The style, language, and format of the manual are directed to the level and technical knowledge of a technician with some experience in plant operation, design, inspection or performance evaluation. It is recommended that performance evaluators complete a training program which includes the evaluation of several wastewater treatment plants using this manual and other evaluation methods.

The manual is organized into four major sections:

Section 1 INTRODUCTION. The purpose, scope and format of the manual are described in this section.

Section 2 GENERAL PROCEDURES FOR EVALUATION AND TROUBLESHOOTING.

This section contains a step-by-step procedure for organizing information before a plant is visited and for performing the on-site evaluation.

Section 3 OVERALL SYSTEM CONSIDERATIONS. This section discusses different unit processes and how their operations can affect other processes. It also presents information on safety, staffing, monitoring, emergency procedures, and maintenance considerations which are common to the unit processes in Section 4.

Section 4 UNIT PROCESS EVALUATION AND TROUBLESHOOTING INFORMATION. For each unit process, this section contains the following information:

- Description of the Process
- Typical Design Criteria & Performance Evaluation
- Control Considerations
- Design Shortcomings and Ways to Compensate
- Troubleshooting Guide

SECTION 2

GENERAL PROCEDURES FOR EVALUATING AND TROUBLESHOOTING

Procedures for evaluating and troubleshooting at municipal wastewater treatment facilities include a detailed study of the following:

- Plant performance
- Operating personnel
- Laboratory facilities
- Testing and sampling program
- Costs and budgets for O & M
- Operational problems

Information and data for each element may be gathered and analyzed in five basic steps:

1. Collection of basic data before site visit
2. Facility inspection
3. Total plant evaluation
4. Identification of problems
5. Analysis and reporting

The detail of the evaluation will be greater if:

- Data collected at the plant are questionable
- Discharge quality does not meet standards
- O & M costs are very different than would be expected
- There are important O & M problems

COLLECTION OF BASIC DATA

Preparation for the on-site inspection should include the collection and review of information describing the plants layout and design, operating personnel, any available plant performance records, and previous inspection reports. This data collection will help the evaluator to understand the treatment plant he will inspect. Preparation for the site visit will also help the evaluator see possible problem areas which may need more detailed attention during the facility inspection. The evaluator should gather the following information:

General Information

- Physical location of plant - (with attention to possible effects of climate on plant performance. Extremes of both temperature and rainfall should be noted.)

- Population and area served by the plant (domestic, industrial, etc.)

- Prior evaluation or inspection reports

Information Related To The Plant And Staff

- Type of treatment system (identify plant by type of treatment it provides; primary, secondary, or advanced waste treatment, as shown in Figure 1).

- Size of system (design, average daily flows, peak flows).

- Types of unit operations and basic plant components.

- Plant documents (including schematic and design drawings, plant plans and specifications, O & M manuals, and operating reports).

- Historical operating data (including complaint record).

- Plant discharge requirements (this might include allowable SS, pH, BOD_5, etc., or any special controlling conditions such as minimum DO and chlorine residuals).

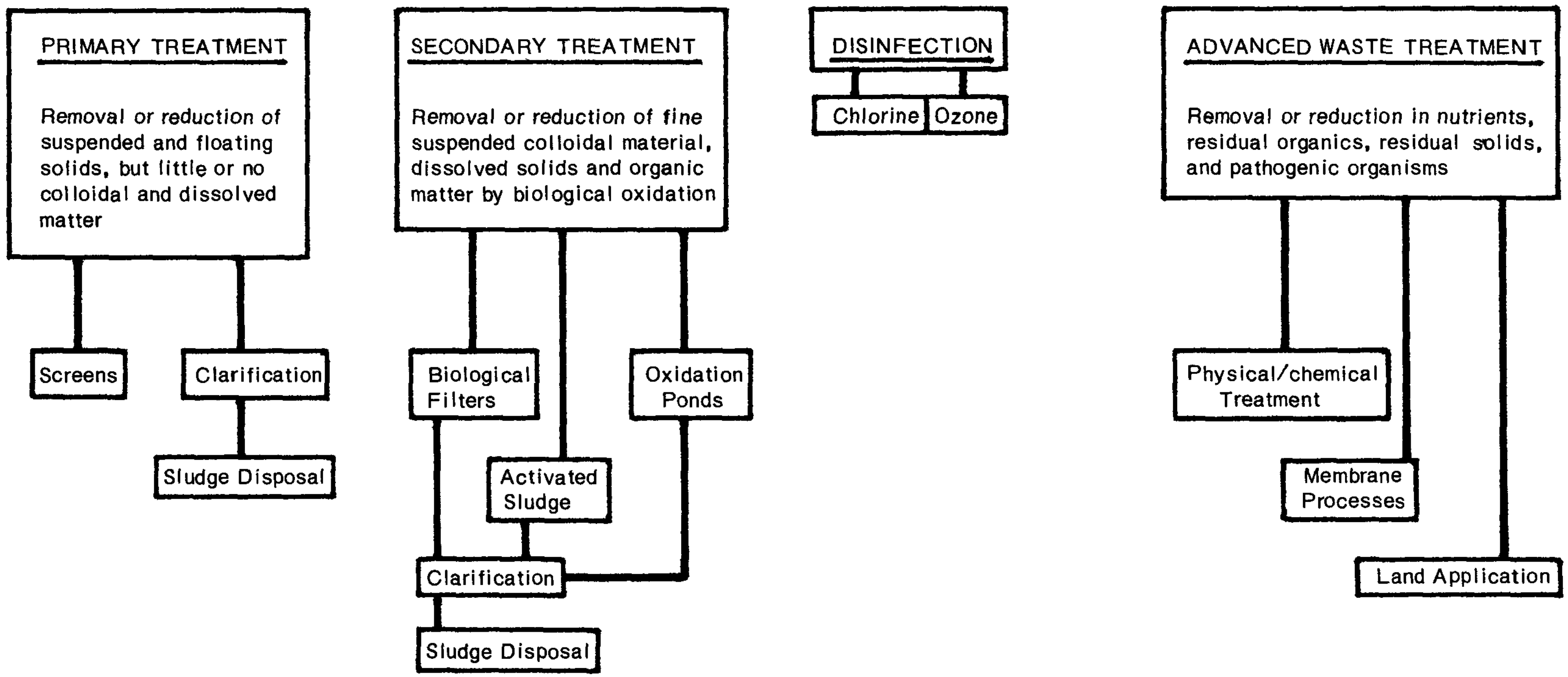
- Characteristics of the plant's influents and effluents - this should include physical and chemical measurements taken at the plant (BOD_5, pH, COD, temperature, etc.), and flow quantity and variations with time. If the official data are not readily available from the plant, then local and/or state health departments and various pollution control agencies may be able to supply the needed information. These data should then be compared to discharge requirements.

- Size of staff, their qualifications, education and experience, as well as the amount of time spent on each unit operation. This information should be compared to the number of people at other treatment plants as discussed in Section 3 of this manual. Above average skills and motivation may allow good operation at lower levels of manpower than shown in the references in Section 3. References 2 and 3 listed at the end of this section provide more detailed guidance for evaluating staffing requirements for each unit process.

FACILITY INSPECTION

Visual Observations

Problem identification begins with an on-site tour of the facility. The plant engineer or operator should provide a complete tour of the



* Not all operations are used in all plants

Figure 1. Classification of wastewater treatment plants by unit operations*

facilities. Watch for and ask about:

- Excessive solids passing over overflow weirs
- Excessive grease and scum buildup
- Any unusual equipment such as special pumps, chemical feeders, temporary construction on systems which are being used to correct problems (or possibly cause them)
- Diurnal flow variations
- Evidence of flow in by-pass channels because of problems in normal operating units
- Flow splitting between units
- Excessive odors
- Abnormal color of wastewater in various process stages
- Treatment units out of service - why and how long
- Sludge handling problems
- Evidence of severe corrosion problems
- Use of proper safety precautions

If any special changes in the plant were made, determine their:

- Purpose
- Physical makeup
- Effect on the other treatment processes by comparing old operational data with data after modification

Page 5 of EPA Form 7500-5 may serve as a useful guide in the visual inspection of the plant.

Available Manpower

During the on-site inspection, the inspector should ask how much time is usually spent on the O & M of each unit process and a list of plant personnel should be completed. The inventory should include:

- Numbers and qualifications of all plant personnel
- Their certification

- Special training and skills also should be noted and compared to the personnel requirements usually needed for effective unit process operation. (EPA publications on estimating staffing may be useful.)

Training programs available to plant personnel also should be examined during this part of the inspection. Training programs may be:

- Short courses conducted by universities

- Vocational schools, and high schools

- Advanced training in laboratory skills, treatment methods, electrical skills, or mechanical skills

- Special training programs as part of local, state, and national certification programs

- Correspondence courses

Analytical Techniques

The following elements should be studied during the laboratory evaluation:

- Tests used in various unit operations (including type, frequency and location of test)

- Testing procedures and analyses used

- Equipment used (including type, quantity and general condition of equipment)

- Laboratory personnel

- Review of test records

This information should be compared with recommended sampling and testing for each unit process. Flow measurement records and techniques should be reviewed for:

- Agreement with the design flow and population served

- Over and under-loading of each treatment unit

- Meter calibration

Budgets for O & M

Costs and budgets for operation and maintenance of the plant should be reviewed and evaluated. The following data should be identified, with unusually high or low costs being noted:

- Preventive maintenance
- Corrective maintenance
- Major repairs
- Alteration
- Unit costs ($/hr for labor, cents/kwh, $/Btu, etc.)

The plant records should show a breakdown of costs for materials used and purchased, as well as labor hours spent for the maintenance item.

EVALUATION OF PERFORMANCE

Total evaluation of plant performance should include the following:

Treatment Efficiency

Actual plant performance should be compared with the expected design performance and typical performance as described in Section 4 of this manual. Actual plant discharges also should be evaluated and compared to applicable discharge requirements. EPA Form 7500-5 will be useful in this evaluation.

Operating and Maintenance Procedures

The plant's maintenance program can best be evaluated by comparing maintenance records at the plant with manufacturer's and O & M manual maintenance schedules for components. The plant maintenance system should be examined for the following:

- Preventive maintenance records
- The preventive maintenance schedule for each piece of equipment
- Specifications on each major piece of equipment, the supplier, and where spare parts can be purchased
- Spare parts list, and
- Instructions for operation and maintenance of each item of major equipment

Operating procedures checked should include:

- Sampling and analysis data logs (process control testing data sheets and trend charts)
- Daily operating logs

Staffing Levels

As part of the preparation for the on-site inspection, plant staffing data should have been gathered. As shown on EPA Form 7500-5, actual personnel (and their classification) should be compared with the number of persons budgeted and recommended for various types of treatment plant operations.

Costs

An analysis of costs and budgets should be included as part of the total plant performance evaluation.

DEFINITION OF PROBLEMS

In general, the problems detailed in Section 4 of the manual are those most often found for each unit process. However, the following procedures can be used for any kind of problem evaluation. The first step in troubleshooting is to determine if the plant is meeting design performance standards. This is done by comparing the plant effluent quality and overall efficiency with that listed on the design and/or discharge permit. If the plant does not always operate correctly, the problem usually falls under one of the following causes:

- Overloads (organic or hydraulic)
- Poor O & M procedures
- Poor staffing
- Poor laboratory control
- Mechanical/electrical failure
- Lack of money for O & M
- Outdated equipment

Once the problem area has been defined, the cause of the problem should be identified. For example, overload problems may be caused by infiltration, combined sewers, industrial growth, rapid population growth, increased service area, or some other cause.

The troubleshooting guide in Section 4 of this manual will help to identify and solve common problems with each unit process. For problems not covered in the manual, and if the evaluator is not able to solve the problem, a consultant should be hired.

REPORTING

To make sure the evaluation is complete and to help report the plant inspection, EPA Form 7500-5 may be used. Also, a final report should be prepared and should contain the following:

- Summary of on-site visit
- A list of problems found
- Solutions recommended
- Proposed action and other recommendations

USEFUL REFERENCES

The following reports, or other similar references may provide the plant evaluator or troubleshooter with more complete and detailed information.

1. "NPDES Compliance Evaluation Inspection Manual", EPA (Office of Water Enforcement, Compliance Branch) July,1976. Detailed information on EPA procedures and policies regarding plant inspections.

2. "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities", EPA Project 17090 DAN, October, 1971.

3. "Estimating Staffing for Municipal Wastewater Facilities", EPA Contract 68-01-0328, March, 1973.

4. "Considerations for Preparation of Operation and Maintenance Manuals", EPA 430/9-74-001, 1974.

5. "Maintenance Management Systems for Municipal Wastewater Facilities", EPA 430/9-74-004, October, 1973.

6. "Estimating Laboratory Needs for Municipal Wastewater Treatment Facilities", EPA 430/9-74-002, June, 1973.

SECTION 3

OVERALL SYSTEMS CONSIDERATIONS

The next Section of this manual presents process evaluation and troubleshooting information for each unit process. However, in evaluating plant performance, it must be understood that:

- Operating each unit process at its best does not always result in the best overall plant performance,
- The performance of one unit process is often related to other processes, and
- Failure or poor performance of one unit process can have bad effects on either upstream or downstream processes.

Because the number of potential combinations of unit processes in plant design is very large, it is not practical to discuss all potential plant designs. However, each unit process section contains a discussion of how a specific unit process performance can affect the overall plant performance.

Although the information on optimum unit process performance presented later is useful in evaluating a process, it is important to remember that each unit process must be operated to meet the needs of the other processes used in the plant. For example, if a sludge will burn without the need for added fuel at 30% solids, there is no need to operate a filter press feeding an incinerator to provide a 40% solids concentration - even though the filter press might easily reach such a concentration. Added costs would be associated for sludge conditioning and longer filter runs for the drier cake. It is possible to operate a sludge thickener so well that it will produce a sludge so thick that it will not readily pass through a downstream centrifuge. This is another example of how the operation of one process must be based on the other processes used in a plant.

The relationship between unit processes must be carefully considered in plant evaluation and troubleshooting. For example, a sudden increase in final effluent suspended solids may result from the failure of a chemical feed pump in the sludge conditioning system. Because of improper conditioning, a large amount of solids may be recycled to the treatment plant causing poor effluent quality. The source of the problem would be unrelated to the operation of the biological system or to the final clarifier. It requires understanding how one process affects another to trace the problem to a small pump in a part of the plant remote from where the operator first notices the problem. Jamming of mechanical surface aerators may be unrelated to the maintenance or operation of the aerators; for example, the cause could be rags and debris passing through the upstream screening process.

Failure or poor performance of a unit process may result in upstream or downstream problems - or both. The supernatant from a poorly operated anaerobic digester, for example, could cause odor problems when recycled to the upstream wastewater processes. The sludge withdrawn from the digester could also cause problems in the downstream sludge handling processes.

The above examples show the need to consider the relationships between processes in tracing problems and in plant evaluation. The location and amounts of flows recycled to the main wastewater treatment process is often the source of important information. The next section includes information on how each unit process can affect the overall system. It is important to consider the overall system when reviewing individual unit processes.

There are several aspects of the unit processes discussed in Section 4 which are covered in other available references or which are common to several unit processes. These aspects include staffing requirements, monitoring programs, emergency operating procedures, maintenance system considerations, and safety considerations. The following paragraphs discuss each of these aspects.

Staffing Requirements

An inadequate or improperly qualified staff can be a source of major operational problems. Staffing requirements for the operation and maintenance of various unit processes are presented in detail in the following two references:

"Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities", EPA Project 17090 DAN, October, 1971.

"Estimating Staffing for Municipal Wastewater Facilities", EPA Contract 68-01-0328, March, 1973.

Because of the many differences in personnel from plant to plant, the manpower estimates in these references should be used only as general guides. Should the troubleshooter see equipment out of operation or performing poorly due to lack of maintenance or poor housekeeping, he should investigate the level and quality of staffing. A high rate of personnel turnover may be caused by poor pay scales and poor management. Poor training programs will also contribute to operational problems.

Monitoring Programs

The troubleshooter should refer to the EPA publication "Estimating Laboratory Needs for Municipal Wastewater Treatment Facilities", (EPA

430/9-74-002, June, 1973) for information on monitoring programs for various unit processes as well as information on appropriate laboratory space, equipment and manpower.

Emergency Operating Procedures

The discussions of control considerations presented for each unit process in Section 4 tell how failure of one unit process can upset the control of upstream and downstream processes. Detailed mechanical/electrical problems depend on the equipment used at the plant and the troubleshooter should review the plant operations and maintenance manual to determine if it has detailed emergency instructions. Suggestions on plant operation during an emergency may be found in "Design Criteria for Mechanical, Electric, and Fluid System and Component Reliability", (EPA 430/9-74-001). Guidance on emergency planning may also be found in "Emergency Planning for Municipal Wastewater Treatment Facilities", (EPA 430/9-74-013).

Maintenance System Considerations

A sound maintenance management system can be a major factor in the successful long-term performance of a municipal wastewater system. The agency responsible for the wastewater system must give full support to the maintenance program if it is to be successful. The records from a good maintenance system are also very useful in preparing realistic budgets and in planning the needed supply of replacement parts. Where poor maintenance programs are a source of problems, the troubleshooter should refer to the following references for detailed guidance:

"Maintenance Management System for Municipal Wastewater Facilities", EPA 430/9-74-004, October, 1973.

"Considerations for Preparation of Operation and Maintenance Manuals", EPA 430/9-74-001, 1974.

"Operation of Wastewater Treatment Plants", Manual of Practice No. 11, Water Pollution Control Federation (1976) (Chapter 30).

Safety Considerations

Although safety problems do not usually cause poor process performance, the troubleshooter should look for hazardous conditions for both his protection and the protection of the operating staff. The following references will be useful:

"Safety in Wastewater Works", Manual of Practice No. 1, Water Pollution Control Federation (1969).

"Operation of Wastewater Treatment Plants", Manual of Practice No. 11, Water Pollution Control Federation (1976) (Chapter 31).

SECTION 4

UNIT PROCESS EVALUATION AND TROUBLESHOOTING INFORMATION

RAW SEWAGE PUMP STATIONS

Process Description

Many wastewater treatment plants need pump stations to provide flow of the wastewater through the treatment plant.

Where practical, grit removal and screening facilities are located ahead of the raw wastewater pumps in order to protect the pump. Since screening equipment, either of the bar screen or comminutor type, may be easily built in pumping station influent channels, such equipment is normally included in the station design. As a result, most raw sewage pumping facilities include the pumping station structure, pumping unit, screening facilities, controls, and discharge piping.

The most commonly used systems for raw sewage pumping include centrifugal pumps, screw lift pumps, and air lift ejectors. Centrifugal pumps can deliver a wide range of flows depending on their design, speed and total dynamic head. Most centrifugal pumps used for raw sewage pumping have smooth channels and impellers with large openings to allow a free-flowing condition and reduce the chances of clogging. Figure 2 shows how the centrifugal pump works.

Because of its simple open design, the screw lift pump is most often used for pumping unscreened raw wastewater. As shown in Figure 3, the general design is a semi-circular channel that is open at the top, with a revolving screw inside the channel. The screw normally rotates at speeds ranging from 20 to 110 rpm, and can produce 30 to 50 feet of head. Depending on the design and size of the screw, it is possible to reach pumping capacities up to 80,000 gpm.

Air lift ejectors are very useful for pumping raw, unscreened wastewater, since there are no moving parts to clog. As shown in Figure 4, the ejector has a sealed chamber with a cone-shaped floor, inlet and discharge lines with check valves, a compressed air inlet, an automatic air shut-off valve, and a vent valve for releasing the pressure in the chamber. As the raw wastewater fills the chamber and touches the electrode level detector, air is forced into the container and the wastewater is ejected through the discharge line.

Typical Design Criteria

Because of the many kinds of pump designs and capacity, the manufacturer's performance curves should be used to provide information on discharge, power requirements, and head characteristics for a specific pump.

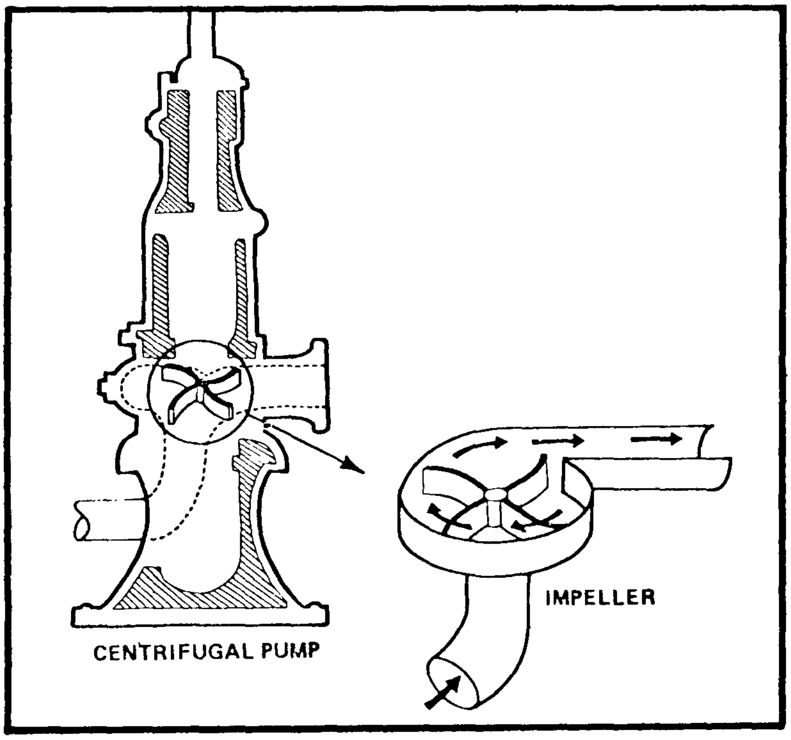


Figure 2. Centrifugal pump.

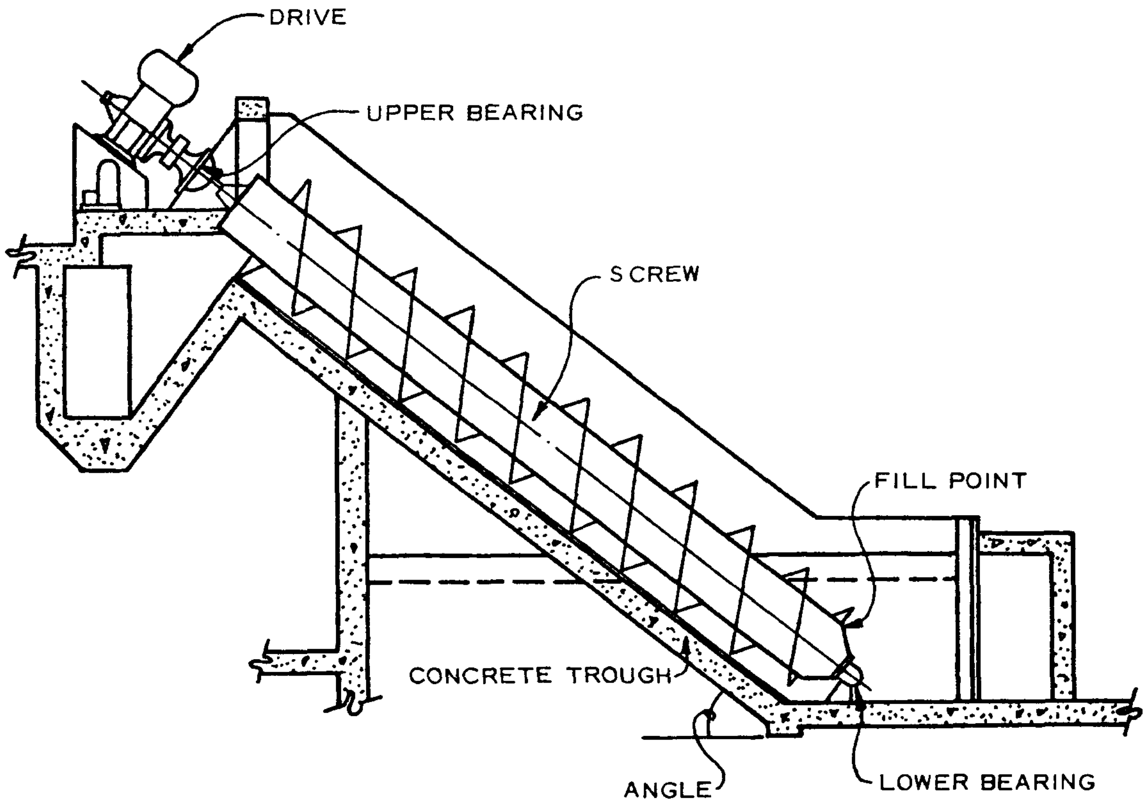


Figure 3. Screw pump.

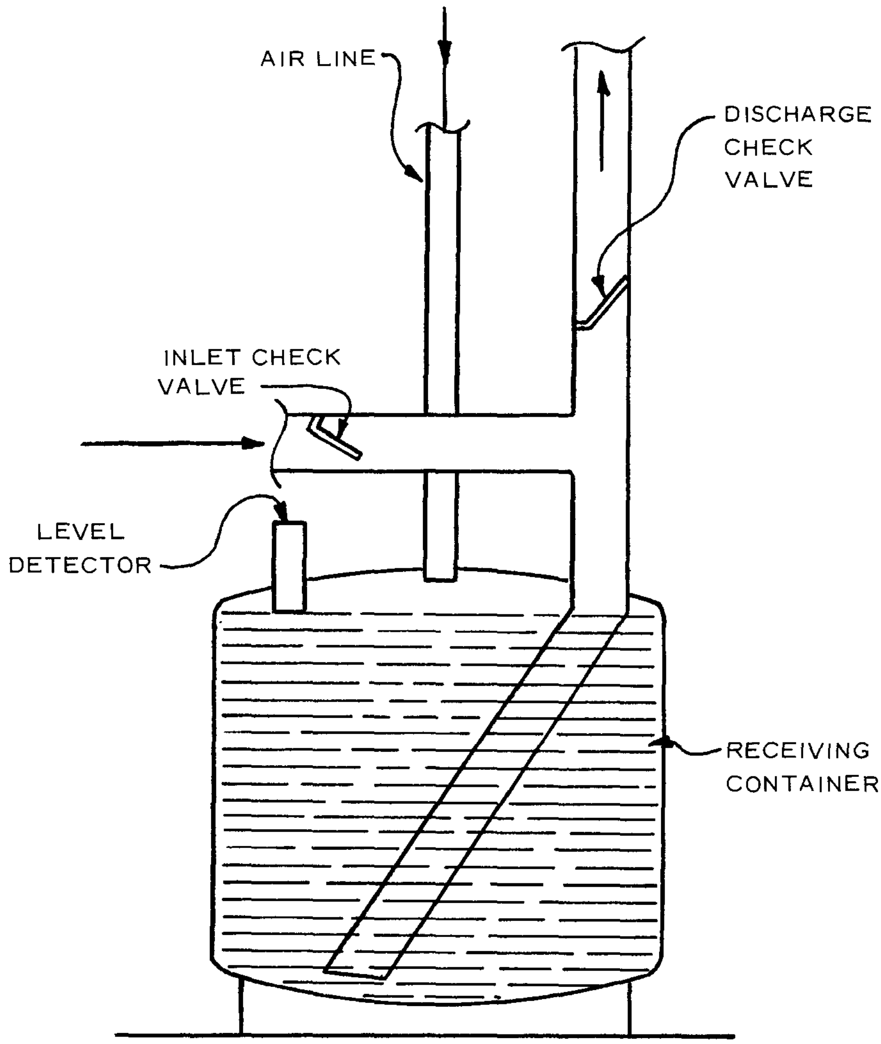


Figure 4. Air lift ejector.

To evaluate the performance of the pump station, the following should be checked:

1. Determine the physical conditions affecting pump operation.

Height of influent above pump (suction head)	= 10 ft
Height of pump effluent above pump (discharge head)	= 20 ft
Friction loss (f)	= 1 ft
Pump efficiency	= 90%
Motor efficiency	= 80%
Plant flow (mgd)	= 5 mgd
$\text{gal/min} = \dfrac{\text{mgd}}{24 \times 60}$	= 3472 gal/min

2. Determine the head characteristics that the pump is operating under.

Static head (ft) = Difference in elevation between discharge and suction
= 20 - 10 ft
= 10 ft

Total head, H (ft) = Static head + friction loss
= 10 + 1 ft
= 11 ft

3. Determine the horsepower characteristics of the pump and motor.

$$\text{Required pump HP} = \frac{(\text{flow in gal/min})\ (\text{total H in ft})}{3960} = \frac{(3472\quad(11)}{3960} = 9.64\ \text{HP}$$

$$\text{Required motor HP} = \frac{(\text{pump HP})}{(\text{pump efficiency})\ (\text{motor efficiency})} = \frac{9.64}{(.9)\ \ (.8)} = 13.4\ \text{HP}$$

4. Compare the actual computed head and power characteristics of the pump with those provided by the pump manufacturer. Check to see that the pump is not being forced to operate under conditions beyond its design.

5. The Shortcomings and Troubleshooting guide also may be useful in providing a visual inspection of proper pump operation.

Control Considerations

In many cases, raw sewage pump stations have screens or racks to protect pumps from abrasive material and objects that can plug the suction lines.

Pumping stations have an important effect on the overall performance of the treatment plant, since the flow through the plant depends on the pump capacity. Intermittent pumping during periods of low flow and frequent changes in pumping rates can cause process upsets. As a result, it is desirable for the pump capacity and storage capacity to be designed so that frequent stops and starts of the lead pump are avoided, and changes in pumping rates are minimal.

Flow rate in piping generally should range from 4 to 6 ft/sec. Velocities in excess of 10 ft/sec result in high lead loss, and velocities less than 2 ft/sec allow solids to settle out in the pipes.

Because pump stations are important in overall plant operation, spare parts should be kept on-site so that the pumps can be quickly repaired.

Common Design Shortcomings and Ways to Compensate

	Shortcoming	Solution
1.	Difficulty in handling high peak flows.	1. Provide standby pumps with automatic control.
2.	No preliminary screening or shredding provided prior to pumping may result in clogging.	2. Install screen in wet well prior to pumping.
3.	In wet-pit installations - explosive and corrosive gases are close to electrical motors and equipment.	3. Construct a separate compartment, (dry well) for this equipment.
4.	Float control systems for measuring levels in wet wells may become greasy.	4. Install air bubbler control system.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Black and odorous septic wastewater.	1a. Improper operation of lift station.	1a. Inspect lift station.	1a. Repair lift station.
	1b. Flat grades in collection system.	1b. Velocity in collecting lines.	1b. Flushing program to maintain correct velocities.
2. Intermittent flow or surging.	2a. Improper wet well sensor adjustment.	2a. Check sensor adjustment.	2a. Adjust level sensors.
	2b. Hydraulic capacity of station is exceeded.	2b. Check designed capacity.	2b. Install surge tank.
	2c. Illegal connections to the system.	2c. Check sanitary sewer system to determine the source.	2c. Remove and prevent illegal connections.
3. Intermittent flow or surging during heavy rainfall.	3a. Flooded streets and water entering through manholes.	3a. Check seals on manholes.	3a. Seal manholes and repair cracks in manhole structures.
	3b. Broken lines.	3b. Inspect for broken lines.	3b. Repair broken lines.
4. Pump not running.	4a. Defective control circuit.	4a. Use a meter to check switching circuits.	4a. Replace defective part.
	4b. Defective motor.	4b. Motor operation.	4b. Replace motor.
5. Pump not running, circuit breaker will not reset.	5a. Clogged pump or closed valve.	5a. Inspect pump for obstruction.	5a. Remove obstruction.
6. Pump is running, but reduced discharge.	6a. Pump air-bound.	6a. Air bleed pipe.	6a. Remove obstruction.
	6b. Clogged impeller.	6b. Inspect for obstructions.	6b. Remove obstruction.
	6c. Wearing rings.	6c. Check clearance.	6c. Replace worn rings.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
7. Clogged pump or pump suction line.	7a. Grease accumulations.	7a. Check grease accumulation on walls of wet well.	7a. Frequent cleaning of wet well or removal of grease by dewatering the well, and scraping the bottom.
8. Rising power consumption per gallon.	8a. Clogged pump.	8a. Total daily pumpage and maximum and minimum flow rates.	8a. Remove obstruction in pump.
	8b. Misaligned belt drives.	8b. Alignment.	8b. Realign belt drive.
9. Improper liquid levels.	9a. Coating on liquid high probes.	9a. Probe.	9a. Clean probe.
	9b. Hang-ups in float level detectors.	9b. Float detector.	9b. Remove obstruction, release float.
	9c. Leaks in bladders.	9c. Bladder.	9c. Repair or replace bladder.
	9d. Fouling in bubbler controls.	9d. Bubbler.	9d. Clean bubbler.
10. Excessive wear or damage to pumps.	10a. Sand accumulations in wet well.	10a. Inspect for eroding action, corrosion, and solids build up.	10a. Remove sand from wet well.
	10b. Grease accumulations in the wet well.	10b. Inspect wet well walls.	10b. Clean wet well. (see 7a. solution)

SCREENING

Process Description

As wastewater enters a plant for primary treatment, it flows through a screen which removes the large floating objects such as rags, sticks, and other items that may clog pumps and small pipes. Screens may be coarse or fine. Coarse screens are typically made of parallel steel or iron bars with spacings ranging from 2 to 4 inches. Fine screens, on the other hand, consist of perforated plates, woven wire cloth or closely spaced bars. When fine bar screens are utilized, the spacing may range from 0.75 to 2.0 inches. As shown in Figure 5, screens are often placed in a chamber or channel in a slanted position in order to make the cleaning process easier. The debris is caught on the upstream surface of the screen and can be raked out manually or mechanically. Most wastewater treatment plants utilize mechanical cleaning rather than manual cleaning to reduce labor costs and provide better flow conditions (see Figure 6).

The three most commonly used fine mesh screen systems are the traveling water screen, the static screen and the rotating drum. The traveling screen has wire mesh panels attached to a conveyor belt system with steps or shelves located at the lower edge of each panel, where heavier material is allowed to collect. The panels of the screen usually are set in the vertical position. The channels usually range in width from 2 to 10 ft. As the panels are raised to the top of the unit, a high pressure spray washes the debris from the screen and drops it into a collecting bin where it can be easily removed.

Like bar screens, static screens are slanted at an angle, but with openings ranging from 0.09 to 0.25 inches.

In the rotating drum system (Figure 7), a large drum is covered with a fine mesh screen and partially submerged in the wastewater stream. The screening material usually is a layer of wire cloth; however, heavy backup screens sometimes are used to provide extra strength. As the drum rotates, the wastewater filters through the mesh and allows material to accumulate on the surface. The accumulated solids are then continuously removed from the unsubmerged portion of the drum using a high pressure spray of water.

Typical Design Criteria and Performance Evaluation

Figure 8 shows typical design data for various classifications of screens. These data may be used by the plant evaluator to compare actual plant screening performance to typical design performance. Since screens are primarily used to protect downstream equipment from damage, the

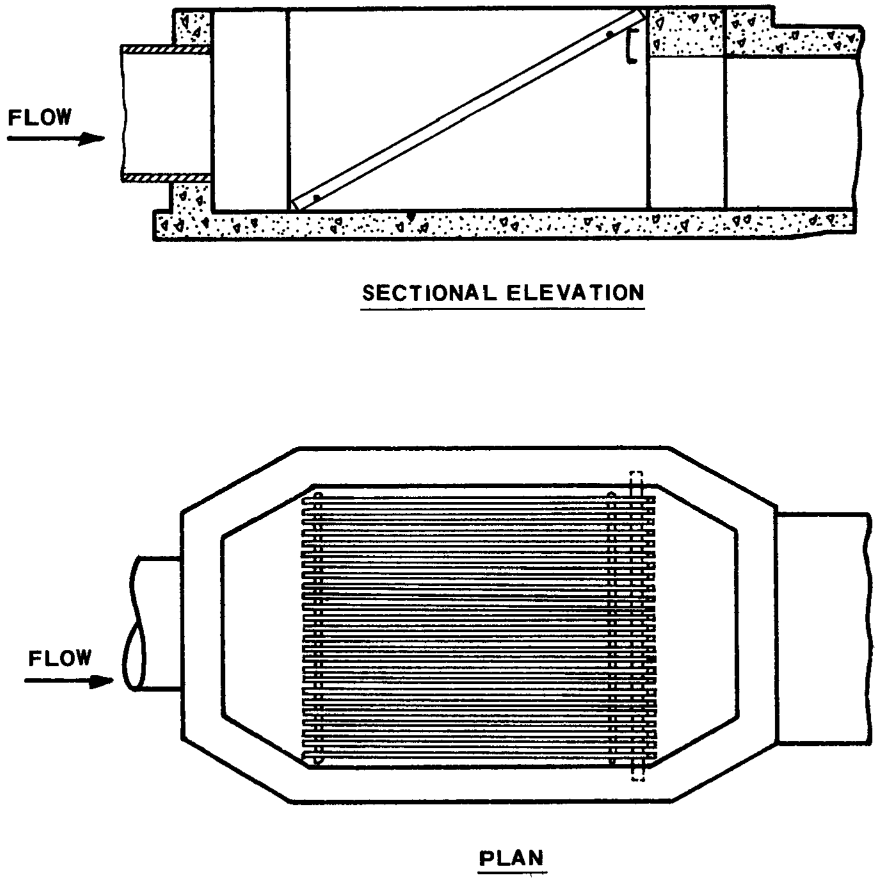


Figure 5. Bar screen.

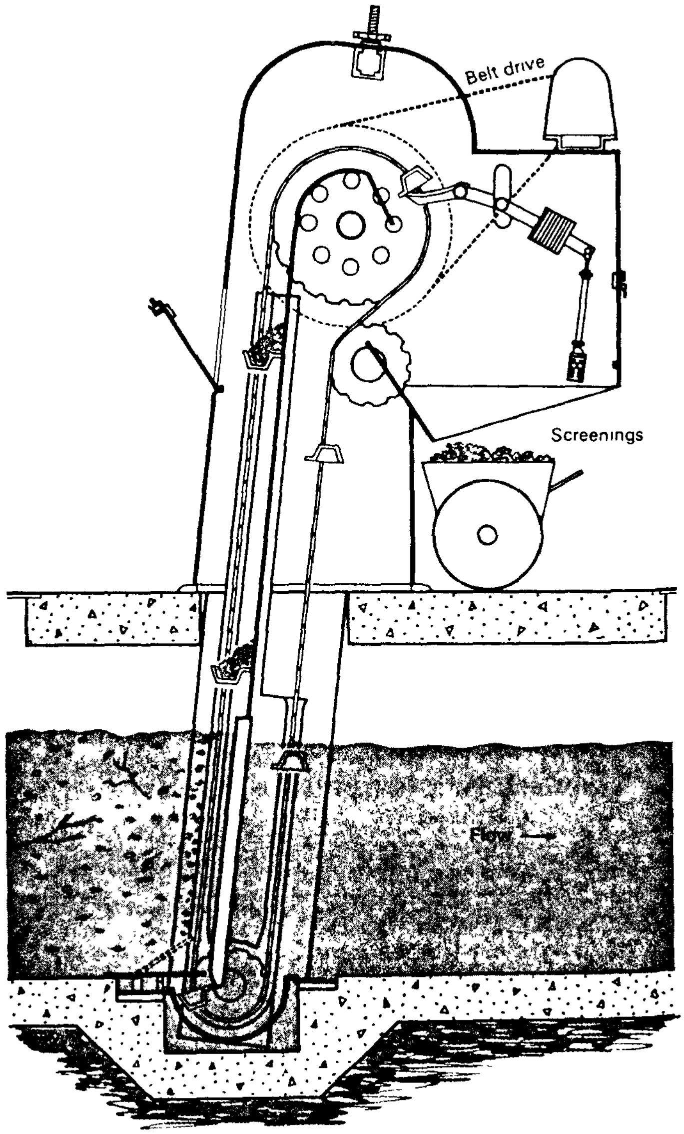


Figure 6. Mechanically cleaned screen.

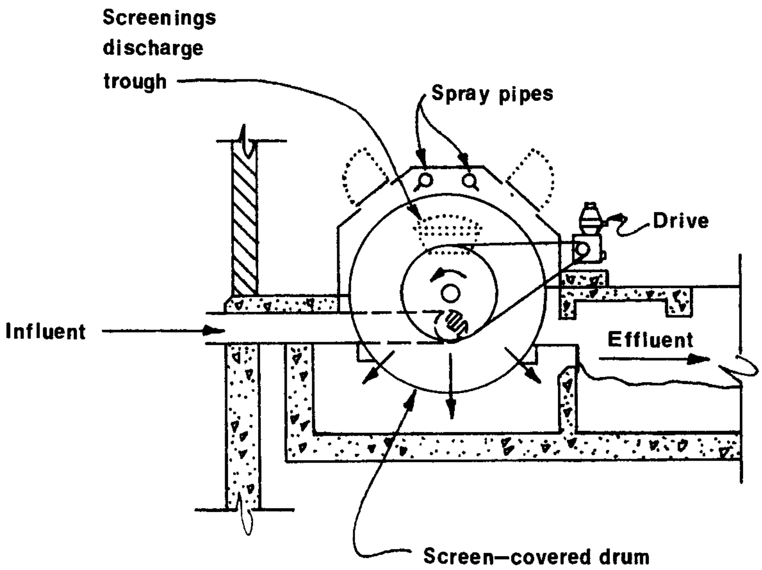


Figure 7. Fine screen mounted on a drum.

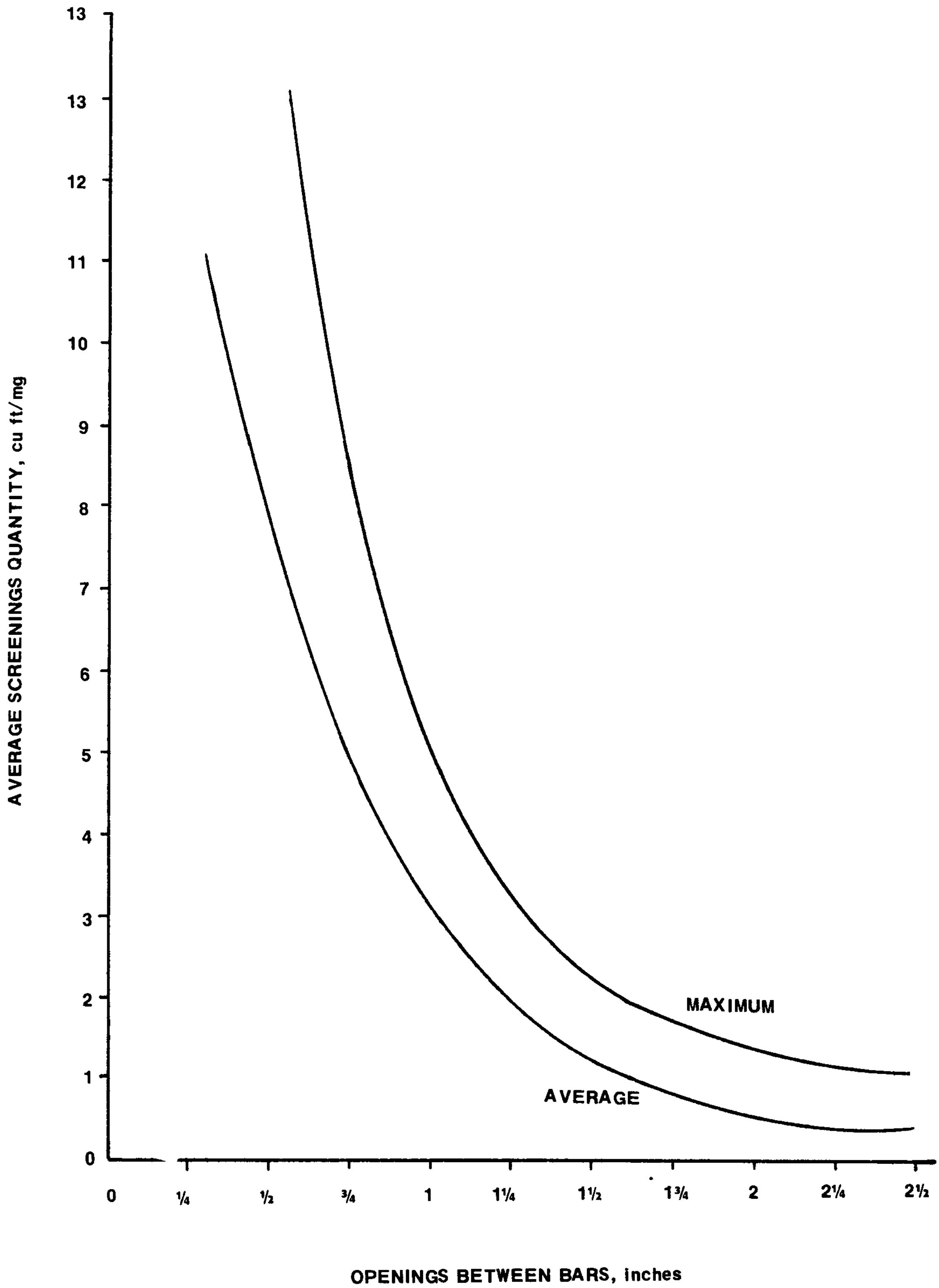


Figure 8. Mechanically cleaned bar screen. (Cubic feet of screenings per million gallons sewage).

evaluator should check equipment repair records to see if poor screen operation has resulted in damage to other plant equipment. The evaluator should also check the shortcomings and troubleshooting guide for visual inspection of screen performance.

Control Considerations

Screens are used to collect material which will block flow. Therefore, if a screen is not cleaned often enough, water will back up in the channel leading to the screen, resulting in surges of high flow after the screen has been cleaned. These conditions can cause problems in clarifier and aeration tanks which may follow the screening process.

The velocity of flow ahead of and through the screen affects its operation. Generally, flows of 2 to 4 ft/sec are acceptable.

The efficient design and operation of screening facilities are essential to overall plant performance, especially where no shredding or grinding units are provided. Poorly screened debris will damage equipment and will interfere with good operation of other processes.

Common Design Shortcomings and Ways to Compensate

Shortcomings	Solution
1. Debris suddenly accumulates on screen and clock-operated timers set for automatic timed operation of screen rakes do not remove debris fast enough.	1. Pressure-sensitive bubbler systems may be installed in parallel with the timer in order to activate the raking mechanism when unusual quantities of debris accumulate.
2. Storage and separate disposal of screened debris is causing problems.	2. Install a comminutor.
3. Front cleaned bar screens become jammed at the bottom.	3. Provide back cleaning device.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Obnoxious odors, flies, and other insects.	1a. Accumulation of rags and debris.	1a. Method and frequency of debris removal.	1a. Increase frequency of removal and disposal.
2. Excessive grit in bar screen chamber.	2a. Surging in chamber due to increased water level. 2b. Flow velocity too low.	2a. Depth of grit in chamber, irregular chamber bottom. 2b. Flow velocity.	2a. Remove bottom irregularity, or reslope the bottom. 2b. Increase flow velocity in chamber or flush regularly with a hose.
3. Excessive screen clogging.	3a. Unusual amount of debris in wastewater.	3a. Screen size and velocity of wastewater through screen.	3a. Use a coarser screen, or identify source of waste causing the problem so its discharge into the system can be stopped.
4. Mechanical rake inoperable, circuit breaker will not reset	4a. Jammed mechanism.	4a. Screen channel.	4a. Remove obstruction.
5. Rake inoperative, but motor runs.	5a. Broken chain or cable. 5b. Broken limit switch.	5a. Inspect chain. 5b. Inspect switch.	5a. Replace chain or cable. 5b. Replace limit switch.
6. Rake inoperative, no visible problem.	6a. Defective remote control circuit. 6b. Defective motor.	6a. Check switching circuits. 6b. Check motor operation.	6a. Replace circuit. 6b. Replace motor.

SHREDDING AND GRINDING

Process Description

Shredders and grinders are used to reduce the size of objects in a wastewater stream before treatment. Some plants use a comminutor which combines the functions of a screen and grinder at the same time. In this system, debris is shredded and then returned to the wastewater stream as shown in Figure 9.

There are two general types of shredders and grinders. In one design, the whole wastewater stream flows through the unit and all material is automatically shredded. In the second type, called a barminutor, shredders and grinders are used with coarse bar screens (Figure 10). Comminutors of this type are generally one of two of the following designs: (1) the shredder or grinder may be attached to the top of the mechanically cleaned bar screen where large objects are automatically dropped into the hopper of a shredder, and (2) revolving cutters may be employed which slide up and down the face of the screen, shredding objects which accumulate.

Typical Design Criteria and Performance Evaluation

Comminutors generally have capacities ranging from 0.35 to 25 mgd. They are typically capable of handling 650 to 5,200 lbs of waste per hr.

A simple evaluation of shredders and grinders should include:

1. Observe flow and cutting action of shredder or grinder. Plugging may occur if rags and debris are not properly cut up.

2. Check maintenance records for regular sharpening and adjustment of teeth.

3. Read the shortcomings and troubleshooting guide for any problems that may appear.

Control Considerations

If screenings are not properly ground or shredded, serious problems may occur in downstream treatment processes. For example, grit chambers could become clogged or subject to odors as a result of submerged rags and debris. In addition, pumps and suction lines could become clogged, and pump impellers damaged by poorly shredded material. Mechanical surface aerators also may become clogged with rags and debris.

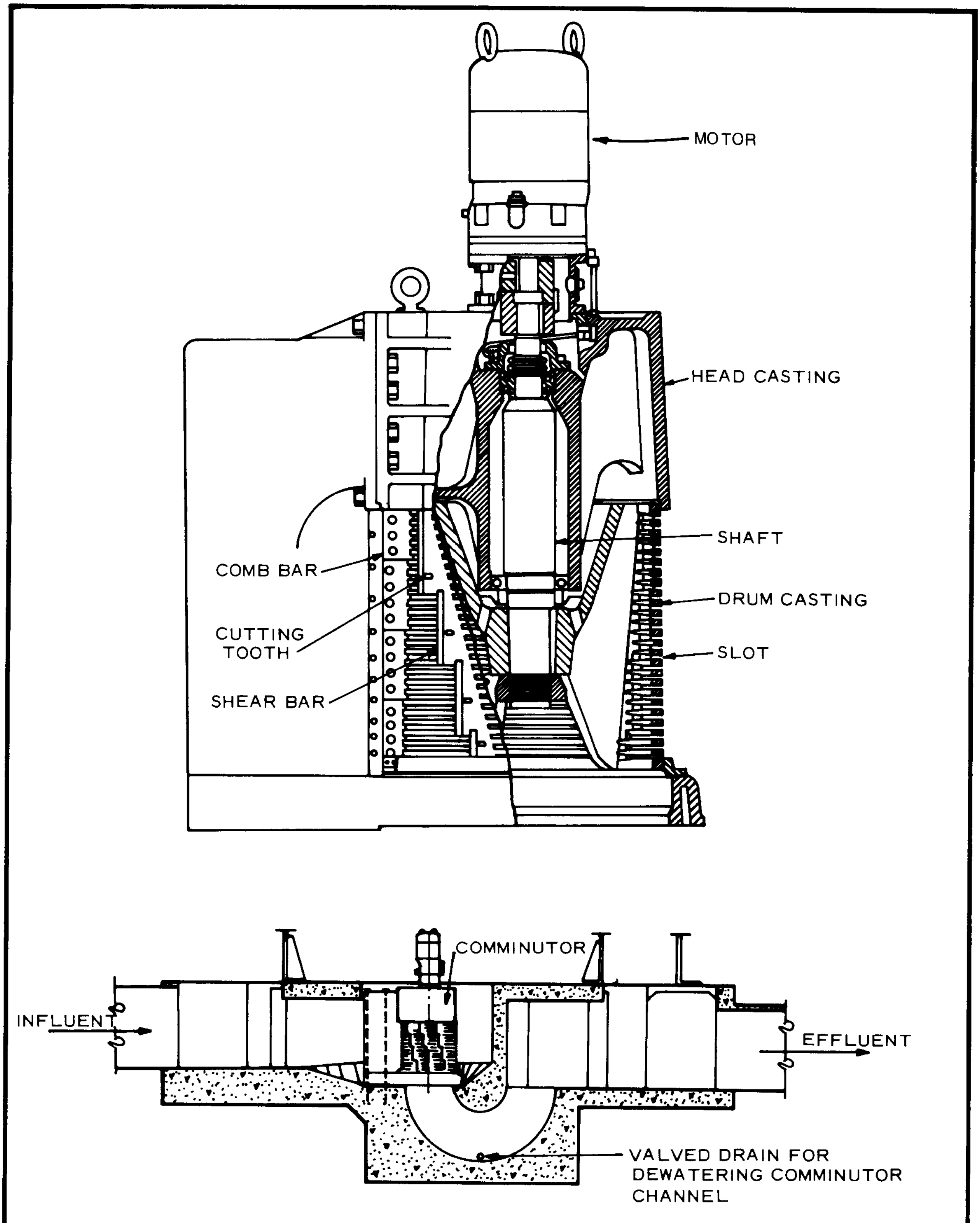
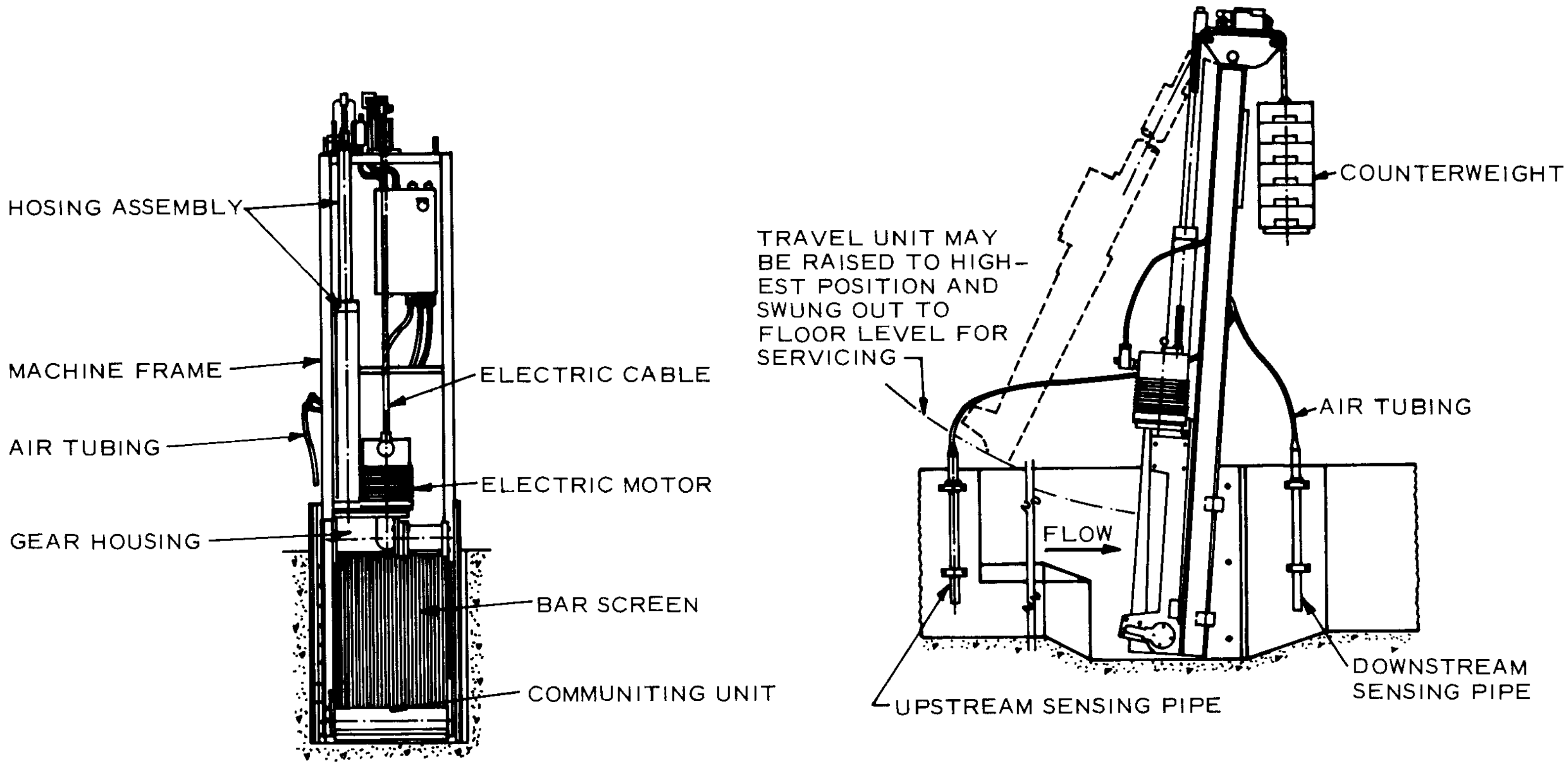


Figure 9. Typical rotating comminutor.



FRONT ELEVATION **SIDE ELEVATION**

Figure 10. Typical bar screen comminutor unit.

Failure of shredders and grinders can be minimized by proper, regular maintenance. Regular resharpening and readjustment of cutting teeth and cutting edges is one maintenance item that can reduce the chances of problems occuring in downstream treatment processes.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. No provision made for by-passing malfunctioning comminutor - sewage overflows channel.	1. Install by-pass channel with manually cleaned screen.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. System inoperable, circuit breaker will not reset.	1a. Jammed mechanism.	1a. Check for obstructions.	1a. Remove obstruction.
2. System inoperable, but motor runs.	2a. Broken coupling.	2a. Check coupling.	2a. Replace coupling.
3. Receiving chute clogged.	3a. Insufficient wash	3a. Wash water feed rate.	3a. Open valve to provide more water.
	3b. Broken swing hammer blades.	3b. Inspect blades.	3b. Remove broken pieces and replace blades.
4. Output coarser than usual.	4a. Dull blades.	4a. Check blades.	4a. Sharpen or replace blades.
	4b. Broken teeth.	4b. Check teeth.	4b. Replace broken teeth.

GRIT REMOVAL

Process Description

After wastewater has been screened, it usually passes into a grit chamber where sand, grit, cinders, small stones and other material settle out. Grit removal is an important process for a number of reasons: (1) to prevent clogging in pipes and problems in pumping sludge, (2) to prevent cementing effects on the bottom of sludge digesters and primary sedimentation tanks, (3) to protect moving mechanical equipment and pumps from unnecessary wear and abrasion, (4) to reduce accumulations of materials in aeration tanks and sludge digesters which would result in loss of usable volume.

Grit removal equipment can be velocity controlled, aerated, or of the cyclone degritter type. Velocity controlled grit removal systems have chambers which can be either manually or mechanically cleaned. As shown in Figure 11, these systems usually are square or rectangular with a flow control device and a chain-and-flight mechanism to move the grit into a sump for later disposal. The grit is then removed from the sump using a pump or bucket elevator.

Aerated grit removal systems (Figure 12) inject air into a chamber to produce a spiral-type flow in the wastewater. The air flow is adjusted to a low enough velocity to allow the grit to settle out.

Cyclone degritters use centrifugal force in a cone-shaped unit to separate grit from the rest of the wastewater. In this system, the wastewater is fed into the degritter at the edge of the upper end. This feed creates a vortex that forces the heavier grit particles to the outside of the rotating flow stream. The grit stream then falls into a grit washer and the degritted flow leaves the cyclone degritter through an opening near the top of the unit where it is channeled for further treatment.

Figure 13 shows a cyclone degritter and the location of the feed inlet, degritted effluent, and grit removal drain. Since there are no moving parts in the cyclone, the pump which feeds the wastewater into the system creates the vortex flow. As a result, characteristics of the slurry, particularly its viscosity, determine how well the process works. The size of the upper and lower orifices may require changing after the system has been installed.

Removed grit or gravel is usually washed clean to remove organics prior to its disposal in a landfill.

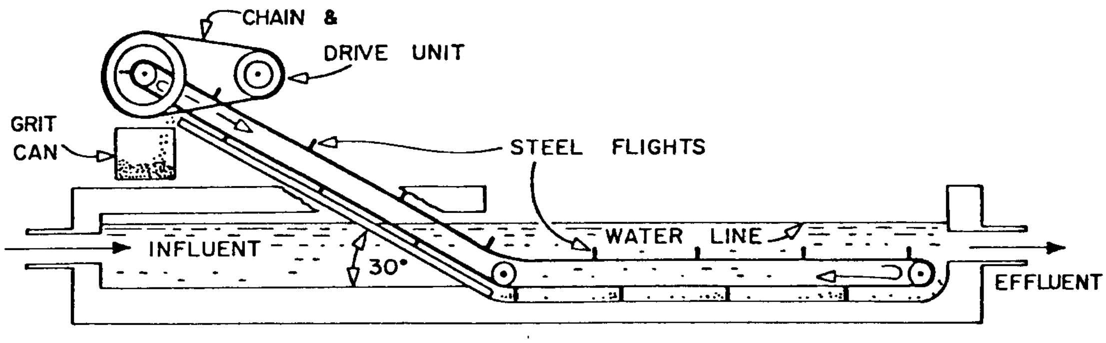


Figure 11. Chain and flight grit collector section.

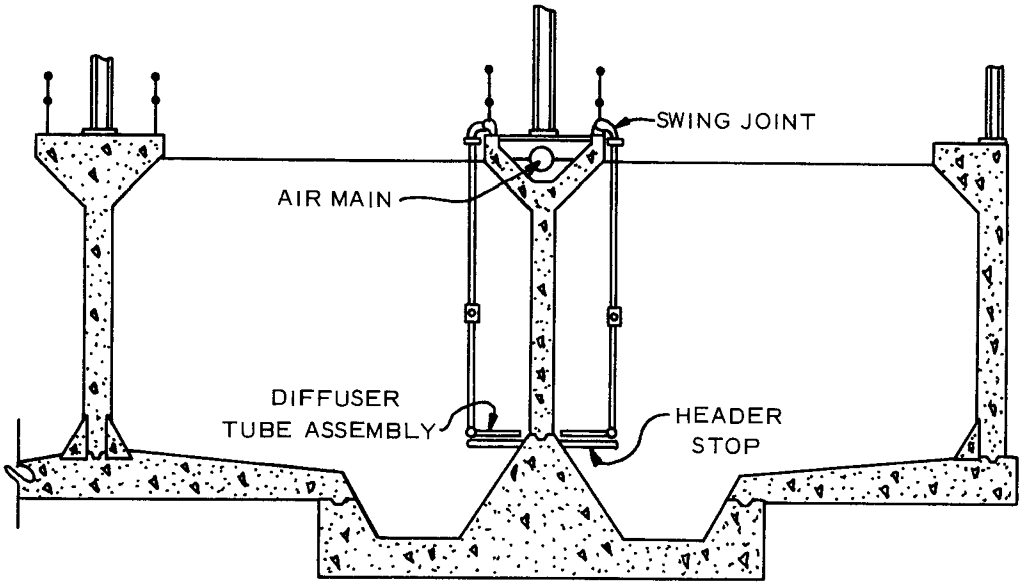


Figure 12. Typical cross section of an aerated grit chamber.

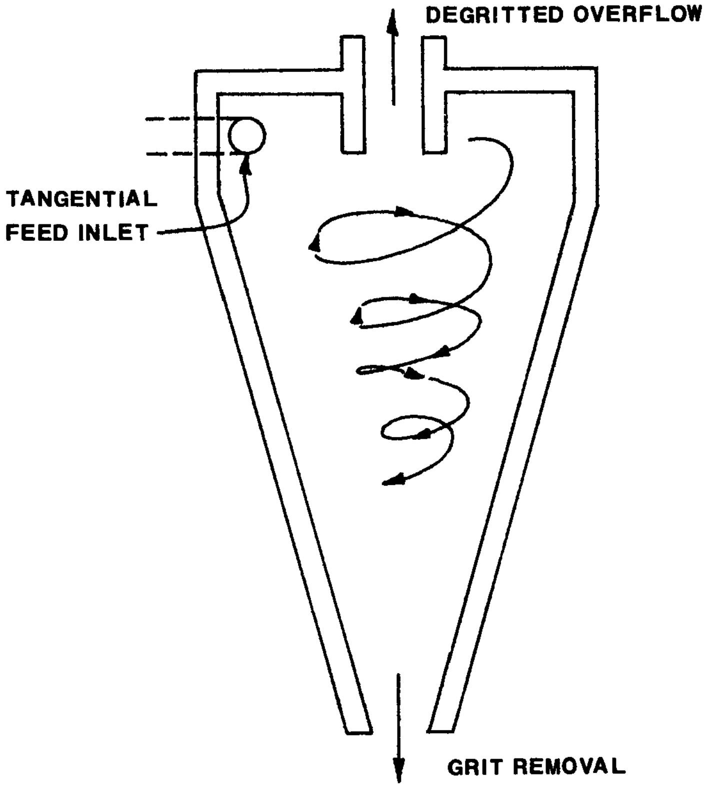


Figure 13. Cyclone degritter.

Typical Design Criteria and Performance Evaluation

Typical loading and performance data for air injected grit removal systems are presented in Table 1. The plant evaluator can use this information as a general guide for evaluating the performance of the actual grit removal system he is evaluating. The shortcomings and troubleshooting guide also should be read if any problem is noted during the plant evaluation.

Control Considerations

Inadequate grit removal causes wear on pipes and other downstream equipment. In determining how to best operate the grit removal unit, the fact that the grit removal equipment wears out faster at an increased grit removal efficiency, must be weighed against the improved downstream equipment life.

When operating velocity-controlled degritters, the scrapers should be operated at a low speed while the bucket elevator should function at a rate fast enough to remove the collected grit. Improper speed control will result in damage, due to grit packing in the basin.

In aerated grit removal systems, the operator must control the air flow into the grit chamber. The air rate must be adjusted to create a velocity near the floor of the chamber, low enough to allow the grit to settle, but high enough to prevent organic material from being removed with the grit.

TABLE 1. AERATED GRIT REMOVAL

Parameter	Typical operating ranges
Transverse velocity at surface	2 - 2.5 ft/sec
Depth to width ratio	1.5/1 - 2/1
Air supply	3 - 5 ft^3/min/ft of length 0.04 - 0.06 ft^3/gal
Detention time	3 - 5 min
Quantity of grit	1 - 10 ft^3/MG
Quantity of scum (skimmings)	1 - 6 ft^3/ MG

Common Design Shortcomings and Ways to Compensate

	Shortcoming		Solution
1.	Aerated grit chamber may be subject to short-circuiting.	1.	Install submerged baffles next to diffusers or along the wall opposite the diffusers.
2.	Increased removal of grit may result in increased removal of organic materials which cause objectionable odors.	2.	Install and properly operate grit washer equipment.
3.	Corrosion of metal work and concrete.	3.	Install blowers and gas scrubbers for oxidizing gases and reducing corrosive atmosphere.
4.	Grit storage hoppers equipped with slide gates may become clogged.	4.	Provide hopper with flushing water.
5.	Excessive wear on the bucket elevator of mechanically cleaned chambers may occur.	5.	Wear can be reduced by one or more of the following modifications: a) Use cast nylon or other strong and light-weight buckets. b) Install a jet to spray water to wash the emerging chain of grit which may be lodged in links.
6.	Excessive wear on shoes and rails of mechanically cleaned chambers may occur.	6.	Attach polyurethane floats to flights in order to reduce their weight and which would otherwise increase wear.
7.	Bottom scour may reduce grit chamber efficiency.	7.	In non-mechanical chambers, removable partitions or floor gratings between storage section and flow-through section may be installed.
8.	Jamming and clogging of equipment.	8.	Install screens and/or grinders ahead of grit chamber.
9.	Excessive deposition of grit in inlet distribution flumes.	9.	Aerate inlet flume.
10.	Unpleasant duties of handling grit.	10.	Install mechanically-cleaned grit chambers, and automatic removal of grit into storage hoppers to reduce handling.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Grit packed on collectors.	1a. Collector operating at excessive speeds.	1a. Collector speed.	1a. Reduce collector speed.
	1b. Bucket elevator or removal equipment operating at slow speeds.	1b. Removal system speed.	1b. Increase speed of grit removal from collector.
2. Too much vibration of cyclone degritter.	2a. Obstruction in the lower port.	2a. Lower port.	2a. Remove obstruction.
	2b. Obstruction in the upper port.	2b Too much flow in lower end.	2b. Reduce flow.
3. Rotten egg odor in grit chamber.	3a. Hydrogen sulfide formation.	3a. Sample for total and dissolved sulfides.	3a. Wash chamber and dose with hypochlorite.
	3b. Submerged debris.	3b Inspect chamber for debris	3b. Wash chamber daily.
4. Corrosion of metal and concrete.	4a. Inadequate ventilation.	4a. Ventilation	4a. Increase ventilation (also see Shortcomings).
5. Removed grit is grey in color, smells and feels greasy.	5a. Improper pressure on cyclone degritter.	5a. Discharge pressure on cyclone degritter.	5a. Keep pressure between 4 and 6 psi by governing pump speed.
	5b. Inadequate air flow rate.	5b. Check air flow rate.	5b. Increase air flow rate.
	5c. Grit removal system velocity too low.	5c. Use dye releases to check velocity.	5c. Increase velocity in grit chamber.
6. Surface turbulance in aerated grit chamber is reduced.	6a. Diffusers covered by rags or grit.	6a. Diffusers.	6a. Clean diffusers.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
7. Low recovery rate of grit.	7a. Bottom scour.	7a. Velocity.	7a. Maintain velocity near 1 ft/sec.
	7b. Too much aeration.	7b. Aeration.	7b. Reduce aeration.
	7c. Not enough retention time.	7c. Retention period.	7c. Increase retention time.
8. Overflowing grit chamber.	8a. Pump surge problem.	8a. Pumps.	8a. Adjust pump controls.
9. Septic waste with grease and gas bubbles rising in grit chamber.	9a. Sludge on bottom of chamber.	9a. Grit chamber bottom.	9a. Wash chamber daily.

PRIMARY CLARIFICATION

Process Description

With screening and grit removal finished, the wastewater still contains large amounts of settleable and floatable solids. Primary clarifiers are tanks used to remove or reduce suspended solids and organic loading from the wastewater before it goes to secondary treatment units.

The principal objectives of primary clarification are:

1. Removal of settleable solids.

2. Removal of floatable solids.

Clarifiers may be rectangular, square, or circular in shape. In rectangular tanks, the wastewater flows from one end to the other and the settled sludge is moved to a hopper at one end, either by flights set on parallel chains (Figure 14), or by a single bottom scraper set on a traveling bridge (Figure 15). Floating materials such as grease and oil, are collected by a surface skimmer and then removed from the tank.

In circular tanks (Figure 16), the wastewater usually enters in the middle and flows toward the outside edge. Settled sludge is pushed to a hopper that is in the middle of the tank bottom, and floating material is removed by a surface skimmer connected to the sludge collector.

A number of factors affect the performance of sedimentation tanks, including the following:

1. Rate of flow through the clarifier tank expressed in terms of gallons per day per square foot of surface area of the tank.

2. Wastewater characteristic (wastewater strength, freshness, and temperature; types and amount of industrial waste; and the density, shapes, and sizes of particles).

3. Pretreatment operations (carryover of grit and screenings).

4. Nature and amount of any in-plant wastes recycled to the plant ahead of the primary clarifier.

Typical Design Criteria and Performance Evaluation

Figure 17 shows how much BOD and suspended solids can be removed from

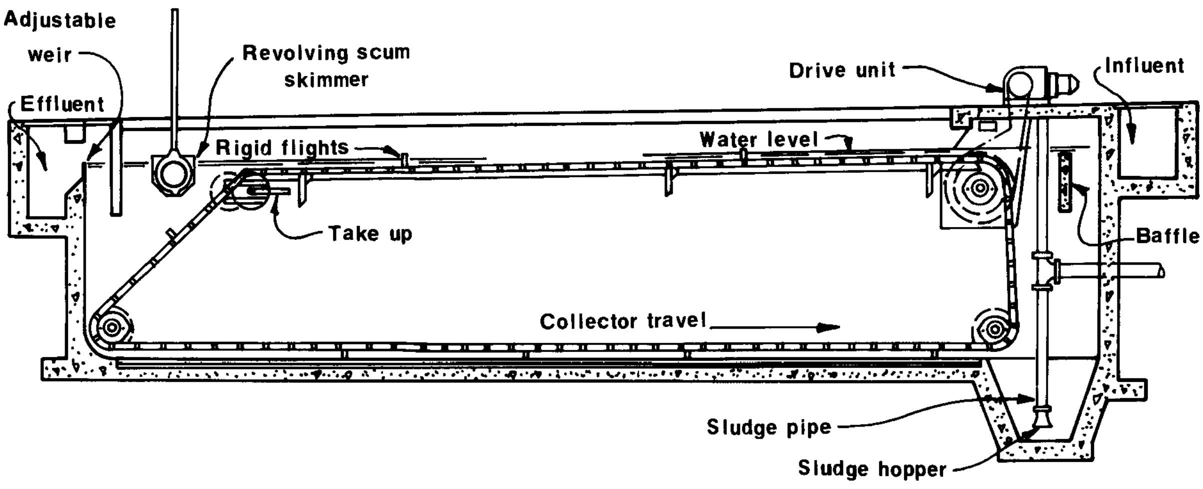


Figure 14. Rectangular basin, chain sludge collector.

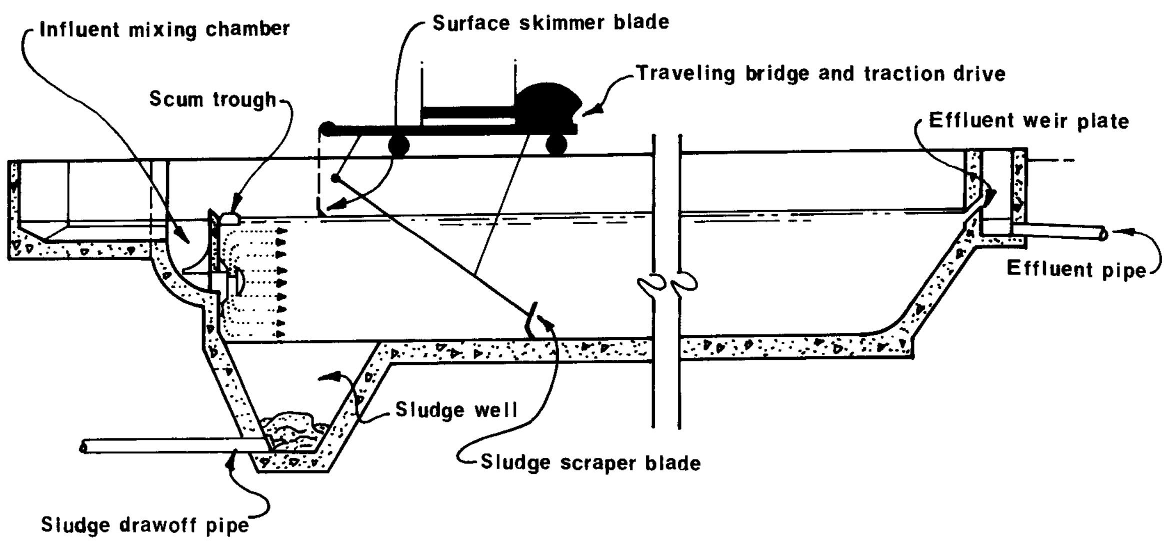


Figure 15. Rectangular basin, traveling bridge collector.

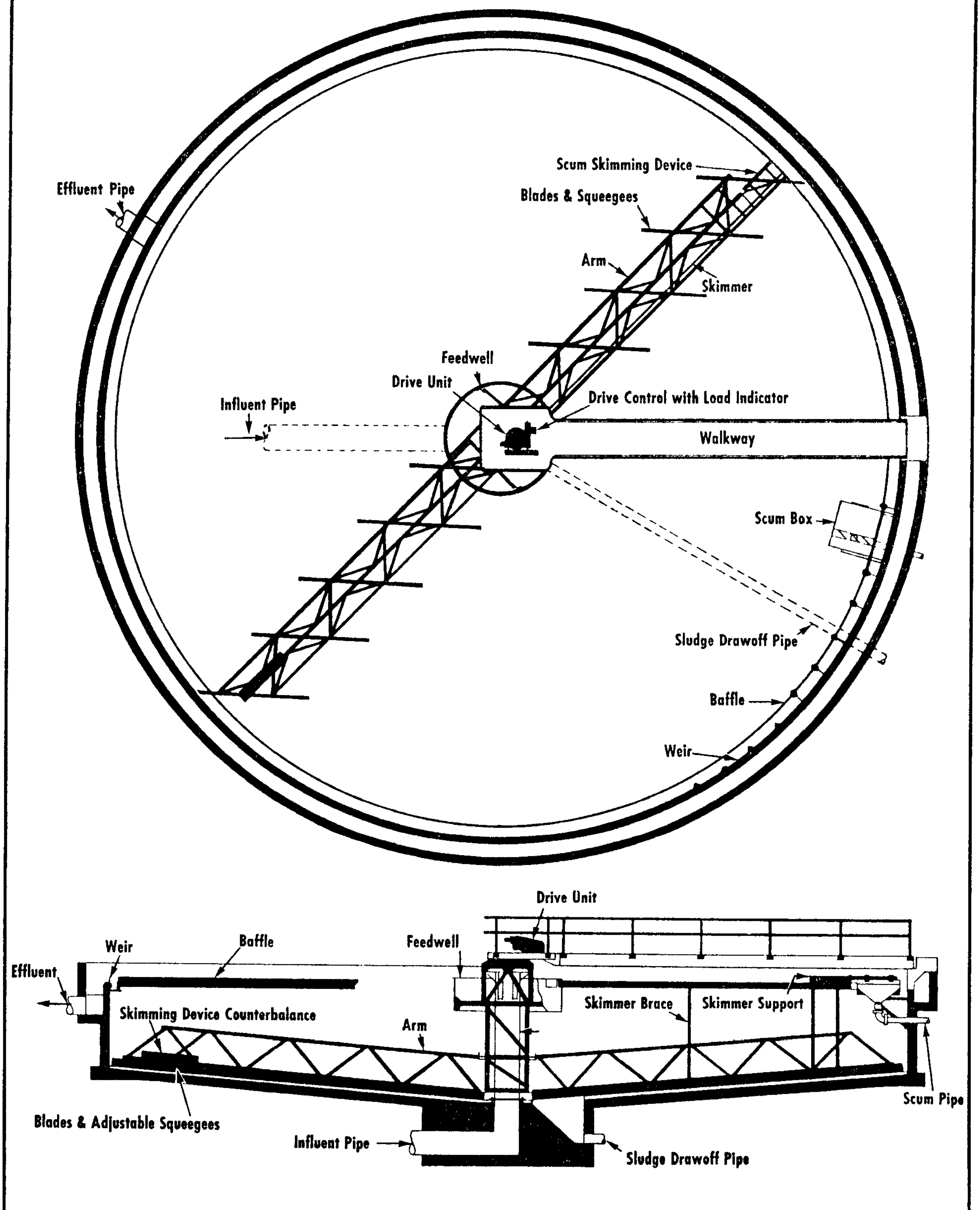


Figure 16. Circular basin.

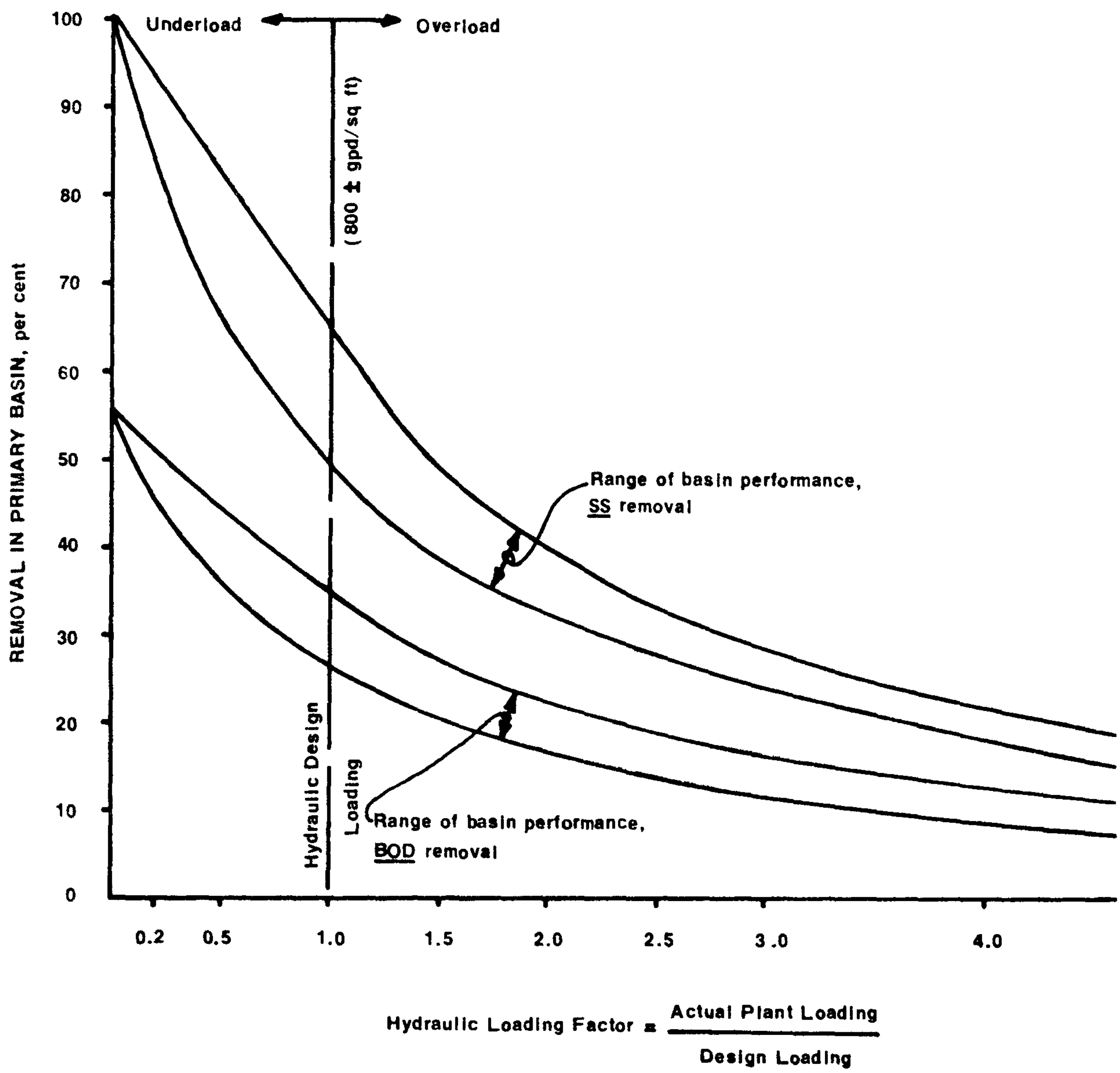


Figure 17. Estimated removals of suspended solids and BOD in primary basins at various hydraulic loadings.

wastewater in a primary clarifier using the ratio of actual to design flow. The figure shows a design overflow rate of 800 gpd/sq ft. Because of the fixed size of the tank, the overflow flow rate and detention time will change with flow, resulting in variable removal efficiencies. Design overflow rates usually expected for primary clarifiers are in the range of 600-1,000 gpd/sq ft. The clarifier depth (usually 10-15 ft) should be set to provide a detention time of 90 to 150 minutes.

Procedures for evaluating the performance of a primary clarifier are illustrated in the following example:

1. Determine clarifier configuration, dimensions and design criteria.

Circular		
Diameter, dia.	=	100 ft
Depth, D	=	12 ft
Clarifier area, $A = (\pi/4)\ dia^2$	=	7,850 sq ft
Clarifier volume, $V = A \times D \times 7.48$	=	704,616 gal
Design surface loading rate	=	800 gpd/sq ft

2. Determine total clarifier flow.

Total = Influent Flow + Recycle Flow
Daily Average: 6 mgd + 0.5 mgd = 6.5 mgd
Peak Hour: 8.5 mgd + 0.5 mgd = 9.0 mgd

3. Determine actual hydraulic surface loading rate (both daily average and peak hour) for clarifier.

$$\text{Hydraulic Surface Loading Rate} = \frac{\text{flow in gal/day}}{\text{surface area in sq ft}}$$

$$\text{Daily Average Loading Rate} = \frac{6{,}500{,}000}{7{,}850} = 828 \text{ gpd/sq ft}$$

$$\text{Peak Hour Loading Rate} = \frac{9{,}000{,}000}{7{,}850} = 1{,}146 \text{ gpd/sq ft}$$

4. Determine actual detention time for clarifier.

$$\text{Detention Time} = \frac{(\text{volume in gal}) \times 24 \text{ hr/day} \times 60 \text{ min/hr}}{\text{flow in gal/day}}$$

$$= \frac{704{,}616 \times 24 \times 60}{6{,}500{,}000}$$

$$= 156 \text{ minutes}$$

5. Compare actual clarifier operational data with typical design criteria.

Parameters	Actual	Typical Design
Average daily hydraulic loading, gpd/sq ft	828	600 - 1,000
Peak hour hydraulic loading, gpd/sq ft	1,146	1,200 - 2,500
Detention Time, min	156	90 - 150

6. Determine the ratio of actual plant loading to design loading. Use this ratio to predict removal efficiencies expected under average and peak conditions.

$$\text{Loading factor ratio} = \frac{\text{actual loading}}{\text{design loading}}$$

$$\text{Average conditions} = \frac{828}{800} = 1.0$$

$$\text{Peak conditions} = \frac{1,146}{800} = 1.4$$

Referring to Figure 17, a loading factor of 1.0 (average condition) should result in 50 to 65% SS removal and 25 to 35% BOD removal. Under peak loading conditions, a factor of 1.4 should provide 40 to 50% SS removal, and 20 to 30% BOD removal.

7. If the clarifier does not provide acceptable treatment, the shortcomings and troubleshooting sections of this manual should be read.

It is important for the clarifier to be designed properly and have the ability to handle the actual average and peak flows. In some cases, especially in combined collection systems, the peak flow conditions should govern the design. It should be noted, however, that clarifier efficiency at peak flows is dependent on both magnitude and duration. Therefore, it is important to examine past flow data and the characteristics of the collection system in order to assure that the design is not based on a short duration peak which may have little effect on clarifier efficiency.

Control Considerations

As with most unit processes, primary clarification is related to other plant processes, both upstream and downstream. Upstream, some of the factors that will affect settling tank operation include recycling of waste sludge and supernatant, and carryover of grit and screenings from pretreatment. The frequency and duration of sludge pumping determines the solids concentration in the sludge which in turn has a major effect on downstream sludge thickening and dewatering processes. Pumping of thin sludge may lower plant digester capacity; cause hydraulic overloads to sludge thickening processes; and use too much fuel for sludge heating purposes. If sludge becomes septic, downstream sludge handling processes may be affected and odor problems made worse. Laboratory "spin" tests (small centrifuge) are often used by operators to determine when it is time to pump out the sludge. Primary sludge concentrations of 5-7% are often found with proper operation of the sludge pumping system.

A properly operated primary clarifier will do much to provide smooth and efficient operation of downstream unit processes. For example, improper control of primary tank operations may cause solids and BOD overloading problems for secondary processes. Solids not removed in primary treatment result in greater amounts of secondary sludge being produced, and grease carryover can upset aeration tank and trickling filter operations. This often results in a poor quality effluent.

For good operation, clarifier flows must be distributed evenly among all available tanks. Uneven flows to the various tanks results in a poor overall reduction of SS and BOD.

Common Design Shortcomings and Ways to Compensate

	Shortcoming		Solution
1.	Poor flotation of grease.	1.	Pre-aeration of wastewater to increase grease buoyancy.
2.	Scum overflow.	2.	Move scum collection system away from outlet weir.
3.	Sludge hard to remove from hopper because of excessive grit.	3.	Install grit chamber or eliminate sources of grit entering the system.
4.	Short circuiting of flow through tank causing poor solids removal.	4.	Modify hydraulic design and install appropriate baffles to disperse flow and reduce inlet velocities.
5.	Heavy wear and frequent breakage of scrapers and shear pins due to grit.	5.	Install grit chamber.
6.	Grease particles adhered to wooden flights.	6.	Lower return wooden flights to below the water surface or install water sprays to remove grease into scum troughs.
7.	Inadequate removal of heavy grease loading.	7.	Install flotation or evacuator equipment.
8.	Low grease removal due to inadequate particle agglomeration.	8.	Provide chlorine contact tanks with grease removal equipment to enhance agglomeration.

Shortcoming	Solution
9. Septic conditions resulting from overloading.	9. Divert or provide alternate disposal for other plant process wastes (i.e. centrates and supernates) which are normally recirculated into the sedimentation tank.
10. Excessive corrosion due to septic wastewater.	10. Coat all surfaces with proper paint and/or install sacrificial anode.
11. Consistent problems with thermal currents in clarifier.	11. Install flow equalization and mixing basin ahead of clarifier.
12. Poor scum removal due to wind.	12. Install a wind barrier to protect tank from wind effects.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Floating sludge.	1a. Sludge decomposing in tank.		1a. Remove sludge more frequently or at a higher rate.
	1b. Scrapers worn or damaged.	1b. Inspect scraper.	1b. Repair or replace as necessary.
	1c. Return of well nitrified waste activated sludge.	1c. Effluent nitrates.	1c. Vary age of returned sludge, or move point of waste sludge recycle.
	1d. Sludge withdrawal line plugged.	1d. Sludge pump output.	1d. Clear line by reversing flow.
	1e. Damaged or missing inlet baffles.	1e. Baffles.	1e. Repair or replace baffles.
2. Black and odorous septic wastewater.	2a. Sludge collectors worn or damaged.	2a. Inspect sludge collectors.	2a. Repair or replace as necessary.
	2b. Improper sludge removal pumping cycles.	2b. Sludge density.	2b. Increase frequency and duration of pumping cycles until sludge density decreases to undesirably low value.
	2c. Inadequate pretreatment of organic industrial wastes.	2c. Pretreatment practices.	2c. Pre-aerate waste.
	2d. Sewage decomposing in collection system.	2d. Retention time, and velocity in collection lines.	2d. Chlorinate in collection system.
	2e. Recycle of excessively strong digester supernatant.	2e. Digester supernatant quality and quantity.	2e. Provide treatment before recycling, or reduce rate of return.
	2f. Sludge withdrawal line plugged.	2f. Sludge pump output.	2f. Clean line by reversing flow.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
3. Erratic operation of sludge collection mechanism.	3a. Broken shear pins, damaged collector.	3a. Shear pins and sludge collector.	3a. Repair or replace damaged parts.
	3b. Rags and debris entangled around collector mechanism.	3b. Sludge collector.	3b. Remove debris.
	3c. Excessive sludge accumulation.	3c. Sound bottom of tank.	3c. Increase frequency of pumping sludge from tank.
4. Scum overflow.	4a. Frequency of removal inadequate.	4a. Scum removal rate.	4a. Remove scum more frequently.
	4b. Heavy industrial waste contributions.	4b. Influent waste.	4b. Limit industrial waste contributions.
	4c. Worn or damaged scum wiper blades.	4c. Wiper blades.	4c. Clean or replace wiper blades.
	4d. Improper alignment of skimmer.	4d. Alignment.	4d. Adjust alignment.
5. Broken scraper chains and frequent shear pin failure.	5a. Improper shear pin sizing and flight alignment.	5a. Pin sizing and flight alignment.	5a. Realign flights and change shear pin size.
	5b. Ice formation on walls and surfaces.	5b. Inspect walls and surfaces.	5b. Remove or break up ice formation.
	5c. Excessive loading on mechanical sludge scraper.	5c. Sludge loading.	5c. Operate collector for longer period and/or remove sludge more often.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
6. Sludge hard to remove from hopper.	6a. Excessive grit, clay and other easily compacted material. 6b. Low velocity in withdrawal lines. 6c. Pipe or pump clogged.	6a. Operation of grit removal system. 6b. Sludge removal velocity.	6a. Improve operation of grit removal unit. 6b. Increase velocity in sludge withdrawal lines. 6c. Backflush clogged pipe lines and pump sludge more frequently.
7. Undesirably low solids content in sludge.	7a. Hydraulic overload. 7b. Short circuiting of flow through tanks. 7c. Over-pumping of sludge.	7a. Influent flow rate. 7b. Dye or other flow tracers. 7c. Frequency and duration of sludge pumping; SS concentration.	7a. Provide more even flow distribution in all tanks, if multiple tanks. 7b. (See 8a and 8b). 7c. Reduce frequency and duration of pumping cycles.
8. Short circuiting of flow through tanks.	8a. Uneven weir settings. 8b. Damaged or missing inlet line baffles.	8a. Weir settings. 8b. Damaged baffles.	8a. Change weir settings. 8b. Repair or replace baffles.
9. Surging flow.	9a. Poor influent pump programming.	9a. Pump cycling.	9a. Modify pumping cycle.
10. Excessive sedimentation in inlet channel.	10a. Velocity too low.	10a. Velocity.	10a. Increase velocity or agitate with air or water to prevent decomposition.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
11. Excessive growth on surfaces and weirs.	11a. Accumulations of wastewater solids and resultant growth.	11a. Inspect surfaces.	11a. Frequent and thorough cleaning of surfaces.
12. Excessive corrosion on unit.	12a. Septic wastewater.	12a. Color and odor of wastewater.	12a. Paint surfaces with corrosion-resistant paint.
13. Noisy chain drive.	13a. Moving parts rub stationary parts.	13a. Alignment.	13a. Tighten and align casing and chain. Remove dirt or other interfering matter.
	13b. Chain does not fit sprockets.		13b. Replace with correct parts.
	13c. Loose chain.		13c. Maintain taut chain at all times.
	13d. Faulty lubrication.	13d. Lubrication.	13d. Lubricate properly.
	13e. Misalignment or improper assembly.	13e. Alignment and assembly.	13e. Correct alignment and assembly of drive.
	13f. Worn parts.		13f. Replace worn chain or bearings. Reverse worn sprockets before replacing.
14. Rapid wear of chain drive.	14a. Faulty lubrication.	14a. Lubrication.	14a. Lubricate properly.
	14b. Loose or misaligned parts.	14b. Alignment.	14b. Align and tighten entire drive.
15. Chain climbs sprockets.	15a. Chain does not fit sprockets.		15a. Replace chain or sprockets.
	15b. Worn out chain or worn sprockets.		15b. Replace chain. Reverse or replace sprockets.
	15c. Loose chain.		15c. Tighten.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
16. Stiff chain.	16a. Faulty lubrication.	16a. Lubrication.	16a. Lubricate properly.
	16b. Rust or corrosion.		16b. Clean and lubricate.
	16c. Misalignment or improper assembly.	16c. Alignment and assembly.	16c. Correct alignment and assembly of drive.
	16d. Worn out chain or worn sprockets.		16d. Replace chain. Reverse or replace sprockets.
17. Broken chain or sprockets in chain drive system.	17a. Shock or overload.	17a. Influent flow rate.	17a. Avoid shock and overload or isolate through couplings.
	17b. Wrong size chain or chain that does not fit sprockets.		17b. Replace chain. Reverse or replace sprockets.
	17c. Rust or corrosion.		17c. Replace parts. Correct corrosive conditions.
	17d. Misalignment.	17d. Alignment.	17d. Correct alignment.
	17e. Interferences.		17e. Make sure no solids interfere between chain and sprocket teeth. Loosen chain if necessary for proper clearance over sprocket teeth.
18. Oil seal leak.	18a. Oil seal failure.	18a. Oil seal.	18a. Replace seal.
19. Bearing or universal joint failure.	19a. Excessive wear.		19a. Replace joint or bearing.
	19b. Lack of lubrication.	19b. Lubrication.	19b. Lubricate joint and/or bearings.
20. Binding of sludge pump shaft.	20a. Improper adjustment of packing.		20a. Adjust packing.

ACTIVATED SLUDGE

Process Description

The activated-sludge process is a treatment technique in which wastewater and biological sludge (microorganisms) is mixed and aerated. The biological solids are then separated from the treated wastewater and returned to the aeration process as needed.

In the activated-sludge process, microorganisms are mixed thoroughly with the organics so that they grow by using the organics as food. As the microorganisms grow and are mixed by the agitation of the air, the individual organisms clump together (flocculate) to form an active mass of microbes called "activated sludge". The wastewater flows continuously into an aeration tank where air is injected to mix the activated sludge with the wastewater and to supply the oxygen needed for the microbes to break down the organics (Figure 18). The mixture of activated sludge and wastewater in the aeration tank is called "mixed liquor". The mixed liquor flows from the aeration tank to a secondary clarifier where the activated sludge is settled. Most of the settled sludge is returned to the aeration tank to maintain a high population of microbes to permit rapid breakdown of the organics. Because more activated sludge is produced than can be used in the process, some of the return sludge is diverted or "wasted" to the sludge-handling system for treatment and disposal. Air is introduced into the aeration basins either by injecting it into diffusers near the bottom of the aeration tank (Figures 24 and 25) or by mechanical mixers located at the surface of the aeration tank (Figures 26 and 27). The volume of sludge returned to the aeration basin is typically 20-50% of the wastewater flow. There are many variations of this conventional system as described in the following paragraphs.

In long, narrow aeration tanks, the demand for oxygen is much greater at the inlet to the aeration basin where the wastewater enters. As a result, the "tapered aeration" process can be used. In this process, a greater portion of the air is injected at the inlet end than at the outlet end of the aeration basin. The total amount of air used is the same, but its distribution is tapered along the aeration tank. Another variation is one in which the wastewater flow is introduced at several points rather than all at once. The process is known as "step aeration" (Figure 19). Multiple feed points spread the oxygen demand over more of the aeration basin, which results in more efficient use of the oxygen. Existing conventional plants are often modified to the step aeration process to increase their capacity. To extend even further the benefits achieved with step aeration, the "complete mix" activated-sludge concept may be used (Figure 20). In this system, the influent wastewater is fed as evenly as possible along the entire length of the aeration basin, so that the oxygen demand is uniform from one end to the other.

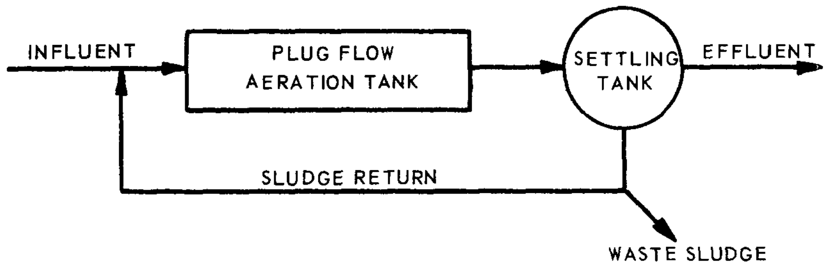


Figure 18. Conventional activated sludge.

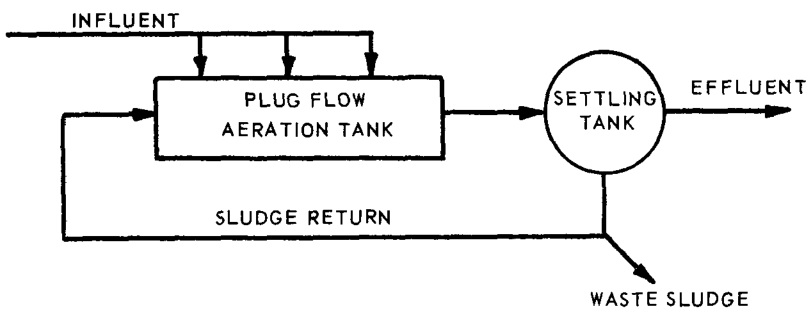


Figure 19. Step aeration.

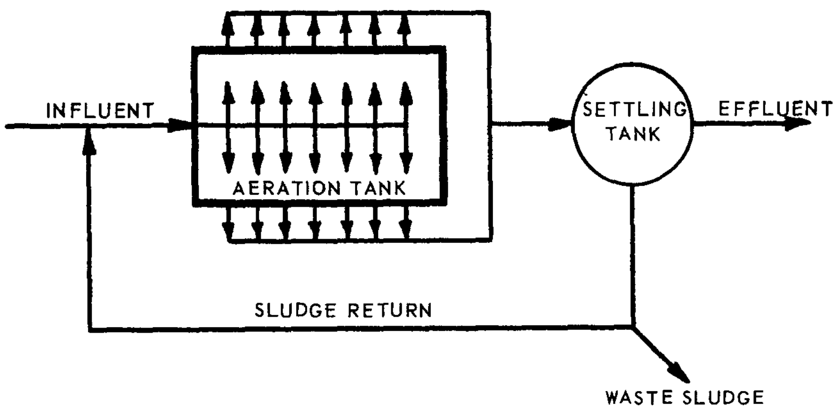


Figure 20. Complete mix activated sludge (CMAS).

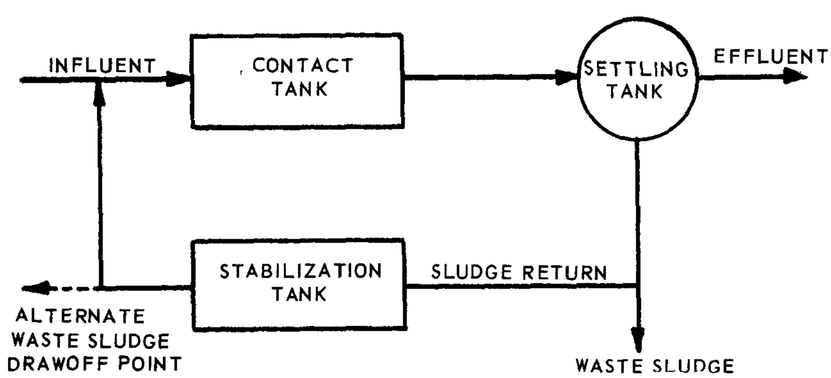


Figure 21. Contact stabilization.

Another variation of activated sludge is the contact stabilization process (Figure 21). In this system, the incoming wastewater is mixed briefly (20-30 mins) with the activated sludge - just long enough for the microbes to absorb the organic pollutants from solution but not long enough for them to actually break down the organics. The activated sludge is then settled out and returned to another aerated basin (stabilization tank), in which it is aerated for 2-3 hrs to allow the microbes to break down the absorbed organics. Because the settled volume of the activated sludge is much smaller than the total wastewater flow, the total size of the plant is reduced.

Many small activated-sludge plants use the "extended aeration" form of activated sludge. The process flow diagram is essentially the same as in the complete mix system, except that these small plants usually have no primary treatment and aerate the raw wastewater for a 24-hr period rather than the 6-8 hrs used in conventional plants. The long aeration time allows the activated sludge to be partially digested within the aeration tank so that it can be dewatered and disposed of without the need for large sludge digestion capacity.

A variation of the conventional process, called the oxidation ditch, has been very popular (Figure 22). A surface-type aerator is used that both aerates and circulates the wastewater through the ditch (Figure 28). The process is commonly designed with a 24-hr aeration period and is considered a form of the extended aeration process.

Since 1970, there has been interest in systems using pure oxygen instead of air. To provide efficient use of the oxygen, the aeration tanks are often covered and the oxygen is recirculated through several stages (Figure 23). When the tanks are covered, very pure oxygen (over 90%) enters the first stage of the system and flows through the oxygenation basin together with the wastewater being treated. Pressure under the tank covers maintains control and prevent backmixing from stage to stage. This system allows for efficient oxygen use at low power requirements. Surface aerators or submerged rotating-sparge systems are used for mixing. Instead of using covered basins, special oxygen diffusers can be used in open basins. The number of stages and the type of mixing device selected depends on waste characteristics, plant size, land availability, treatment requirements, and other similar considerations. Pure oxygen allows the use of much smaller aeration tanks (1.5-2 hrs aeration rather than 6-8 hrs). The oxygen used in the process is typically generated onsite. For larger plants, air is liquified and then distilled in "cryogenic" oxygen production units. For smaller plants, air separation is achieved by selectively adsorbing nitrogen from the air and allowing the oxygen to pass through a "sieve" or "pressure swing adsorption" unit. It is generally more economical to use cryogenic processes for 10 to 2,000 tons/day oxygen production and adsorption processes for 0.5 to 36 tons/day. The choice of a process for the 10 to 36 tons/day range depends on many factors, but adsorption is the simplest process.

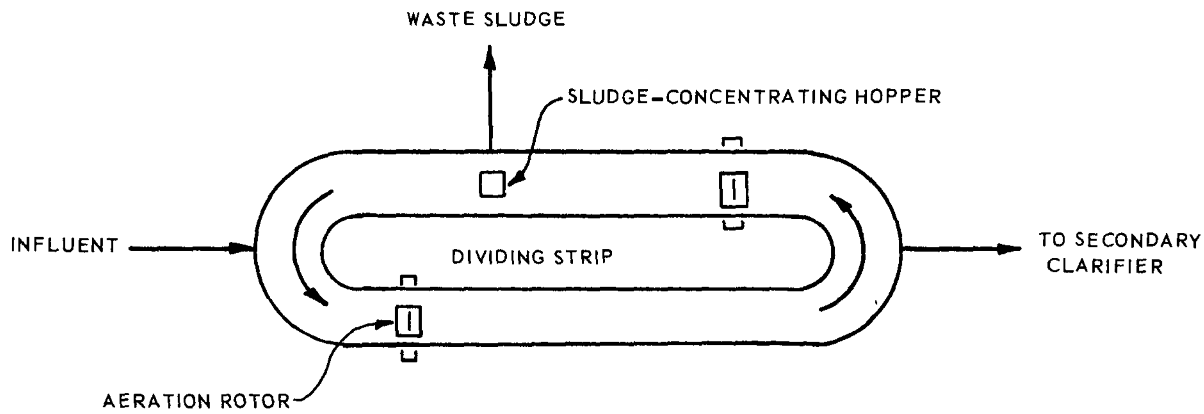


Figure 22. Oxidation ditch.

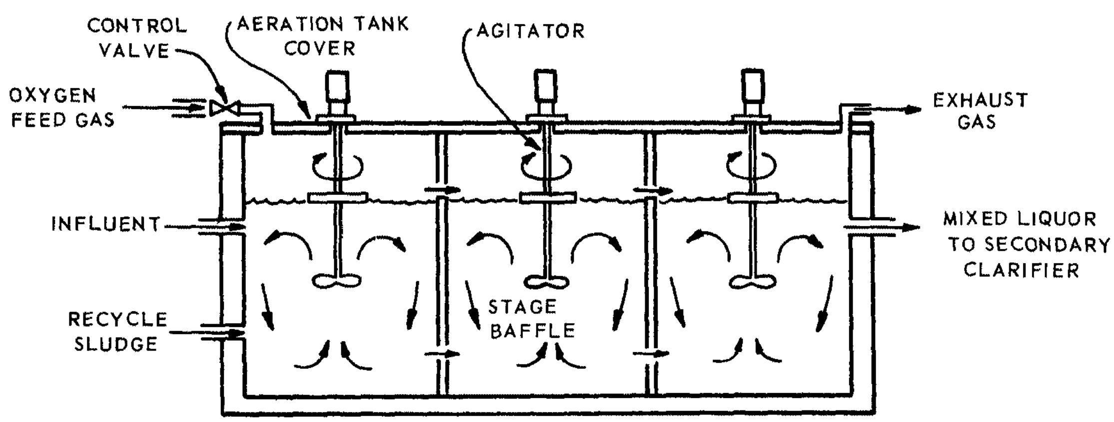


Figure 23. Schematic diagram of multistage oxygen aeration system.

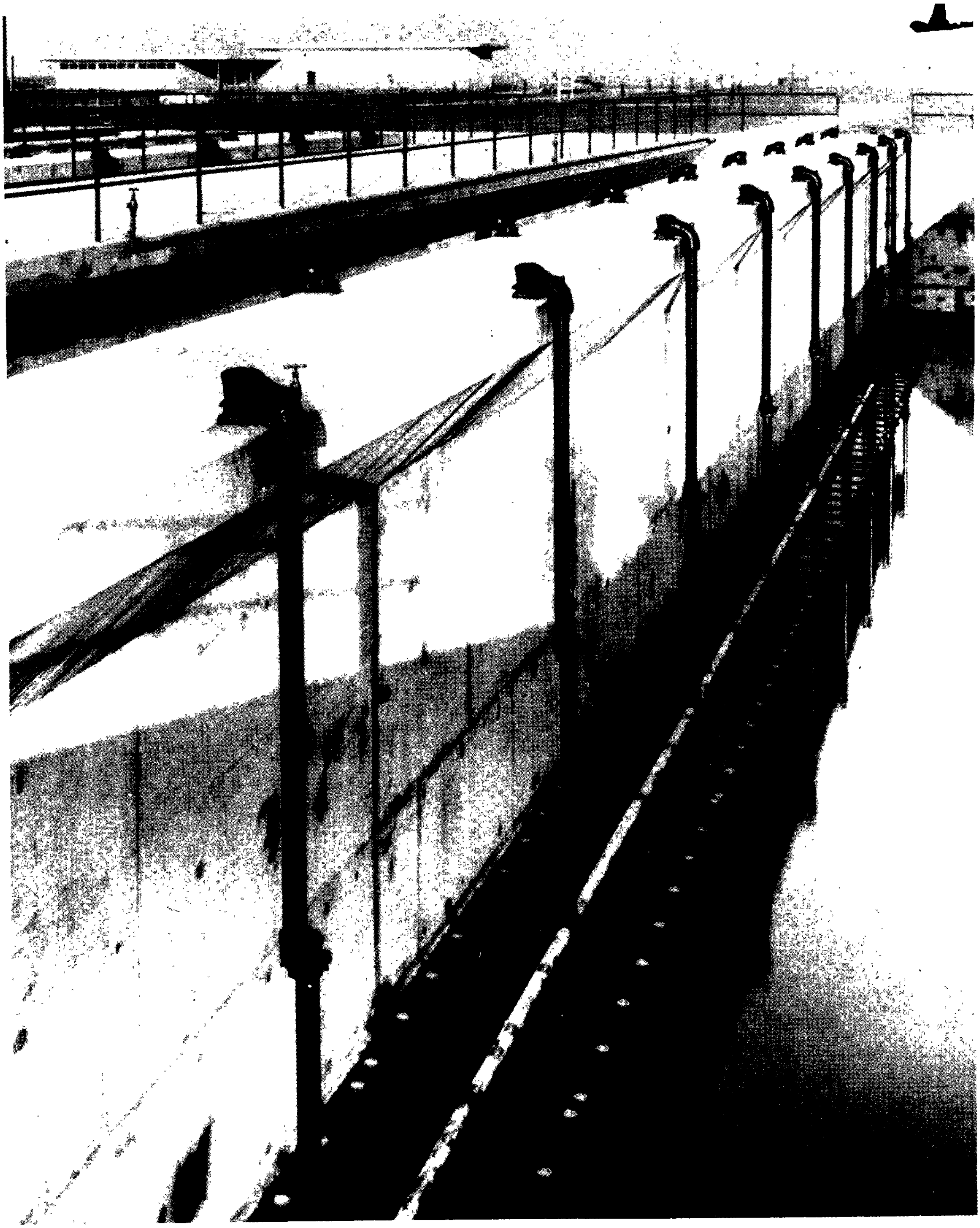


Figure 24. Typical air diffuser system.

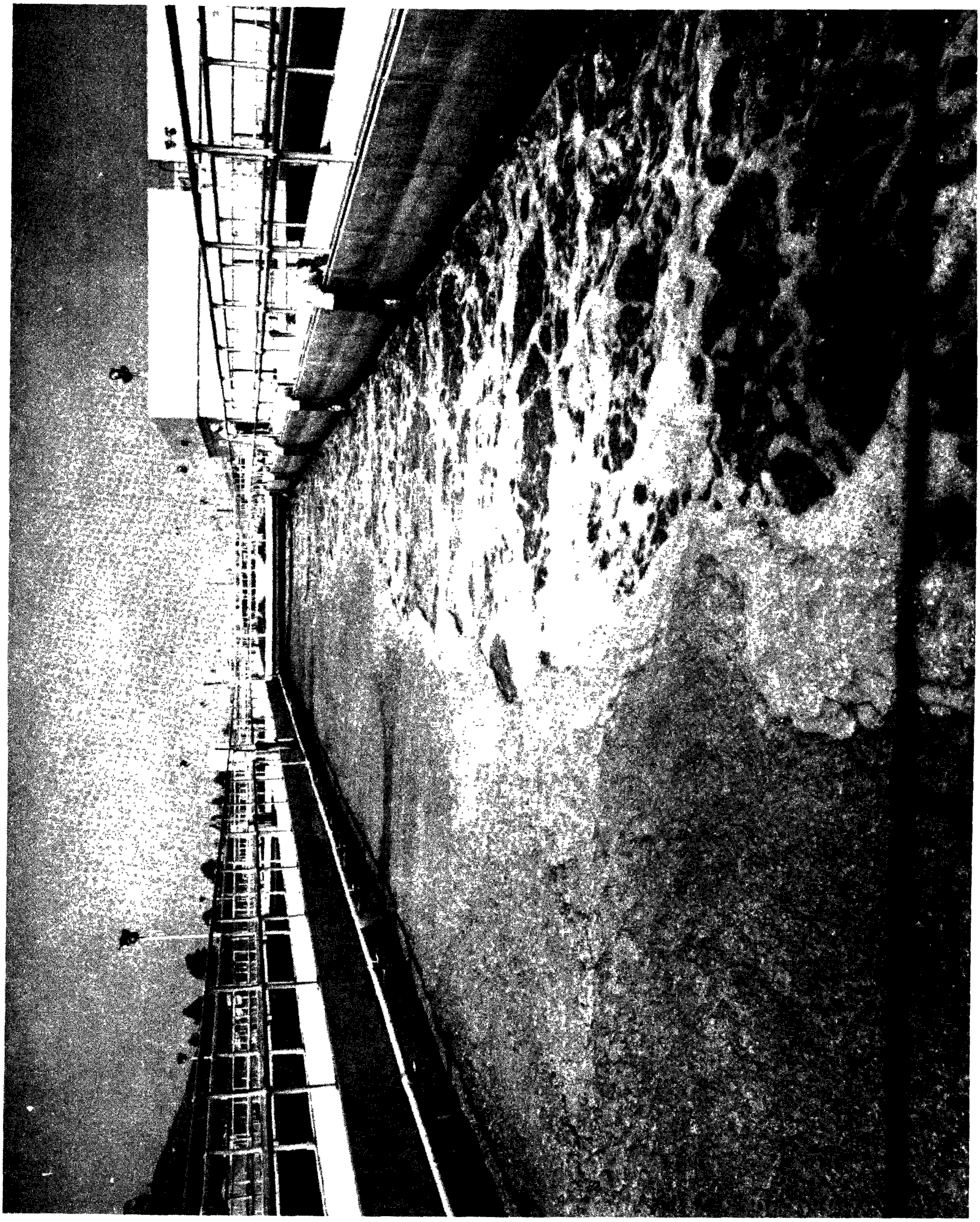


Figure 25. Aeration basin with diffused aeration.

Figure 26. Floating surface, mechanical aerator.

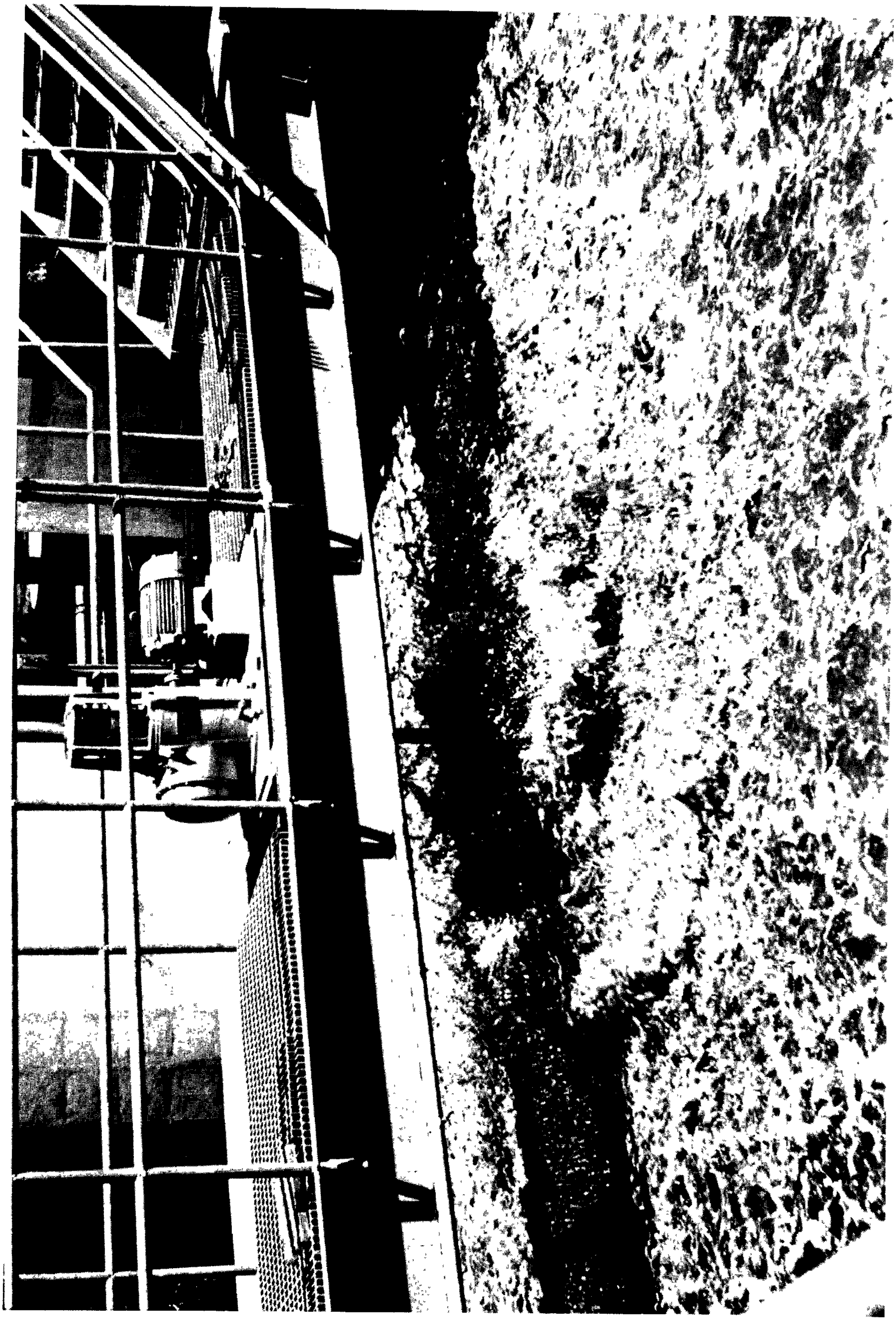


Figure 27. Platform mounted surface aerator.

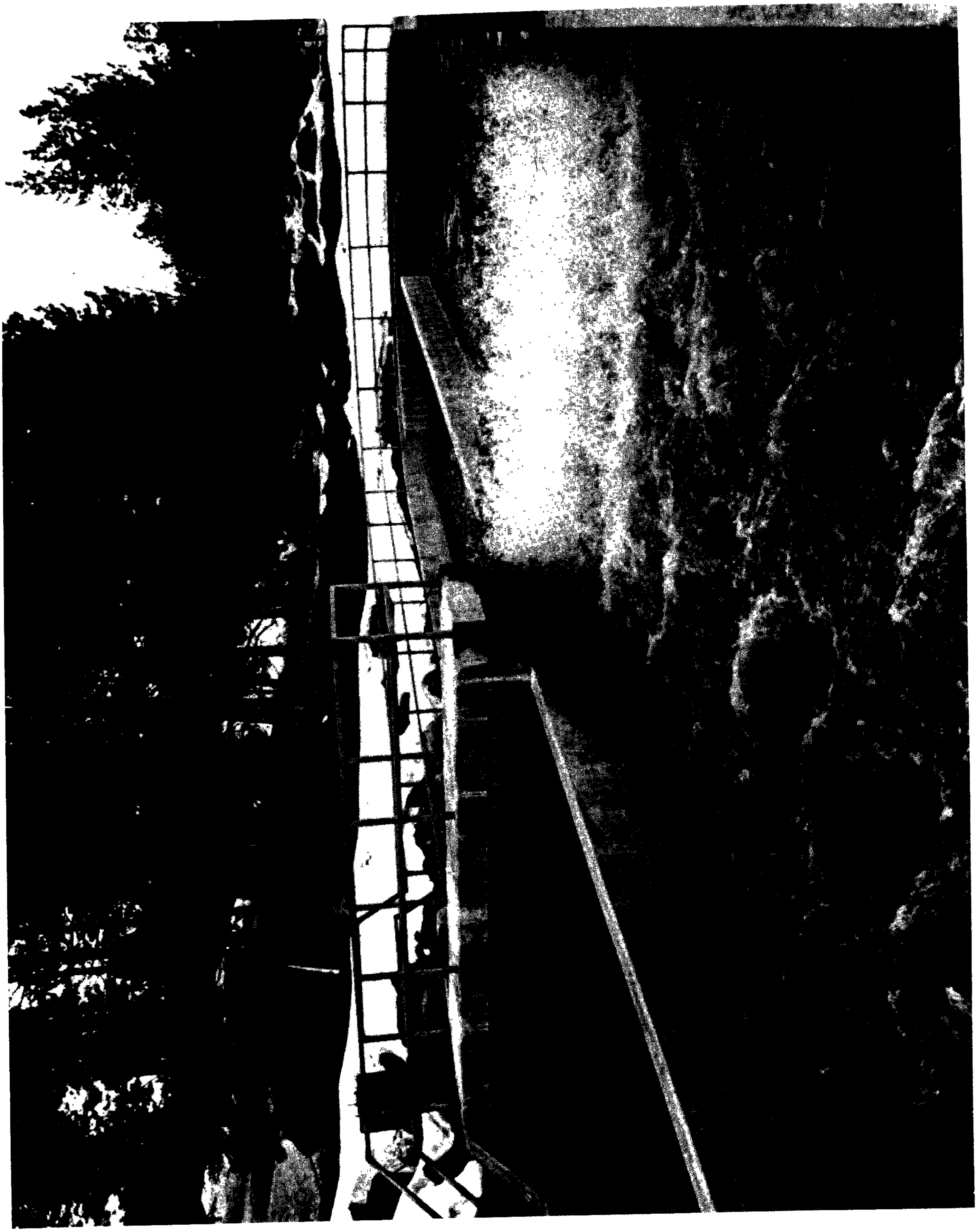


Figure 28. Oxidation ditch aeration system.

Typical Design Criteria and Performance Evaluation

Typical design criteria for variations of the activated sludge process are presented in Table 2.

The activated sludge process can convert nearly all influent soluble organic matter to solids. Solids must be removed in order to have high quality effluents in terms of organics. Unfortunately, plain sedimentation of flocculant solids is not easily predicted. When there are large amounts of solids, density currents, and thickening considerations, careful operational control of solids is needed to produce consistently good effluent quality. When properly designed and operated, an activated sludge plant should consistently produce effluent suspended solids and BOD of 20-30 mg/l.

Many small extended aeration plants do not practice good sludge inventory and wasting management and sometimes discharge high solids concentrations. The oxidation ditch extended aeration process has performed very well and very reliably when solids are managed properly.

The following terms are important in evaluating activated sludge systems.

Mixed Liquor Suspended Solids (MLSS)--

This is a very important measurement and shows the amount of activated sludge inventory. The MLSS is determined often - several times per day at large plants and daily at smaller plants. Typical MLSS concentrations for various activated sludge modifications are shown in Table 2.

Mixed Liquor Volatile Suspended Solids (MLVSS)--

This test indirectly shows the active biological fraction of mixed liquor solids and directly tells the amount of inert solids. For example, MLVSS will typically be 70-80% of the total MLSS. However, during times of heavy infiltration of the sewer system, the carryover of silt into the aeration basins may decrease the MLVSS to 55-60%. When the percent of MLVSS decreases, the total MLSS must be increased to maintain the same level of active organisms.

Sludge Density Index (SDI)--

The rate that activated sludge solids settle to the bottom of a final settling tank depends on the settling characteristics of the sludge. These characteristics are determined by a simple settling test, the results of which can be used to determine the SDI. A 1,000 ml sample is collected from the aeration tank and allowed to settle for 30 mins in a 1,000 ml graduated cylinder. The volume of settled sludge is read at the end of the 30 mins.

$$\text{Sludge Density Index} = \frac{\text{MLSS (mg/l)}}{\text{ml of settled sludge after 30 min settling x 10}}$$

A good Sludge Density Index is about 1.0. A sludge with an index of 1.5 is

TABLE 2. TYPICAL ACTIVATED SLUDGE DESIGN PARAMETERS

Process Modification	Flow regime	Sludge retention time (days)	Food to microorganism ratio-#BOD_5/ MLVSS/day	Aerator loading #BOD_5/ 1,000 ft^3 tank volume	Mixed liquor suspended solids(mg/l)	Detention time (hr)	Recirculation ratio
Conventional	Plug	5-15	0.2 -0.4	20-40	1500-3000	4-8	0.25-0.5
Complete mix	Complete mix	5-15	0.2 -0.6	50-120	3000-6000	3-5	0.25-1.0
Step aeration	Plug	5-15	0.2 -0.4	40-60	2000-3500	3-5	0.25-0.75
Contact stabilization	Plug	5-15	0.2 -0.6	30-75	1000-4000* 4000-10000+	0.5-1.5*	0.5 -1.5
Extended aeration	Complete mix	20-30	0.05-0.15	10-15	2000-6000	24	0.5 -2.0
Pure oxygen systems	Complete mix reactors in series	8-20	0.25-1.0	100-250	4000-8000	2-5	0.25-0.5

* Contact unit

\+ Stabilization tank

dense and settles quickly. An index of less than 1 means a lighter sludge which settles slowly.

Sludge Volume Index (SVI)--

This index is also used to reflect the settling characteristics of activated sludge, but is defined as:

$$SVI = \frac{\text{ml of settled sludge after 30 min settling x 1,000}}{\text{MLSS (mg/l)}}$$

In this case, the lower the SVI, the more dense the sludge. An SVI of 100 or less is generally considered a good settling sludge.

Food to Microorganism (F/M) Ratio--

This parameter is used to express the total loading of organics on the biological system. It is the ratio of lbs of BOD_5 entering the aeration basin per day to the lbs of MLVSS in the aeration basin and the secondary clarifier.

A high F/M reflects a high loading on the activated sludge system which will result in more waste activated sludge generated per pound of BOD removal. A very high F/M (above 0.5) indicates a more unstable system.

A low F/M at normal MLSS concentrations (less than 0.1) indicates a lightly loaded activated sludge plant. The waste sludge should be stable and may not require any added digestion.

Solids Retention Time (SRT)--

The Solids Retention Time is the average length of time that the activated sludge solids are kept in the process.

The following steps are examples of how to calculate the above terms in evaluating plant performance.

1. Determine the operating conditions:

Flow = 2 mgd
MLSS = 2500 mg/l
MLVSS = 2000 mg/l
SS, secondary effluent = 20 mg/l
BOD, primary effluent = 120 mg/l
BOD, secondary effluent = 15 mg/l
Return Activated Sludge Flow = 700 gpm = 1 mgd
Waste Activated Sludge Flow = 10,000 gpd = 0.01 mgd
Waste Activated Sludge Concentration = 9200 mg/l
Aeration Tank Size = 10 ft deep x 125 ft long x 40 ft wide
Secondary clarifier = 65 ft diameter x 12 ft deep
Volume of Settled Sludge in 1000 ml MLSS sample after 30 min settling = 200 ml

The secondary effluent quality is good and there are no apparent major problems.

2. Calculate volume of aeration tank and secondary clarifier

Aeration tank volume = 10 ft x 125 ft x 40 ft x 7.48 gals/cu ft
= 374,000 gals

Clarifier volume = $\frac{\pi}{4}(65)^2$ x 12 ft x 7.48 gals/cu ft
= 24,808 gals

3. Calculate Sludge Volume Index

$$SVI = \frac{200 \times 1000}{2500} = 80$$

A sludge volume index of less than 100 indicates a good settling sludge.

4. Calculate F/M Ratio

F = 120 mg/l x 2 mgd x 8.34 lbs/mg/mg/l = 2000 lbs/day
M = MLVSS in aeration tank + MLVSS in clarifier
= 2000 mg/l x 8.34 lbs/mg/mg/l x (0.374 + 0.025) = 6655 lbs

$$F/M = \frac{2000}{6655} = 0.30$$

As can be seen from Table 2, the F/M value is within the range normally used in conventional activated sludge systems.

5. Determine the amount of activated sludge being wasted. The amount of sludge wasted from a conventional plant is normally about 0.5-0.6 lbs of activated sludge per lb of BOD removed. If greater amounts are being wasted, the MLSS will decrease and eventually reach levels that are too low. If smaller amounts are wasted, then MLSS will increase to the point where they will eventually spill over the secondary clarifier weirs.

Lbs BOD Removed/Day = (120-15) x 8.34 lbs/mg/mg/l x 2 mgd
= 1751 lbs/day
Lbs Activated Sludge Wasted/Day = 0.01 mgd x 9200 mg/l x 8.34
= 767 lbs/day
= 0.44 lbs/lb BOD removed

This wasting rate is somewhat lower than normal. If the MLSS have been increasing, the wasting rate should be increased about 20%.

6. Calculate Sludge Retention Time (SRT)

$$SRT = \frac{\text{MLSS in aeration tank and final clarifier}}{\text{solids wasted + solids lost in effluent/day}}$$

$$= \frac{2000 \text{ mg/l} \times 8.34 \times (0.374 + 0.025 \text{ mil gal})}{9200 \text{ mg/l} \times 8.34 \times 0.01 \text{ mgd} + 20 \times 8.34 \times 2.0 \text{ mgd}}$$

$$= \frac{6655}{767 + 334}$$

$$= 6.0 \text{ days}$$

As shown in Table 2, this is within the normal range of 5-15 days found in conventional activated sludge plants.

7. Calculate Sludge Recirculation Rates

$$\text{Recirculation Rates} = \frac{\text{Return Sludge Flow Rate}}{\text{Influent Flow Rate}}$$

$$= \frac{1 \text{ mgd}}{2 \text{ mgd}}$$

$$= 0.5$$

This is at the high end of the range usually found for conventional activated sludge plants. With the good settling sludge at this plant, it should be possible to use a lower return rate without problems of solids carryover from the secondary clarifiers.

Control Considerations

Dissolved Oxygen in Aeration Tank--

With conventional aeration systems, dissolved oxygen (DO) in the mixed liquor should be maintained in the 1-3 mg/l range. With pure oxygen systems, higher levels of DO are maintained with minimum levels being 2 mg/l. Good mixing is also very important, but it is a fixed parameter with some aeration systems. The operator should monitor the aeration tank DO levels and air flow rates periodically (every 2 hrs is suggested) to make appropriate air rate adjustments as required. If DO monitoring instrumentation is provided, it is imperative that it be properly maintained and calibrated to provide values that are valid and reliable.

In varying the suspended solids concentration in the aeration basins, oxygen demand will tend to increase as the solids concentration is increased. The dissolved oxygen level should be watched as the suspended solids concentration is increased. The MLSS should be carried at a level to maintain the desired Solids Retention Time (SRT), but carefully controlled by frequent sludge wasting as discussed later.

Return Activated Sludge Flow Rate--

To properly operate the activated sludge process, a good settling mixed liquor must be achieved and maintained. The MLSS are settled in a clarifier, and then returned to the aeration tank as the Return Activated Sludge (RAS). The RAS makes it possible for the microorganisms to be in the treatment system longer than the flowing wastewater. For conventional activated sludge operations, the RAS flow is generally about 20 to 50% of the incoming wastewater flow. Changes in the activated sludge quality will require different RAS flow rates due to settling characteristics of the sludge.

There are two basic approaches that can be used to control the RAS flow rate. These approaches are based on the following:

- Controlling the RAS flow rate independently from the influent flow.
- Controlling the RAS flow rate as a constant percentage of the influent flow.

Most activated sludge operations perform well and require less attention when the constant RAS flow rate approach is used. However, setting the RAS at a constant flow rate results in a continuously varying MLSS concentration because the MLSS are flowing into the clarifier at a higher rate during peak flow but they are being removed at a constant rate. At minimum influent flow rates, the MLSS are being returned to the aeration tank at a higher rate than they are flowing into the clarifier. The clarifier acts as a storage reservoir for the MLSS, and the clarifier has a constantly changing depth of sludge blanket as the MLSS moves from the aeration tank to the clarifier. The advantage of using this approach is simplicity, because it minimizes the amount of effort for control. Many plants do not have the controls necessary to control RAS flow rates at a constant percentage of influent flow.

Sludge Blanket Depth in Secondary Clarifier--

Checking the depth of the sludge blanket in the clarifier is the most direct method for determining the RAS flow rate. The location of the sludge blanket may be found by several types of devices. Some are commercially available while others must be made by the operator. The following are some of the different types of blanket finders:

- A series of air lift pumps mounted within the clarifier at various depths.
- Gravity flow tubes located at various depths
- Electronic sludge level detector-a light source and photo-electric cell attached to a graduated handle or drop cord. The photo-electric cell actuates a meter, buzzer, light, etc.
- Sight glass finder-a graduated pipe with a sight glass and light source attached at the lower end.
- Plexiglass core sampler
- Some type of portable pumping unit with a graduated suction pipe or hose

The blanket depth should be kept to less than one-fourth of the clarifier sidewall water depth. The operator must check the blanket depth on a routine basis, making adjustments in the RAS to control the blanket depth. If the depth of the sludge blanket is increasing, the increase may result from having too much activated sludge in the treatment system, and/or, because of a poorly settling sludge, or plugging of the sludge removal system. Long-term corrections must be made that will improve the settling characteristics of the sludge or remove the excess solids from the treatment system.

Measurements of the sludge blanket depth in the clarifier should be made at the same time each day. The best time to make these measurements is during the period of maximum daily flow, because the clarifier is operating under the highest solids loading rate. The sludge blanket should be measured daily,and adjustments to the RAS rate can be made as necessary. Adjustments in the RAS flow rate should only be needed occasionally if the activated sludge process is operating properly.

Waste Activated Sludge Flow Rate--

The objective of wasting activated sludge is to maintain a balance between the microorganisms and the amount of BOD. When the microorganisms remove BOD from wastewater, the amount of activated sludge increases. The rate at which these microorganisms grow is called the growth rate and is defined as the increase in the amount of activated sludge that takes place in one day. The objective of sludge wasting is to remove just that amount of microorganisms that grow. When this is done the amount of activated sludge formed by the microorganism growth is just balanced by that which is removed from the process. This allows the total amount of activated sludge in the process to remain nearly constant. This condition is called "steady-state" which is a desirable condition for operation. However, "steady-state" can only be approximated because of the variations in the nature and quantity of the food supply (BOD) and of the microorganism population.

Wasting of the activated sludge is normally done by removing a portion of the RAS flow. The waste activated sludge is either pumped to thickening facilities and then to a digester, or to the primary clarifiers where it is pumped to a digester with the raw sludge.

An alternate method for wasting sludge is from the mixed liquor in the aeration tank. There is much higher concentration of suspended matter in the RAS than there is in the mixed liquor. When wasting is done from the mixed liquor, larger sludge handling facilities are required. However, wasting from the mixed liquor has the advantage of not wasting excessive amounts of sludge because of the large quantity of sludge involved. The extra security of wasting from the mixed liquor should not be underestimated. Many plants do not have the flexibility to waste from the mixed liquor nor are there sufficient sludge handling facilities to handle the more dilute sludge.

Wasting of the activated sludge can be done on an intermittent or continuous basis. The intermittent wasting of sludge means that wasting is conducted on a batch basis from day to day. Intermittent wasting of sludge has the advantage that less variation in the suspended matter concentration will occur during the wasting period, and the amount of sludge wasted will be more accurately known. The disadvantages of intermittent wasting are that the sludge handling facilities in the treatment plant may be loaded at a higher hydraulic loading rate and that the activated sludge process is out of balance for a period of time until the micoorganisms regrow to replace those wasted over the shorter period of time.

The simplest and most commonly used approach in controlling the amount of sludge wasted is to waste enough to maintain a nearly constant MLVSS. This technique usually produces good quality effluent as long as the incoming wastewater characteristics are fairly constant with minimal variations in influent flow rates. The operator tries to maintain a constant MLVSS concentration in the aeration tank to treat the incoming wastewater organic load. To put it in simple terms, if it is found that a MLVSS concentration of 2000 mg/l produces a good quality effluent, the operator must waste sludge from the process to maintain that concentration. If the MLVSS level increases above the desired concentration, more sludge is wasted until the desired level is reached again. Other approaches that have been used involve wasting sludge so as to maintain a constant F/M or a constant SRT.

Microscopic Examination--

Microscopic examination of the MLSS can be a significant aid in the evaluation of the activated sludge process. The presence of various microorganisms within the sludge floc can rapidly indicate good or poor treatment. Protozoa play an important role in clarifying the wastewater and act as indicators of the degree of treatment. The protozoa eat the bacteria and help to provide a clear effluent. The presence of rotifers is also an indicator of effluent stability. A predominance of protozoa (ciliates) and rotifers in the MLSS is a sign of good sludge quality. The presence of filamentous organisms and a limited number of protozoa is characteristic of a poor quality activated sludge. This condition is commonly associated with a sludge that settles poorly.

Process Control References--

There have been many articles, reports, manuals, and books written on the control of activated sludge systems. It is not practical to summarize all of this information in this manual. The evaluator should read the following reference (from which portions of this section were drawn) for detailed information on process control:

> "Process Control Manual for Aerobic Biological Wastewater Treatment Facilities", U.S. EPA, Municipal Operations Branch, Office of Water Programs, Washington, D.C. 20460 March, 1977, EPA 430/9-77-006.

Another useful EPA document is:

> West, Alfred W., <u>Operational Control Procedures for the</u>

Activated Sludge Process, Parts I, II, IIA, and IIIB, U.S. EPA National Training & Operational Technology Center, May 1974.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Diffusers plug from dirty air.	1. Install air cleaners on blower.
2. Inadequate screening of raw wastes causing mechanical aerators and sludge return system to plug.	2. Install finer bar screen or comminutor.
3. No or inadequate system to measure and control rate of return or waste activated sludge flow.	3. Install flow measuring devices on RAS and WAS systems.
4. Grit buildup in aeration basin.	4. Install grit removal system.
5. Aeration system not adequate to maintain DO at peak flows.	5. Place more aeration basins in service (if available); install flow equalization facilities; install more aeration equipment. Convert to oxygen system.
6. Surface aeration systems throwing spray onto walkways causing slippery conditions.	6. Install shields.
7. Inadequate return sludge flow capacity.	7. Install added return sludge pumps or increase pump size.
8. Inadequate process flexibility.	8. Modify system to operate in plug, step, or contact stabilization.
9. Inadequate metering to balance flows between multiple units.	9. Install appropriate flow metering system.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Sludge floating to surface of secondary clarifiers.	1a. Filamentous organisms predominating in mixed liquor ("bulking sludge")	1a. SVI[1] - if less than 100, 1(a) is not likely cause; microscopic examination also can be used to determine presence of filamentous organisms.	1a. (1) Increase DO in aeration tank if less than 1 mg/l (2) Increase pH to 7 (3) Supplement deficiency of nutrients so that BOD to nutrient ratio is no more than 100 mg/l BOD to 5 mg/l total nitrogen; to 1 mg/l phosphorus; to 0.5 mg/l iron (4) Add 5-60 mg/l of chlorine to return sludge until SVI <150 (5) Add 50-200 mg/l of hydrogen peroxide to aeration tank until SVI <150 (6) Increase SRT (7) Increase sludge return rate
	1b. Denitrification occurring in secondary clarifiers; nitrogen gas bubbles attaching to sludge particles; sludge rises in clumps	1b. Nitrate concentration in clarifier influent; if no measureable NO_3, than 1(b) is not the cause	1b. (1) Increase sludge return rate (2) Increase DO in aeration tank (3) Reduce SRT
2. Pin floc in secondary clarifier overflow - SVI is good but effluent is turbid	2a. Excessive turbulence in aeration tanks	2a. DO in aeration tank	2a. Reduce aeration agitation
	2b. Overoxidized sludge	2b. Sludge appearance	2b. Increase sludge wasting to decrease SRT
	2c. Anaerobic conditions in aeration tank	2c. DO in aeration tank	2c. Increase DO in aeration tank
	2d. Toxic shock load	2d. Microscopically examine sludge for inactive protozoa	2d. Re-seed sludge with sludge from another plant if possible; enforce industrial waste ordinances

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
3. Very stable dark tan foam on aeration tanks which sprays cannot break up	3a. SRT is too long	3a. If SRT greater than 9 days, this is probable cause	3a. Increase sludge wasting so as to reduce SRT
4. Thick billows of white sudsy foam on aeration tank.	4a. MLSS too low	4a. MLSS	4a. Decrease sludge wasting so as to increase MLSS
5. Aerator contents turn dark-sludge blanket lost in secondary clarifier	5a. Inadequate aeration	5a. Aeration basin DO	5a. (1) Increase aeration by placing another blower in service (2) Decrease loading by placing another aeration basin in service (3) Check aeration system piping for leaks (4) Clean any plugged diffusers
6. MLSS concentrations differ substantially from one aeration basin to another	6a. Unequal flow distribution to aeration	6a. Flow to each basin	6a. Adjust values and/or inlet gates to equally distribute flow
7. Sludge blanket overflowing secondary clarifier weirs uniformly throughout basin	7a. Inadequate rate of sludge return	7a. Sludge return pump output	7a. (1) If return pump is malfunctioning, place another pump in service & repair (2) If pump is in good condition increase rate of return and monitor sludge blanket depth routinely. Maintain 1-3 foot deep blanket. When blanket increases in depth, increase rate of return (3) Clean sludge return line if plugged

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	7b. Unequal flow distribution to clarifiers causing hydraulic overload.	7b. Flow to each clarifier.	7b. Adjust valves and/or inlet gates to equally distribute flow.
	7c. Peak flows are overloading clarifiers.	7c. Hydraulic overflow rates at peak flows if >1,000 gpd/sq ft, this is a likely cause.	7c. Install flow equalization facilities or expand plant.
	7d. Solids loadings are too high on clarifier.	7d. Loadings should not exceed 1.25 lb/sq ft/hr.	7d. Reduce MLSS concentration by increased wasting.
8. Sludge blanket overflowing secondary clarifier weirs in one portion of clarifier.	8a. Unequal flow distribution in clarifier.	8a. Effluent weir.	8a. Level effluent weirs.
9. In diffused aeration basin, air rising in very large bubbles or clumps in some areas.	9a. Diffusers plugged.	9a. Visual inspection.	9a. Clean or replace diffusers Check air supply-install air cleaners ahead of blowers to reduce plugging from dirty air.
10. pH of mixed liquor decreases to 6.7 or lower. Sludge becomes less dense.	10a. Nitrification occurring and wastewater alkalinity is low.	10a. Effluent NH_3; influent and effluent alkalinity.	10a. (1) Decrease sludge age by increased wasting if nitrification not required. (2) Add source of alkalinity - lime or sodium bicarbonate.
	10b. Acid wastewater entering system.	10b. Influent pH	10b. Determine source and stop flow into system.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
11. Sludge concentration in return sludge is low (<8,000 mg/l)	11a. Sludge return rate too high.	11a. Return sludge concentration, solids balance around final clarifier, settleability test.	11a. Reduce sludge return rate.
	11b. Filamentous growth.	11b. Microscopic examination, DO, pH, nitrogen concentration.	11b. Raise DO, raise pH, supplement nitrogen, add chlorine. (see item 1).
	11c. Actinomycetes predominates.	11c. Microscopic examination, dissolved iron content.	11c. Supplement iron feed if dissolved iron less than 5 mg/l.
12. Dead spots in aeration tank.	12a Diffusers plugged.	12a. Visual inspection.	12a. Clean or replace diffusers - check air supply - install air cleaners ahead of blowers to reduce plugging from dirty air.
	12b. Underaeration resulting in low DO.	12b. Check DO and RAS rate.	12b. Increase rate of aeration to bring DO concentration up to 1 to 3 mg/l.

TRICKLING FILTERS

Process Description

A trickling filter consists of a bed of coarse media (such as rock, plastic or other material) covered with microorganisms. Wastewater is applied at a controlled rate, using moving distributors or fixed nozzles. As the wastewater trickles down through the openings of the media, organic matter is removed by contact with the microorganisms. The treated wastewater then is collected by an underdrain system.

Figure 29 shows a trickling filter and its principal components which include:

- The distribution system which applies the wastewater to the filter media
- The filter media which provides surface area for the microorganisms to grow
- The underdrain system which supports the media and provides drainage of the waste flow to a collection channel while permitting air circulation

The trickling filters usually are built with a tank which contains the media. They also may be built by placing the media on an underdrain system and allowing the natural slope of the media at the edges to form their outer boundary. The system may be either square, rectangular or circular in shape, although the circular filter is the most popular.

Two kinds of distribution systems are in use: fixed nozzle and rotary distributors. In a fixed nozzle system, the wastewater is applied using a pipe grid that ends in nozzles evenly spaced over the bed. To distribute the sewage evenly, the water pressure on the nozzles must change during each dosing period. This is accomplished by using a dosing tank and siphon which automatically starts to discharge when full, and stops when empty (Figure 30). The filter rests while the dosing tank refills.

In recent years, the rotary distributor (Figure 29) has become more popular than the fixed type nozzle.

Most of the distributors are rotated by the reaction of the water jets pushing against the air, however, they also may be motor driven. In order to get even distribution of the wastewater over the surface of the bed, the nozzle openings are smaller and spaced farther apart near the center of the bed. The nozzles discharge the wastewater in a thin sheet or a fine spray.

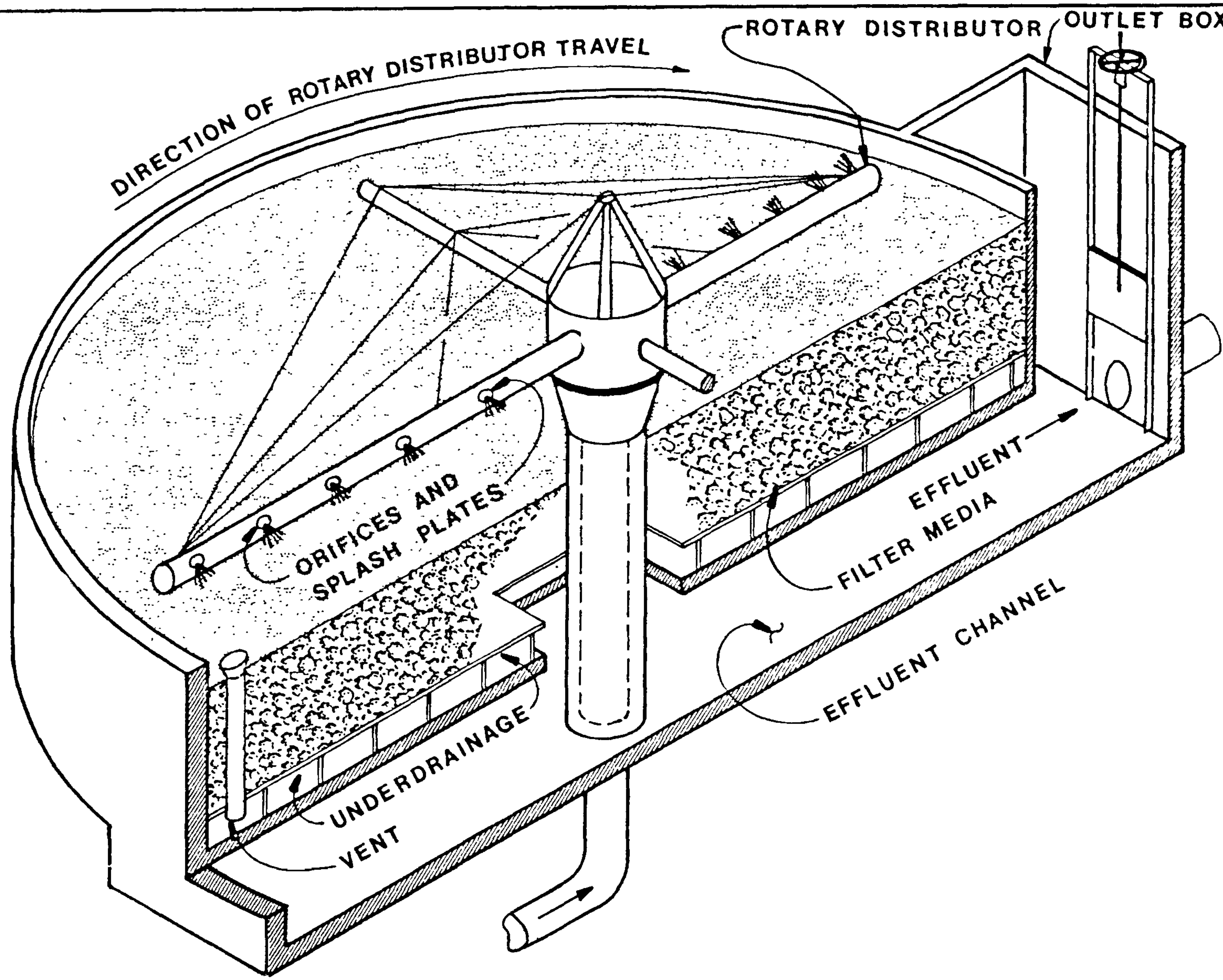


Figure 29. Typical trickling filter in cross section.

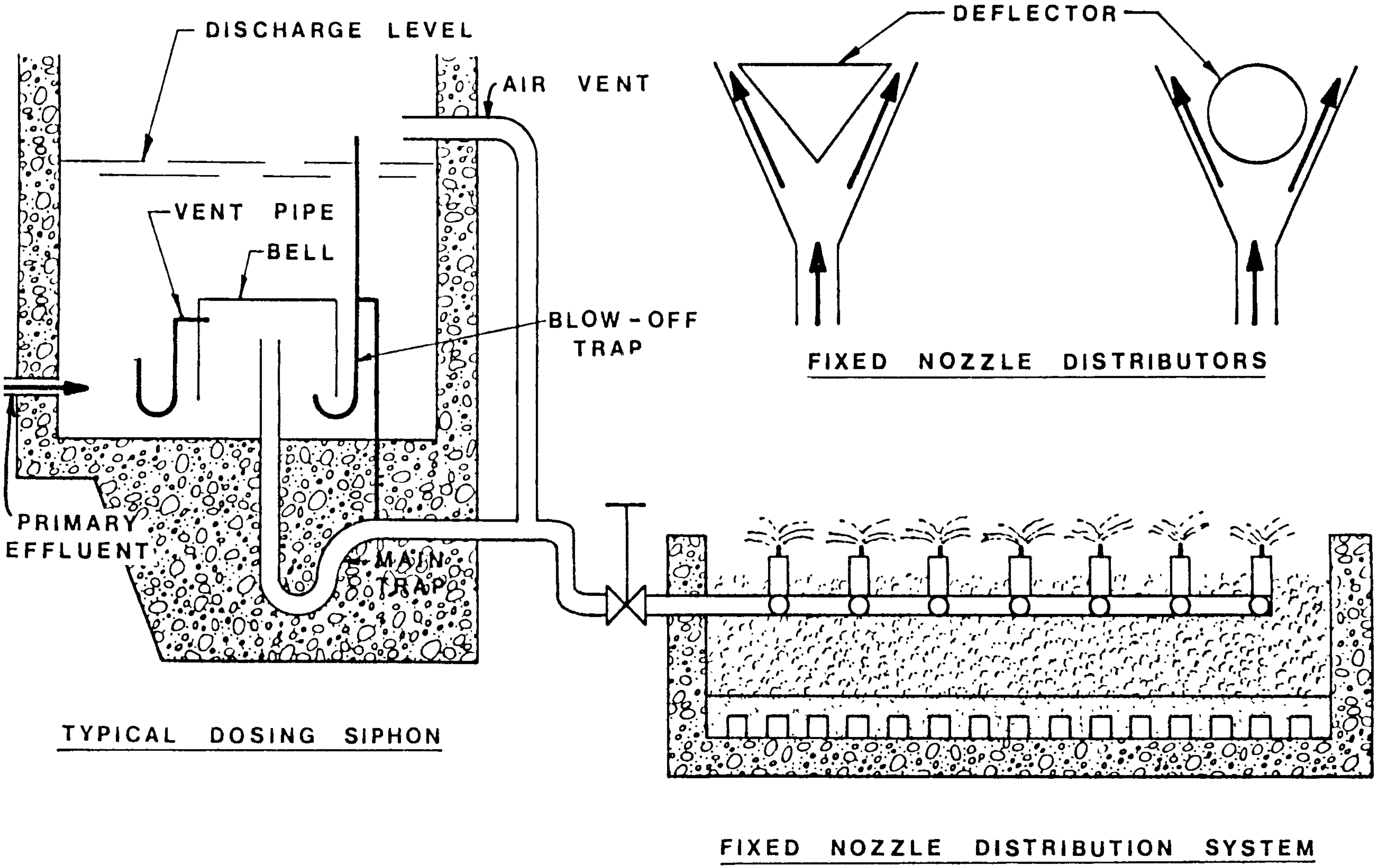


Figure 30. Fixed nozzle distribution system.

Trickling filters are not primarily a filtering or straining process as the name implies (the rocks in a rock filter are 1-4 inches in diameter, too large to strain out solids). Instead, these filters provide large amounts of surface area where the microorganisms cling and grow in a slime on the rocks as they feed on the organic matter. Excess growths of microorganisms wash from the rock media and would cause high levels of suspended solids in the plant effluent if not removed. Thus, the flow from the filter is passed through a secondary clarifier to allow these solids to settle out.

There are several ways to prevent the biological slimes from drying out and dying when wastewater flows are too low to keep the filter wet. One method is to recycle filter effluent. Recirculation reduces odor potential and improves filter efficiency as it provides another opportunity for the microbes to attack any organics that escaped the first pass through the filter. Another approach to improving performance or handling strong wastewaters is to use two filters in series, referred to as a "two-stage" trickling filter system. Figure 31 shows a schematic of typical one and two-stage trickling filter systems.

Although rock trickling filters have performed well for years, certain limitations have been found. Under high organic loadings, the slime growths can be so great that they plug the void spaces between the rocks, causing flooding and failure of the system. Also, the volume of void spaces is limited in a rock filter, which limits the circulation of air in the filter and the amount of oxygen available for the microbes. This problem, in turn, limits the amount of wastewater that can be processed. To overcome these limitations, synthetic media for trickling filters have recently become popular. These materials include modules of corrugated plastic sheets, redwood slats, and plastic rings. These media offer larger surface areas for slime growths (typically 27 sq ft of surface area per cu ft as compared to 12-18 sq ft per cu ft for 3-in rocks) and greatly increase void ratios for increased air flow. The materials are also much lighter than rock (by a factor of about 30), so that the trickling filters can be much taller without structural problems. While rock in filters is usually not more than 10 ft deep, synthetic media depths are often 20 ft or more, reducing the overall space requirements for the trickling filter portion of the treatment plant.

One type of manufactured media consists of vertical stacks of redwood laths constructed into 4 x 4 ft racks, with spacer rails between the layers to allow for air circulation and water flow. (Figure 32).

The molded plastic media uses pieces of interlocking corrugated sheets of plastic that look like a honeycomb. The sheets of media are stacked so that they interlock and fit inside the filter structure (Figure 33).

Typical Design Criteria and Performance Evaluation

Trickling filters are classified on the basis of the hydraulic and organic loads they are designed to treat. Table 3 summarizes the loading

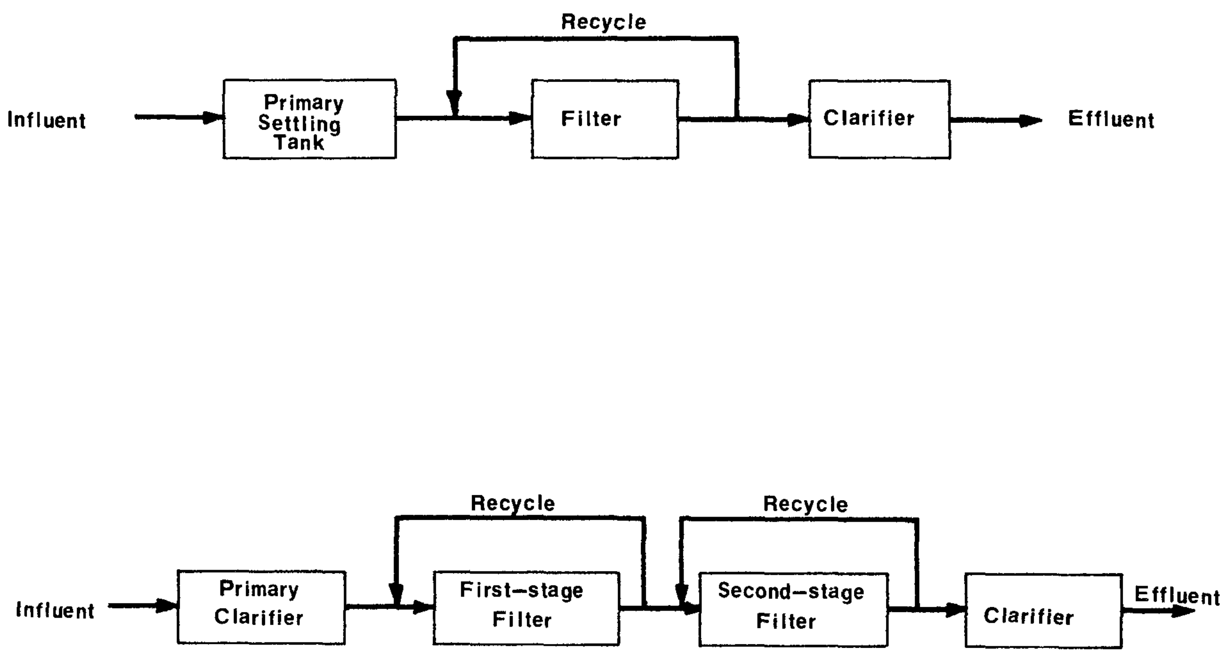


Figure 31. Typical one and two-stage trickling filter systems.

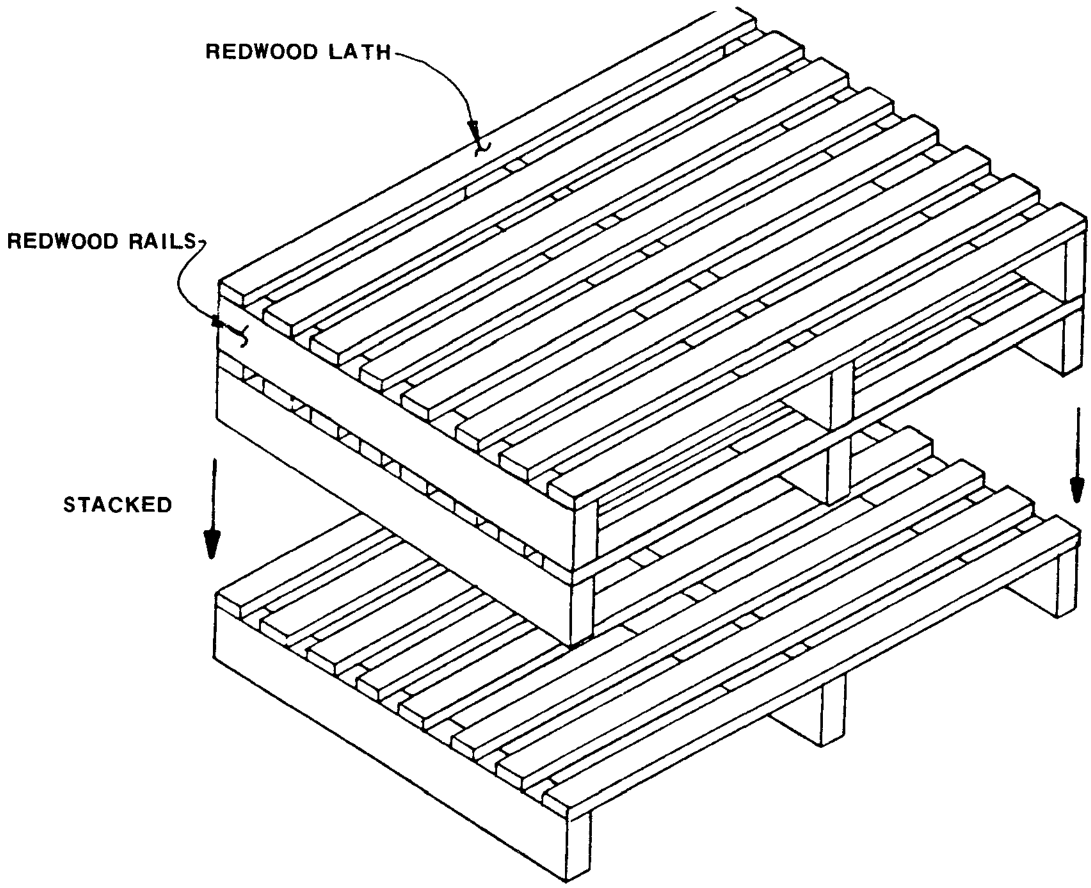


Figure 32. Redwood lath media.

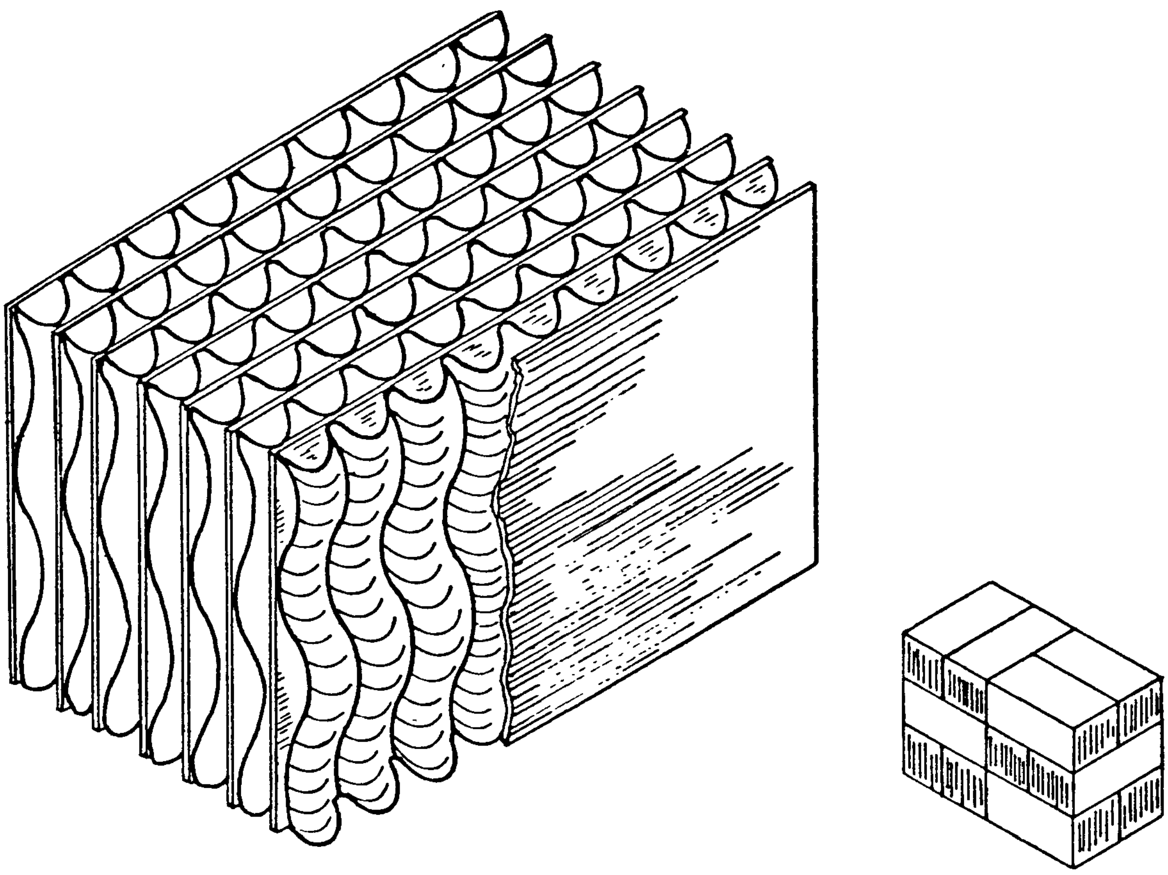


Figure 33. Plastic media.

TABLE 3. TRICKLING FILTER DESIGN AND PERFORMANCE PARAMETERS

Opening characteristics		Low-rate rock media	High-rate rock media	High-rate plastic media
Hydraulic loading:				
	MG/Acre	1-4	10-40	40-190*
	gpm/sf	0.02-0.06	0.2-0.6	0.6-3.0
	gpd/sf	28.8-86.4	288-864	864-4320
Organic loading:				
	lb BOD/ac ft	500-1000	2000-4000	870-13000+
	lb BOD/1000 cu ft	12-22	45-90	40-200
Recirculation ratio		NONE	1:1-4:1	0.5:1-2:1
Depth, ft		6-10	3-8	15-40
BOD removal, %		85	85	40-80+

* Recirculation included

+ Recirculation not included

rates and general operating characteristics for low-rate rock media, high-rate rock media, and high-rate plastic media.

Typical overall efficiency of a trickling filter treatment plant is about 85% removal of BOD and suspended solids for municipal wastewaters, or a concentration of about 30 mg/l of suspended solids and BOD in the final effluent. The actual effectiveness of the trickling filter process, however, depends on the following factors:

- Growth of biological organisms
- Raw wastewater concentration
- Dissolved oxygen
- Temperature
- pH and/or toxic conditions

Trickling filter plant effluent data for 2 plants are presented in Figure 34. Figure 35 shows a guideline summary relating approximate effluent quality to organic loading.

Performance evaluation for trickling filters should consist of BOD removal efficiencies in relationship to:

- Type of media
- Loading parameters
- Plant recirculation flows

The following will serve as an example of step-by-step procedures for evaluating the performance of trickling filters:

1. Define the design and operating mode of the trickling filter.

High Rate Rock Media		
Depth, D	=	6 ft
Diameter, dia	=	133 ft
Surface Area, $A = (\pi/4)\,dia^2$	=	13,893 ft^2
Volume, $V = A \times D$	=	83,358 ft^3
Flow		
Raw wastewater	=	2.5 mgd
Recirculated	=	5.0 mgd
Total, Raw + Recirculated	=	7.5 mgd
BOD, influent	=	200 mg/l
BOD, clarifier effluent	=	30 mg/l

2. Determine the combined efficiency of BOD removal for the trickling filter and secondary clarifier.

$$\%\ \text{BOD removal} = \frac{\text{BOD (primary effluent)} - \text{BOD (clarifier effluent)} \times 100}{\text{BOD (primary effluent)}}$$

$$= \frac{(200-30)}{200}\ 100$$

$$= 85\%$$

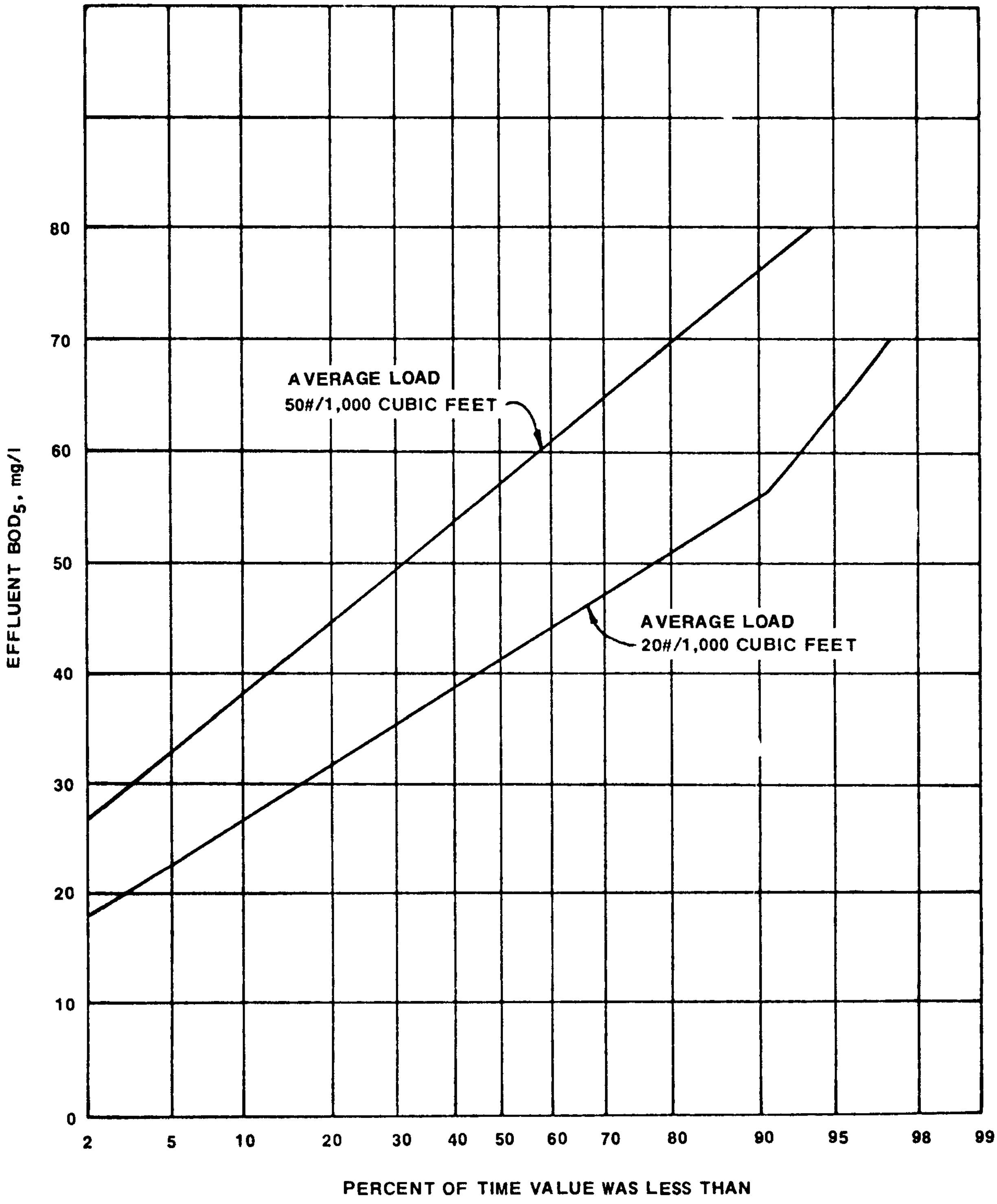


Figure 34. Trickling filter effluent quality - two Texas plants.

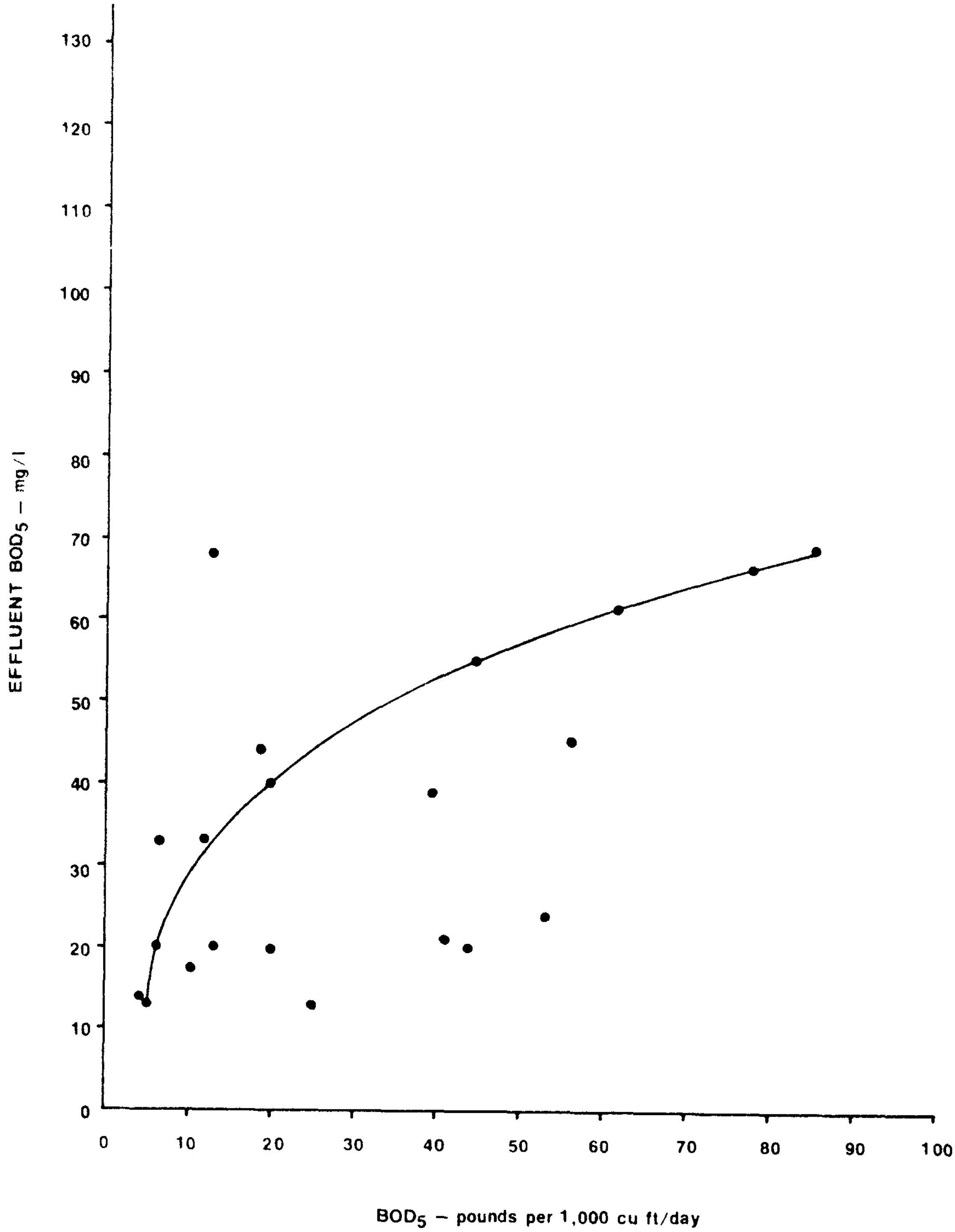


Figure 35. Effluent quality trickling filters.

3. Compare this removal efficiency with the expected removal for high rate rock media shown in Table 3.

Determine the hydraulic loading rate for the filter.

$$\text{Hydraulic load} = \frac{\text{Total Flow in gpd}}{\text{Surface Area in ft}^2}$$
$$= \frac{7.5 \times 10^6 \text{ gpd}}{13{,}893 \text{ ft}^2}$$
$$= 540 \text{ gpd/ft}^2$$

As shown in Table 3, this loading is within the acceptable range of 288-864 gpd/ft^2.

4. Determine the organic loading rate for the filter.

$$\text{Organic Load} = \frac{\text{(Flow in mgd) (BOD mg/l) (8.34 lb/gal)}}{(\text{Vol in ft}^3) \div 1000}$$
$$= \frac{(2.5)\ (200)\ (8.34)\ 1000}{83{,}358}$$
$$= 50 \text{ lb BOD/1000 cu ft}$$

For high rate rock media trickling filters, the organic loading should be between 45 and 90 lb BOD/1000 cu ft as shown in Table 3.

5. Calculate the recirculation ratio for the trickling filter.

$$\text{Recirculation ratio} = \frac{\text{Recirculated flow, mgd}}{\text{Raw wastewater flow, mgd}}$$
$$= \frac{5.0}{2.5}$$
$$= 2/1$$

Usually, the recirculation ratio has a greater effect on filter performance than the recirculation flow scheme. To maximize filter performance and minimize operational problems, recirculation ratios should be controlled within the ranges given in Table 3.

Control Considerations

In the treatment of domestic wastewater, the trickling filter is usually preceded by a primary clarifier and followed by a final clarifier. Where primary sedimentation is not provided, some pretreatment such as that provided by a shredder, grinder or screens may be necessary to prevent filter clogging.

The efficiency of treatment attained by trickling filter plants is greatly affected by the operation of the final settling tanks. It is essential that sludge be removed from the final settling tank before it rises to the surface and is carried out with the final effluent. Sludge from final settling tanks can either be pumped back to the primary settling tanks or directly to a thickener for further sludge treatment and disposal. The operation of final settling tanks is especially important in the case of high rate trickling filters. In this case, sludge becomes septic much faster than the sludge from standard rate filters; consequently, it should be removed more rapidly. Sludge from a low-rate trickling filter is relatively stable, and periodic removal at 3 to 24 hr intervals, depending upon operational conditions, is usually sufficient. During warm summer weather and periods of heavy sloughing, removal at 3 to 6 hr intervals may be required. Sludge from a high-rate trickling filter has a higher oxygen demand, and therefore, it must be removed from the sedimentation tank within a short time, preferably on a continuous basis.

In the trickling filter process, wastewater contacts the microorganisms attached to the filter media, and the organic material is oxidized. As a result, it is very important to keep a healthy population of microorganisms which can continue to do the job.

Because the organic materials in the wastewater are the food source for the organisms, the characteristics of the raw wastewater are important process factors. Changes in the organic strength of the wastewater will cause changes in the way the microorganisms grow. This change in growth will then affect treatment efficiencies. Recirculation of filter or final effluent is one plant operation which can be used to lower the strength of the wastewater applied to the filter. Some of the advantages of recirculation include the following:

- Maintains biological growth throughout media depth.
- May improve operation of primary and final sedimentation units during low flow periods by reducing septicity.
- Dilutes high strength or toxic wastes to make them treatable.
- Minimizes hydraulic and organic loading variations.
- Improves distribution of the wastewater over the filter surface.
- Minimizes odors, ponding, and filter fly breeding by increasing hydraulic loading to encourage continuous sloughing and reduce slime thickness.
- Prevents biological growth from drying out during low flows.

When selecting the recirculation rate, the hydraulic loading on the filter and affected clarifiers must be considered as well as the hydraulics of the distribution and underdrain systems. As a rule of thumb, the underdrain conduits and effluent channels should not flow more than one-half full. Although some experimentally based equations have been developed to calculate the amount of recirculation needed, it is recommended that operational control be based on filter response and process performance. In high-rate trickling filters, recirculation ratios usually range from 0.5 to 4.0 with higher ratios considered to be economically unjustifiable. Common engineering practice is to design the high-rate trickling filter process for ratios of 0.5 to 2.0. Trickling filters utilizing synthetic media employ recirculation as a means of maintaining a hydraulic loading (gpm/sq ft) which will maintain biological growth throughout the media depth.

As an aerobic system, it is important that the trickling filter have enough dissolved oxygen to satisfy the oxygen needed for biological oxidation of the organic material. These oxygen requirements are determined by the BOD loading, the quality of the microorganisms, temperature, and hydraulic loading. Except for changing recirculation, operators have little control over temperature variations. Temperature increases cause more biological activity and greater oxygen utilization, while decreases result in lower activity and less oxygen utilization. This means that winter treatment efficiency may be lower than efficiency in the summer. The effects of temperature changes may be reduced by adjusting the recirculation ratio.

Extreme changes in pH can reduce the filter's efficiency and, in severe cases can even kill biological growth. pH control may be needed if the pH often goes outside the 6.5 to 8.5 range.

For more detailed information on process control, the evaluator should read:

> "Process Control Manual for Aerobic Biological Wastewater Treatment Facilities", U.S. EPA, Municipal Operations Branch, Office of Water Programs, Washington, D.C. 20460 (March, 1977)

<u>Common Design Shortcomings and Ways to Compensate</u>

Shortcomings	Solution
1. Fly nuisance caused by alternately wet and dry filter walls.	1. Modify ends of distributor arms to maintain continuously wet filter walls. (Flies cannot survive on walls which are kept wet.)
2. Odors, resulting from poor ventilation of filter	2. (a) Increase ventilation by forcing air into filter drain system. (b) Cover filter and deodorize the off gases.
3. Ice build up on filter media.	3. (a) Construct wind screen to protect filter from prevailing wind. (b) Cover pump sumps and dosing tanks. (c) Cover filter.

Common Design Shortcomings and Ways to Compensate (Cont'd)

Shortcomings	Solution
4. Clogging of distributor orifices caused by inadequate primary treatment.	4. Improve grease and SS removal in primary clarifier.
5. Filter subject to clogging with leaves from nearby trees.	5. Removal of nearby trees.
6. Excessive sloughing from filter due to excessive organic loading.	6. Decrease loading by using more filters or expanding the plant.
7. Recirculation of secondary clarifier effluent is causing high flows through the clarifier which are carrying solids over the clarifier weir.	7. Modify recirculation system so that trickling filter effluent (secondary clarifier influent) is recirculated directly.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Filter Ponding	1a. Media too small or not uniform in size.	1a. Check size of media for uniformity.	1a. Replace media
	1b. Rock media broken due to temperature extremes.	1b. Fines clogging filter voids.	1b. Replace media
	1c. Improper operation of primary treatment units.	1c. Excessive SS in filter influent	1c. Correct improper operation of primary treatment units.
	1d. Excessive sloughing excessive biological growth.	1d. Slime growth clogging filter voids.	1d. Flush media with high pressure stream of water and/or dose with chlorine to control slime growth.
	1e. Excessive organic loading	1e. Check loading rates.	1e. Increase recirculation or flood the filter to loosen and remove surface accumulations.
	1f. Accumulation of leaves, debris, etc.	1f. Inspect filter	1f. Remove debris from filter media
	1g. Snails, moss, roaches	1g. Visual inspection	1g. Flush filter and/or chlorinate to produce a residual of 0.5 - 1.0 mg/1
2. Filter Flies	2a. Excessive biological growth on filters.	2a. Visual inspection.	2a. Remove excessive growth as described in 1d.
	2b. Plant grounds provide breeding ground for flies.	2b. Inspect grounds.	2b. Maintain grounds so as not to provide a sanctuary for flies.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
2. Filter Flies (cont'd)	2c. Hydraulic loading too low to wash filter of fly larvae.	2c. Hydraulic loading should be greater than 200 gpd/sq ft	2c. Prevent completion of fly life cycle by the following remedies. 1. Increase recirculation rate. 2. Flood filter for several hrs at regular intervals 3. Chlorinate to produce a residual of 0.5-1.0 mg/l. 4. Apply an insecticide to filter walls and areas breeding flies.
	2d. Poor distribution of wastewater especially along filter walls	2d. Visual inspection.	2d. 1. Unclog spray orifices or nozzles. 2. If alternating wet and dry environment exists, see shortcomings.
3. Odors	3a. Excessive organic loading.	3a. Check organic loading.	3a. 1. Maintain aerobic conditions in all treatment units by adding forced ventilation equipment. 2. Chlorinate filter influent when plant flow is low. 3. Increase recirculation rate to dilute organic strength and improve oxygen transfer
	3b. Poor ventilation due to clogged vent pipes or filter drain.	3b. Check vent pipes and filter drain.	3b. 1. Clear vents and drain system of obstructions. 2. If underdrain system is flowing more than half full reduce hydraulic loading.
	3c. Poor ventilation due to excessive biological growth filling media voids.	3c. Inspect media voids.	3c. Increase recirculation rate to filter.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
3. Odors (cont'd)	3d. Poor housekeeping.	3d. Visual inspection.	3d. Remove debris from filter media and wash down distributor splash plates and walls above media.
	3e. Septic filter influent.	3e. Check influent for H_2S.	3e. Correct upstream system by aeration or controlled prechlorination.
4. Ice build up on filter media.	4a. Climate.	4a. Air and wastewater temperature.	4a. 1. Decrease recirculation 2. When used, operate two-stage filters in parallel. 3. Adjust orifices and splash plates for coarse spray. 4. Partially open dump gates at outer end of distributor arms to provide a stream rather than a spray. 5. Break up and remove ice formation (also see shortcomings).
	4b. Uneven distribution during freezing weather.	4b. Visual inspection.	4b. Adjust distributors for more even flow (remove debris if it has clogged orifices).
5. Uneven distribution of flow on filter surface.	5a. Clogging of distributor orifices.	5a. Ponding in some areas with concurrent drying in other areas.	5a. Remove and clean distributor nozzles and flush distributor piping (also see shortcomings).
	5b. Inadequate hydraulic load on filter.	5b. Hydraulic loading rate.	5b. Maintain adequate hydraulic load.
	5c. Seal leaks.	5c. Seal.	5c. Replace seal.
6. Snails, Moss and Roaches.	6a. Climatic conditions and geographical location.	6a. Visual inspection.	6a. 1. Chlorinate to produce residual of 0.5-1.0 mg/l. 2. Flush filter with maximum recirculation rate.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
7. Increase in clarifier effluent suspended solids.	7a. Excessive sloughing from filter due to seasonal change.	7a. Seasonal changes affecting micro-organisms.	7a. Polymer addition to clarifier influent.
	7b. Excessive sloughing due to organic loading.	7b. Organic loading.	7b. Increase clarifier underflow rate (also see shortcomings)
	7c. Excessive sloughing due to pH or toxic conditions.	7c. pH, toxic substances.	7c. Maintain pH between 5.5 and 9.0 and preferably between 6.5 and 8.5.
	7d. Denitrification in clarifier.	7d. Check effluent for nitrification and see if sludge floats in clumps.	7d. Increase clarifier underflow rate.
	7e. Final clarifier hydraulically overloaded.	7e. Clarifier overflow rate (should not exceed 1200 gpd/sq ft)	7e. If due to recirculation, reduce recirculation rate during peak flow periods.
	7f. Final clarifier equipment malfunction.	7f. Check for: 1. Broken sludge collection equipment. 2. Broken baffles. 3. Uneven flows over effluent weirs.	7f. Repair or replace broken equipment; adjust weirs to an equal elevation.
	7g. Temperature currents in final clarifier.	7g. Temperature profile of clarifier.	7g. Install baffles to stop short-circuiting (see "Secondary Sedimentation Process," Trouble-shooting Guide and Shortcomings).

ACTIVATED BIOFILTER (ABF) PROCESS

Process Description

This process uses a combination of both fixed growth systems and suspended microorganisms as in the conventional activated sludge process. (Figure 36). The ABF process recirculates settled sludge from the secondary clarifier. The fixed growth in this system occurs on redwood racks stacked on top of each other. Through sludge recirculation, a population of suspended microbes is developed, in addition to the fixed growth population on the wooden racks. Oxygen is supplied by the splashing of the wastewater between layers of the wooden racks and by the movement of the wastewater across the microbial layer of the racks. The racks usually are stacked to a depth of 14 ft.

An aeration tank like the one described in the activated sludge section of this manual, is sometimes used between the filter and the secondary clarifier to provide secondary treatment. This tank is smaller than the one used for activated sludge and it provides 1-3 hr detention. Part of the bio-cell underflow passes to the aeration basin and the rest is returned to the wet well. The short-term aeration basin is a completely mixed activated sludge unit that helps to oxidize organics and allow them to settle better in the final clarifier.

The combination of fixed microbial growth and high concentration of suspended growths provides good operation and few system upsets. The process has sometimes been added ahead of existing activated sludge basins to increase plant capacity or efficiency. The ABF process takes up less room than a trickling filter plant and is less affected by cold temperatures.

Typical Design Criteria and Performance Evaluation

Table 4 shows the most common design criteria for the ABF process. Activated biofilters using an aeration basin can provide treatment as good as the activated sludge process. The same procedures used in the activated sludge section of this manual should be used to evaluate the performance of an ABF system.

Control Considerations

The control of the ABF process is much like the control of the activated sludge process, with the bio-cell serving as a mixed liquor aerator. The ABF process is usually characterized by good settling activated sludges (SVI = 70-90). The activated sludge control considerations section of this manual should be reviewed for information relevant to the ABF process.

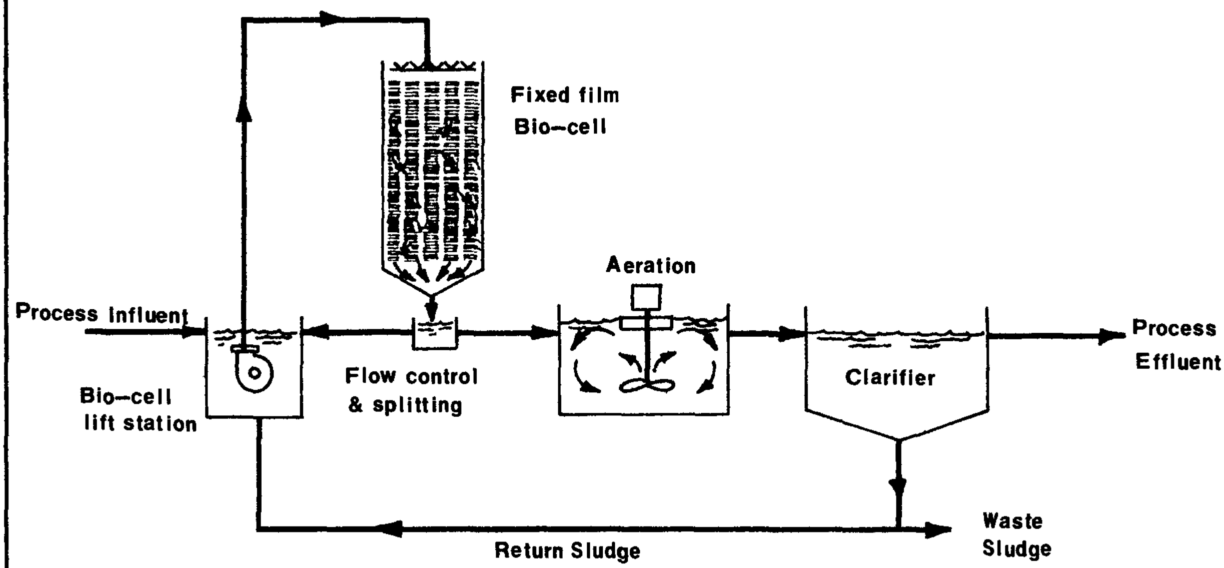


Figure 36. Activated biofilter process schematic.

TABLE 4. TYPICAL ACTIVATED BIOFILTER DESIGN CRITERIA

Media depth	=	14 ft
Biofilter loading	=	200 lbs BOD/1,000 cu ft at peak month loading (1.5 - 5.5 gpm/sq ft)
Aeration basin size	=	0.5 - 2 hrs detention (2.5 - 5 hrs if nitrification required)
Aeration basin F/M	=	0.2 - 0.9 (0.1 - 0.2 if nitrification required)
Aeration basin organic loading	=	50 - 225 lbs BOD/1,000 cf/day (20 - 40 if nitrification required)
Bio-cell recycle	=	0.5 - 2Q
Sludge recycle	=	0.3 - 1Q
MLSS	=	2000 - 5000 mg/l
Return sludge concentration	=	1 - 3%

The amount of recycled flow to the bio-cell lift station is usually adjusted to account for influent and return sludge flow variations in order to keep the bio-cell flow rate constant. This constant flow is maintained to: (a) insure enough aeration of the mixed liquor in the bio-cell under different organic concentrations, (b) maintain uniform flow distribution on the media surface, (c) insure consistent sloughing of fixed film growth, and (d) simplify lift station pump design and operation.

The bio-cell liquid and air flow rates are important process variables because they affect particle-microorganism mixing, reaeration, biofilm shear forces, and reactor temperature change. At low hydraulic rates, reaeration and shear forces are low, which can limit aerobic metabolism and affect uniform biomass sloughing. Also, at very low hydraulic loadings, there is the chance for solids settling and accumulating in the reactor. If hydraulic loadings are less than 0.75 gpm/sq ft, the bio-cell recycle rate should be increased until this minimum rate is reached. Very high liquor loading rates, can affect biofilm performance by washing microbes from the slats. Mixed liquor oxygenation and temperature changes are affected by air and liquid flow rates. Usually, enough oxygen is supplied by natural air flow, since only 75 to 100 scfm air/1,000 cu ft media are required for biologic metabolism during extreme peak demands. At these low air flow rates, the temperature loss across the bio-cell is small.

Return sludge rates of 50% of the average flow rate and bio-cell recycle rates of 50% of the average flow rate are most often used.

Common Design Shortcomings and Ways to Compensate and Troubleshooting Guide

Because of the similarity to the activated sludge process, the shortcomings and troubleshooting guide from the activated sludge section should be referred to for guidance on ABF systems.

LAGOONS

Process Description

Lagoons, or stabilization ponds, are man-made impoundments that treat wastewater through the use of sunlight, wind algae, and oxygen. They are one of the most commonly employed secondary systems and account for about one-third of all secondary plants in the United States. About 90 percent of the ponds are used in towns with less than 10,000 people (1-mgd capacity).

Stabilization ponds are simple basins usually built entirely of earth; they may be dug into natural soil or built above grade by enclosing the area with earthen dikes after removing the natural topsoil. Usually, raw wastewater enters the pond at a single point, either in the middle or at the edge of the pond. The ponds should be deep enough to prevent weed growth, but shallow enough to allow mixing by wind currents.

Figure 37 is a simple illustration of how a stabilization pond works as a wastewater treatment system. Algae grow by taking energy from the sunlight and using up the carbon dioxide and inorganics released by the bacteria in the pond. The algae, in turn, release oxygen needed by the bacteria to add to the oxygen introduced into the pond by wind action. It is important to make sure that there is enough oxygen in the pond for aerobic conditions.

As described in the following paragraphs, there are two main kinds of lagoons that operate almost the same, but differ in depth and in the type of biological life within the lagoon.

An unaerated or facultative lagoon is usually 3 - 5 feet deep, with the organics broken down by aerobic and facultative bacteria. The oxygen in the pond is furnished by oxygen transfer between the air and the water surface and by the algae. In general, a facultative pond has an aerobic zone at the surface, an aerobic and anaerobic zone in the middle depth, and an anaerobic zone at the bottom.

Aeration equipment is sometimes installed in the pond to provide the needed oxygen supply. Such a system is called an "aerated lagoon". Air can be supplied by a compressor that injects air into the pond through tubing installed on the pond bottom or by mechanical aerators installed at the surface of the pond. Aerated ponds are usually about one-fifth the size of a conventional lagoon and are 10 to 15 feet deep.

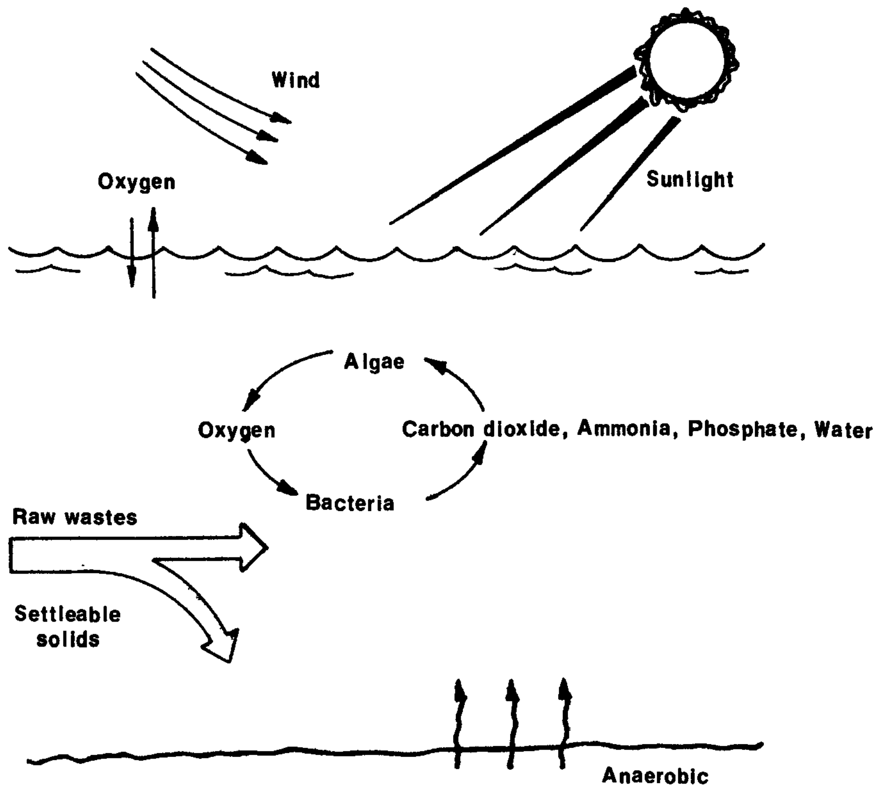


Figure 37. Treatment processes in lagoons.

Typical Design Criteria & Performance Evaluation

Ponds are sometimes designed with several cells in parallel to distribute the wastewater better. This design also avoids localized zones of high oxygen demand caused by uneven deposits of sludges. Several smaller parallel cells also reduce the wave problems that can occur in larger ponds. Ponds are sometimes placed in series for strong wastes or to permit use of the last pond in a series as a polishing step to provide higher removals of suspended solids. Pond effluent is sometimes recirculated to improve mixing and reduce odors.

Typical design parameters for various types of lagoons are shown in Table 5.

Facultative lagoons can often produce a monthly average effluent BOD_5 concentration of less than 30.0 mg/l during most of the year. However, effluent BOD concentrations tend to be higher during the winter months, particularly where ice covers the pond creating anaerobic conditions. Spring overturns can cause increases in effluent BOD_5 concentrations.

Well designed, maintained, and operated facultative ponds can produce a high quality effluent. Although these systems are subject to seasonal upsets, they are capable of producing a low Biochemical Oxygen Demand (BOD_5) effluent that can be polished by several different processes.

In general, the effluent suspended solids concentrations of facultative lagoons follow a seasonal pattern; concentrations are high (40-80 mg/l) during summer months when algal growth is high, and also during the spring and fall overturn periods when settled suspended solids are resuspended from bottom sediments due to mixing. Most of the suspended solids discharged from a facultative lagoon are algal cells which may not be particularly harmful to receiving streams. In areas where effluent suspended solids standards are low, some type of polishing process can be used to reduce suspended solids concentrations to acceptable levels.

Aerated lagoons which are properly designed, operated and maintained can produce an effluent that is low is SS, and which consistently has a BOD_5 concentration of less than 30 mg/l. Aerated lagoon effluent SS concentrations are variable (20-100 mg/l), but BOD_5 concentrations are not affected much by changes in seasons.

In evaluating the performance of a lagoon, the evaluator should check the system records to see that effluent BOD_5 and SS concentrations are generally within the expected ranges described previously.

If the performance is not as good as expected, the following steps should be taken:

1. Determine the design criteria for the pond system.

TABLE 5. DESIGN PARAMETERS FOR STABILIZATION PONDS (Metcalf and Eddy, 1972).

Parameter	Type of Pond: Oxidation Pond	Facultative	Mechanically Aerated Facultative	Mechanically Aerated Lagoons
Detention time, days*	10-40	7-30	7-20	3-10
Depth, ft	3-4	3-6	3-8	6-20
pH	6.5-10.5	6.5-9.0	6.5-8.5	6.5-8.0
Temperature range, °C	0-40	0-50	0-50	0-40
Optimum temperature, °C	20	20	20	20
BOD_5 loading, lb/acre/day	60-120	15-50	30-100	
BOD_5 conversion, percent	80-95	70-95	80-95	80-95
Principal conversion products	Algae, CO_2, bacterial cell tissue	Algae, CO_2, CH_4 bacterial cell tissue	CO_2, CH_4 bacterial cell tissue	CO_2, bacterial cell tissue
Algal concentration, mg/liter	80-200	40-160	10-40	

*Depends on climatic conditions and in cold weather areas detention times as great as 120 days are used for facultative ponds.

Type of Pond, Facultative
Pond Dimensions

Area, A = 872,356 ft^2 or 20 acres
Depth, D = 3 ft
Volume, V = A x D = 60 acre-ft

Flow = 1.0 mgd
BOD = 300 mg/l

2. Determine the detention time of the wastewater within the pond.

$$\text{Detention Time} = \frac{(\text{V in acre-ft})\ (7.48\ \text{gal/ft}^3)\ (43{,}560\ \text{ft}^2/\text{ac})}{(\text{Flow in gpd})}$$

$$= \frac{(60)(7.48)(43{,}560)}{(1 \times 10^6)}$$

$$= 20 \text{ days}$$

For a facultative lagoon, Table 5 shows that a 20 day detention time is within the acceptable 7 to 30 day range.

3. Determine the organic loading for the pond.

$$\text{Organic Loading} = \frac{(\text{Flow in mgd})(\text{BOD, mg/l})(8.34\ \text{lb/gal})}{(\text{Area in Acres})}$$

$$= \frac{(1)(300)(8.34)}{(20)}$$

$$= 125 \text{ lbs BOD/day/acre}$$

By checking Table 5, it is evident that the organic loading of the lagoon is higher than normally expected. If the pond is not performing as desired, the design shortcomings and troubleshooting guide which follow should be read for possible solutions to this problem.

Control Considerations

Properly designed and operated lagoons usually are capable of producing high removal of organic material, solids and bacteria. Primary treatment is sometimes used as pretreatment, but the added cost is usually not justified. Aerated lagoons may be followed by settling tanks and sludge recirculation to the lagoon influent, much like the activated sludge process. The lagoons may be designed and operated to provide complete treatment of the wastewater by allowing complete evaporation of the inflow.

To achieve best results, lagoons must be operated to provide enough mixing to distribute the influent and settleable solids throughout the pond. In unaerated ponds, mixing is provided by wind blowing across the water surface as well as inlets and outlets.

For the light to moderately loaded lagoon, sludge usually does not accumulate in large quantities, although there may be small deposits near the inlet and deposits in cold weather over wider areas. For moderate to heavily loaded lagoons, sludge accumulation may be more significant and may need removal and disposal. The accumulation of sludge must be carefully controlled since the performance of the pond will be reduced, as measured by the SS content of the effluent.

Common Design Shortcomings and Ways to Compensate

	Shortcomings		Solutions
1.	Poor effluent quality due to organic overloading.	1.	a) Install aeration equipment. b) Provide mechanical mixing equipment.
2.	Ice formation resulting in poor effluent quality.	2.	a) Install diffused air system. b) Provide for winter storage.
3.	Short-circuiting of the flow resulting in poor effluent quality.	3.	a) If short-circuiting is wind-induced, install wind screen. b) Revise piping arrangements.
4.	Loss of lagoon volume caused by sludge deposits.	4.	If accumulation is due to excessive land and street drainage, reduce loading via maintenance and repair of sewer system.
5.	Excess turbidity from storm flows, may interfere with light penetration and affect pond performance.	5.	Remove storm flow from sanitary sewer lines by disconnecting storm inlets.
6.	Anaerobic conditions.	6.	a) In the case of unaerated ponds, provide aeration. b) Divert flow from another aerobic pond to it, or pump high D. O. make-up water to it.
7.	Dike erosion.	7.	Plant proper grass cover or add rip rap.
8.	Animals burrowing into the dikes.	8.	a) Place a layer of sand or fine gravel on the inner slope (coarse gravel shall not be used since it tends to breed mosquitos).

Shortcomings		Solutions
	8.	b) If 8-a) fails, trapping may be required.
9. Continual accumulations of scum and floating material collecting in pond corners.	9.	Install a spray with a small pump to supply a spray of water to dispose stagnant accumulations.
10. A single point of entry into a pond tends to overload the pond in the feed zone, resulting in odors.	10.	Utilize multiple entry and single exit approach to distribute the organic load evenly throughout the pond.
11. Thin surface layer of scum forms on calm days.	11.	Provide surface agitation to break up layer.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Poor effluent quality.	1a. Organic overloading.	1a.	1a. Add sodium nitrate to lagoon in order to provide more oxygen or recirculate pond effluent.
	1b. Low temperature.	1b. Air temperature, lagoon brown-colored.	1b. When 2 or more cells provided, operate in series.
	1c. Toxic material in influent.	1c. Brown colored lagoon.	1c. Identity and control at the source.
	1d. Loss of lagoon volume caused by sludge accumulation.	1d.	1d. Remove sludge more frequently.
	1e. Aeration equipment malfunction.	1e. Inspect aeration equipment (if used).	1e. Repair or replace damaged and worn parts.
	1f. Mixing/agitation equipment malfunction.	1f. Inspect mixing/agitation equipment.	1f. Repair or replace damaged and worn parts.
	1g. Excess turbidity from scum and algal mats.	1g. Turbidity.	1g. (1) Break up scum mats. (2) Operate transfer pipes less than ½ full so that unobstructed water surface is maintained between channels and ponds.
	1h. Blockage of light by excessive plant growth on dikes.	1h. Visual inspection.	1h. Remove plant growth at regular intervals.
2. Inability to maintain sufficient liquid level.	2a. Leakage.	2a. Seepage around dikes.	2a. Apply bentonite clay to the pond water to seal leak.
	2b. Excessive evaporation or percolation.	2b. Detention time in pond is probably long.	2b. Divert land drainage or stream flow into lagoon.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
3. Odors.	3a. Anaerobic conditions.	3a. D.O., total and dissolved sulfides.	3a. (1) Break up and re-suspend septic sludge and scum. (2) If available, use extra cell to provide a rest for odorous cell. (3) Add sodium nitrate to pond. (4) Prechlorinate pond influent. (5) Recirculate pond effluent.
	3b. Algal blooms.	3b. Check for blue-green algal growth.	3b. Add $CuSO_4$ at regular monthly intervals: 10 lb/MG for alkalinity >50 mg/l; 5 lb/MG for alkalinity <50 mg/l.
4. Foaming and spray in aerated lagoon.	4. Windy conditions.	4. Visual inspection.	4. Construct a wind barrier around lagoon.
5. Insect generation.	5a. Layers of scum and excessive plant growth in sheltered portions of the lagoon.	5a. Visual inspection.	5a. (1) Weed and scum removal. (2) Application of insecticides.
	5b. Shallow pools of standing water outside lagoon.	5b. Visual inspection.	5b. Cut vegetation outside lagoon, and fill in potholes that collect standing water nearby.
6. Groundwater contamination.	6a. Leakage through bottom and/or sides of lagoon.	6a. Seepage around lagoon dikes.	6a. Apply bentonite clay to pond water to seal leak.
7. Animals burrowing into the dikes.	7a.	7a. Visual inspection.	7a. Alter lagoon level several times in rapid succession. (Also see shortcomings).

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
8. Excessive weeds and tule growth.	8a. Pond too shallow.	8a. Visual inspection mosquitos in the area.	8a. Deepen all pond areas to at least 3 feet.
	8b. Inadequate maintenance program to control vegetation.	8b. Maintenance program.	8b. (1) Correct program deficiency. (2) Install pond lining.
	8c. Poor circulation.	8c. Visual inspection of flow characteristics.	8c. Fluctuate pond level.
9. Low dissolved oxygen content in pond.	9a. Low algal growth.	9a. Pond grey in color.	9a. Remove floating weeds and other debris to increase light penetration.
	9b. Hydrogen sulfides in pond influent.	9b. Hydrogen sulfide odor.	9b. (1) Chlorinate influent. (2) Eliminate septic inflow.
	9c. Detention time.	9c. Detention time is low.	9c. Increase detention time.

ROTATING BIOLOGICAL CONTACTORS

Process Description

A bio-disc or Rotating Biological Contactor (RBC) uses a biological slime of microorganisms which grow on a series of thin discs mounted side by side on a shaft (Figure 38). The discs are rotated slowly and partially submerged in the wastewater. The discs usually are made of lightweight plastic. The RBC is covered to protect the process from low temperatures and from bad weather. When the process is first started, the microbes in the wastewater begin to stick to the disc surfaces and grow there until all the discs are covered with a 1/16 - 1/8-in layer of biological slime. A thin film of wastewater and the organisms on the disc get oxygen from the air as the disc rotates. This film of wastewater then mixes with the rest of the wastewater, adding oxygen to the treated and partially treated wastewater. The excess growth of microbes break off from the discs and flow to the clarifier to be separated from the wastewater. The discs provide media for the buildup of attached microbial growth, bring the growth into contact with the wastewater, and aerate the wastewater and growths in the wastewater reservoir. The speed of rotation can be changed. The attached growth is like the growth in a trickling filter, except that the microbes are passed through the wastewater rather than the wastewater being passed over the microbes. Some of the advantages of both the trickling filter and activated sludge processes are shared. The process can achieve secondary effluent quality or better. By placing several sets of discs in series, it is possible to achieve even higher degrees of treatment - including biological conversion of ammonia to nitrates (nitrification).

Typical Design Criteria and Performance Evaluation

The design of RBC systems is based on the disc surface area and the percent BOD and/or ammonia removal efficiency (see Figures 39 and 40). Common loading rates for secondary treatment of municipal wastewaters are 2-4 gpd/sq ft of effective media area. At temperatures above 15°C, 90% nitrification can be obtained at loadings of 1.5 gpd/sq ft. Systems designed for secondary treatment produce effluent quality like the quality expected from properly designed and operated activated sludge systems. Performance data from one RBC system is shown in Figure 41.

The following will serve as an example of a simple step-by-step procedure for evaluating the performance of an RBC system.

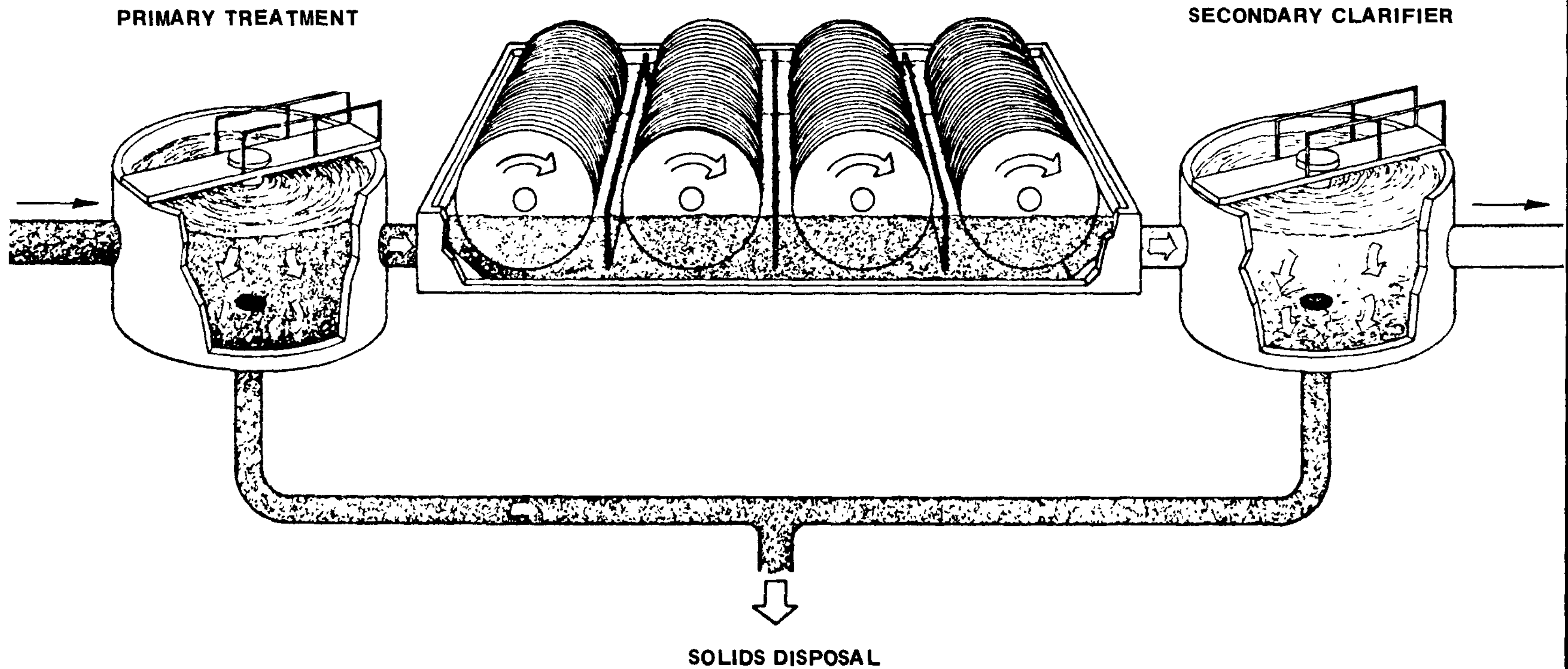


Figure 38. Typical RBC process schematic.

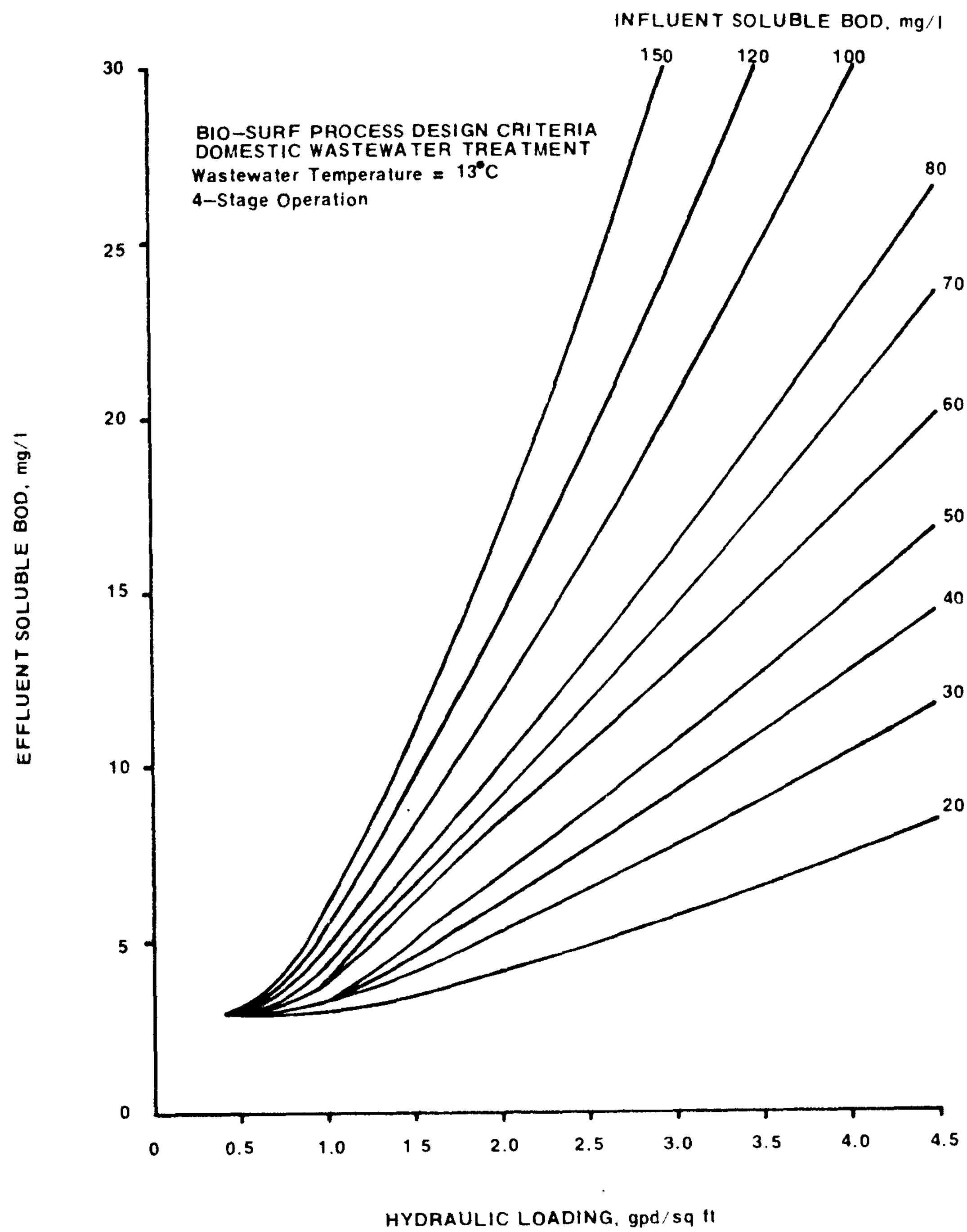


Figure 39. Rotating biological media for secondary treatment.

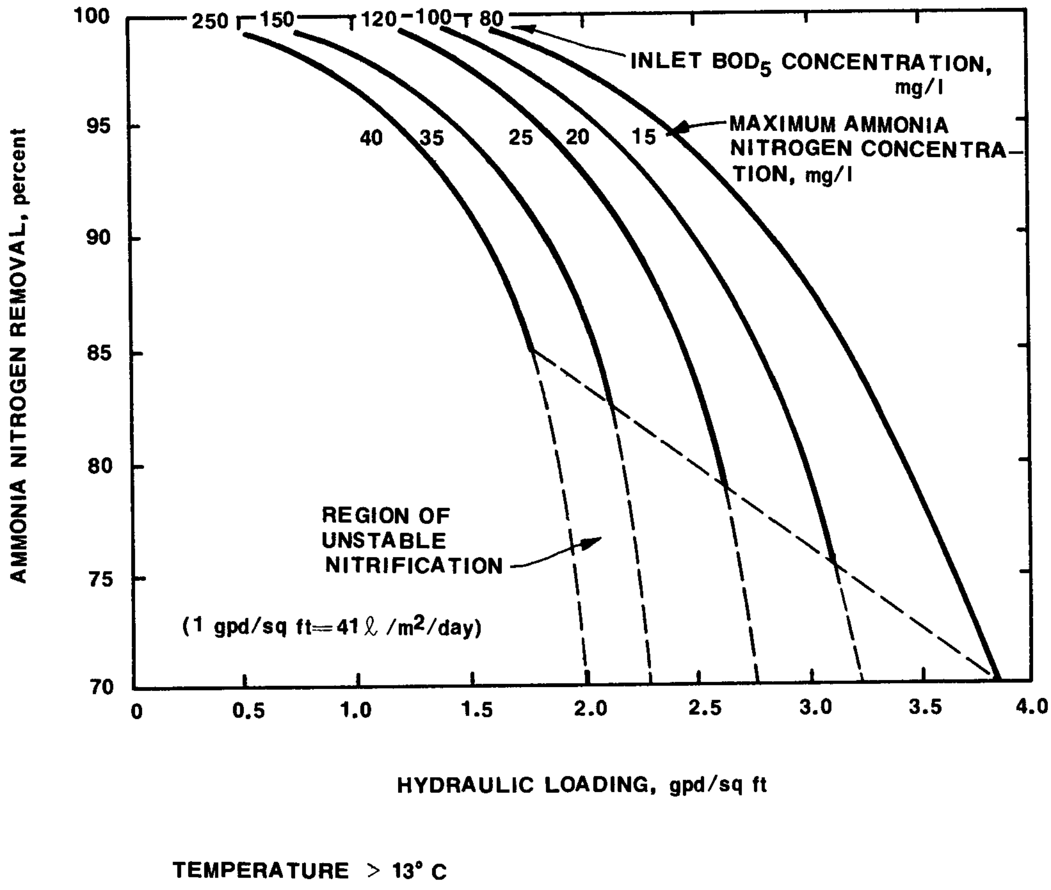


Figure 40. Effect of BOD_5 concentration and hydraulic load on nitrification in the RBC process.

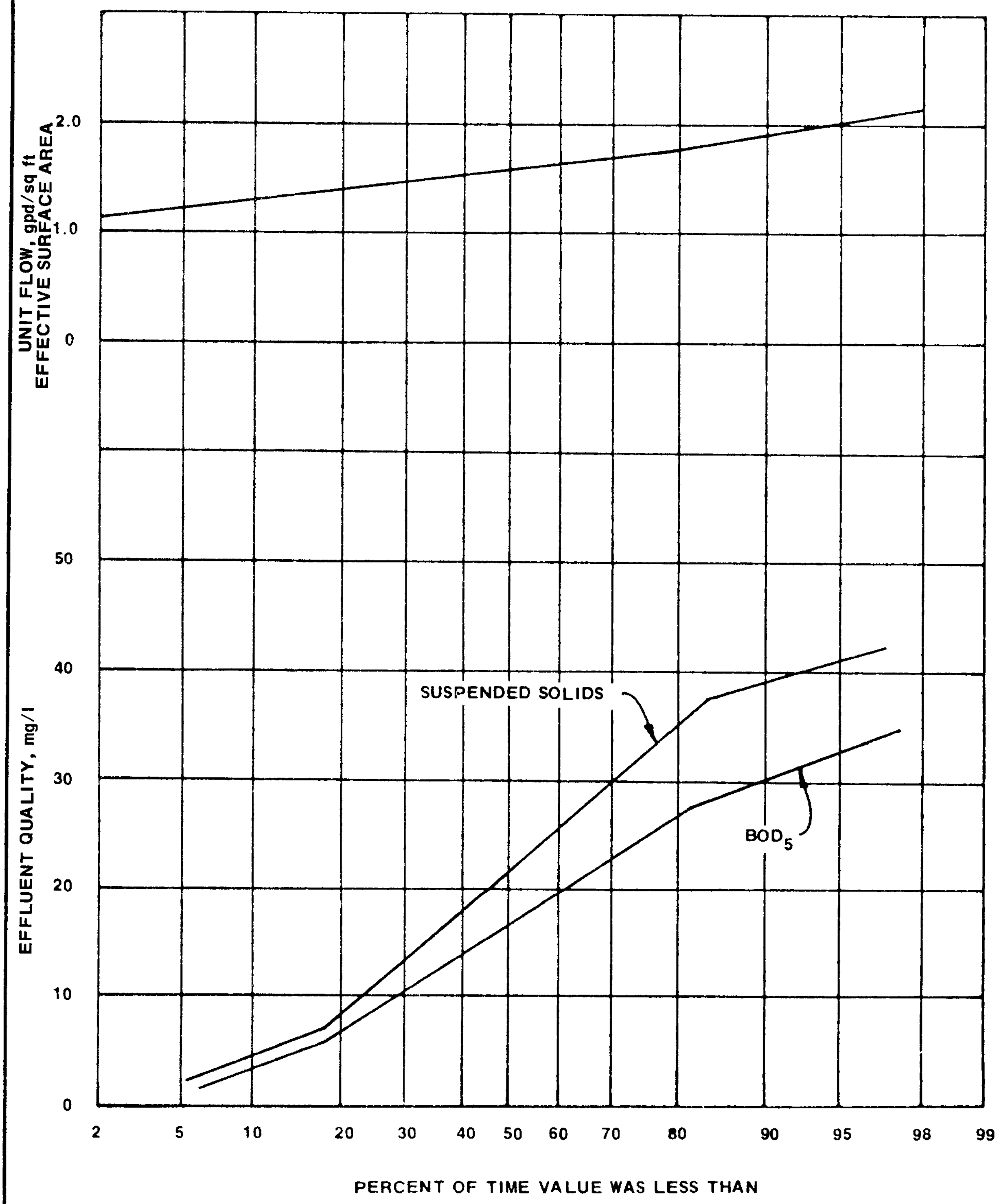


Figure 41. Effluent quality - Gladstone, Michigan.

1. Define the design and operating data for the system.

   4 stage system
   Effective surface area (single stage) = 39,062 ft^2
   Flow = 0.5 mgd
   Influent BOD = 100 mg/l
   Effluent BOD = 20 mg/l

2. Determine the hydraulic loading for the RBC system

   $$\text{Hydraulic loading} = \frac{\text{Total Flow in gpd}}{(\text{No of stages})(\text{area/stage})} = \frac{5 \times 10^5}{(4)(39{,}062)} = 3.2 \text{ gpd/ft}^2$$

3. Determine the efficiency of BOD removal for the system.

   $$\text{\% BOD removal} = \frac{(\text{Influent BOD} - \text{effluent BOD}) \times 100}{\text{Influent BOD}} = \frac{(100 - 20)\ 100}{100} = 80\%$$

4. The calculations determined in steps 2 and 3 should be compared to the expected values shown in Figure 39. As shown in this Figure, a loading rate of 3.2 gpd/ft^2 with an influent BOD of 100 mg/l should produce an effluent BOD around 23 mg/l.

   In the example problem, the effluent BOD was 20 mg/l, slightly better than the expected valve. If the removal were much less than the expected value the troubleshooting guide should be read.

Control Considerations

Very few decisions must be made by the operator to control the process. No sludge or effluent recirculation is practiced, so there is no need for decisions on recycle rates. Sludge should be pumped from the secondary clarifier at a rate high enough to keep the clarifier from going septic, but low enough to avoid very dilute sludge. Where multiple units are used in each stage, flow distribution should be monitored to keep loading uniform. If actual loadings are much less than design loadings, it may be possible not to use some of the equipment, in order to reduce operating costs. Idle units should not be filled with wastewater. A plant designed for secondary treatment will have DO of 0.5 to 1.0 mg/l in the first stage increasing to 1-3 mg/l in the last stage. Nitrification systems often range from 1-3 mg/l in the first stage to 4-8 mg/l in the last stage. Secondary systems usually have a gray, shaggy appearing bio-mass while nitrifying systems have much thinner, less shaggy, and a browner growth.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Decreased treatment efficiency	1a. Organic overload.	1a. Check peak organic loads - if less than twice the daily ave., should not be the cause.	1a. Improve pretreatment or expand plant.
	1b. Hydraulic overload.	1b. Check peak hydraulic loads - if less than twice the daily ave., should not be the cause.	1b. Flow equalization: eliminate source of excessive flow; balance flows between reactors
	1c. pH too high or too low.	1c. Desired range is 6.5 - 8.5 for secondary treatment; 8 - 8.5 for nitrification.	1c. Eliminate source of undesirable pH or add acid or base to adjust pH. When nitrifying, maintain alkalinity at 7 times the influent NH_3 concentrations.
	1d. Low wastewater temperatures.	1d. Temperatures less than 55°F will reduce efficiency.	1d. If available, place added treatment units in service.
2. Excessive sloughing of biomass from discs	2a. Toxic materials in influent.	2a. Determine material and its source.	2a. Eliminate toxic material if possible-if not, use flow equalization to reduce variations in concentration so biomass can acclimate.
	2b. Excessive pH variations.	2b. pH below 5 or above 10 can cause sloughing.	2b. Eliminate source of pH variations or maintain control of influent pH.
3. Development of white biomass over most of disc area.	3a. Septic influent or high H_2S concentrations.	3a. Influent odor.	3a. Preaerate wastewater or add sodium nitrate or hydrogen peroxide.
	3b. First stage is overloaded organically.	3b. Organic loading on first stage.	3b. Adjust baffles between first and second stages to increase fraction of total surface area in first stage.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
4. Solids accumulating in reactors.	4a. Inadequate pretreatment.	4a. Determine if solids are grit or organic.	4a. Remove solids from reactors and provide improved grit removal or primary settling.
5. Shaft bearings running hot or failing.	5a. Inadequate maintenance.	5a. Maintenance schedules and practices.	5a. Lubricate bearings per manufacturers instructions.
6. Motors running hot.	6a. Inadequate maintenance.	6a. Oil level in speed reducer and chain drive.	6a. Lubricate per manufacturers instructions.
	6b. Chain drive alignment improper.	6b. Alignment.	6b. Align properly.

SECONDARY CLARIFIER

Process Description

A secondary clarifier (Figure 42) is constructed and operated very much like a primary clarifier, except that the secondary tank follows the biological treatment process (i.e. trickling filter, activated sludge, etc.). The function of secondary clarifiers varies with the method of biological treatment used. Clarifiers following trickling filters are used to separate biological solids which have broken away from the filter media. Clarifiers in an activated sludge system, however, serve two purposes; Besides providing a clarified effluent, they also provide a concentrated source of return sludge for process control.

Like primary clarifiers, secondary tanks may be round or rectangular in shape. These tanks may be designed for natural settling or chemically aided settling with the tank size being related to one of the following:

- Surface loading rates
- Solids loading rate
- Flow-through velocities
- Weir placement and loading rates
- Retention time of settled sludge

There are several designs of secondary clarifiers, some of which are shown in Figure 43. Hydraulic systems use inlet suction nozzles connected to single hollow collector pipes that sweep the entire tank bottom in a single revolution. This method has the advantage of fast sludge removal and reduces the chances of getting anaerobic sludge. Floating material usually is moved to the skimmer by a surface blade attached to the sludge collector.

Typical Design Criteria and Performance Evaluation

Preceding sections on activated sludge and trickling filters presents information on evaluation of the secondary clarifier portion of these procedures.

Typical design data for secondary clarifiers following different kinds of treatment processes are presented in Table 6.

For clarifiers following trickling filters, the design is based on hydraulic overflow rates like those described for primary clarifiers. Design overflow rates must include recirculated flow where clarified secondary

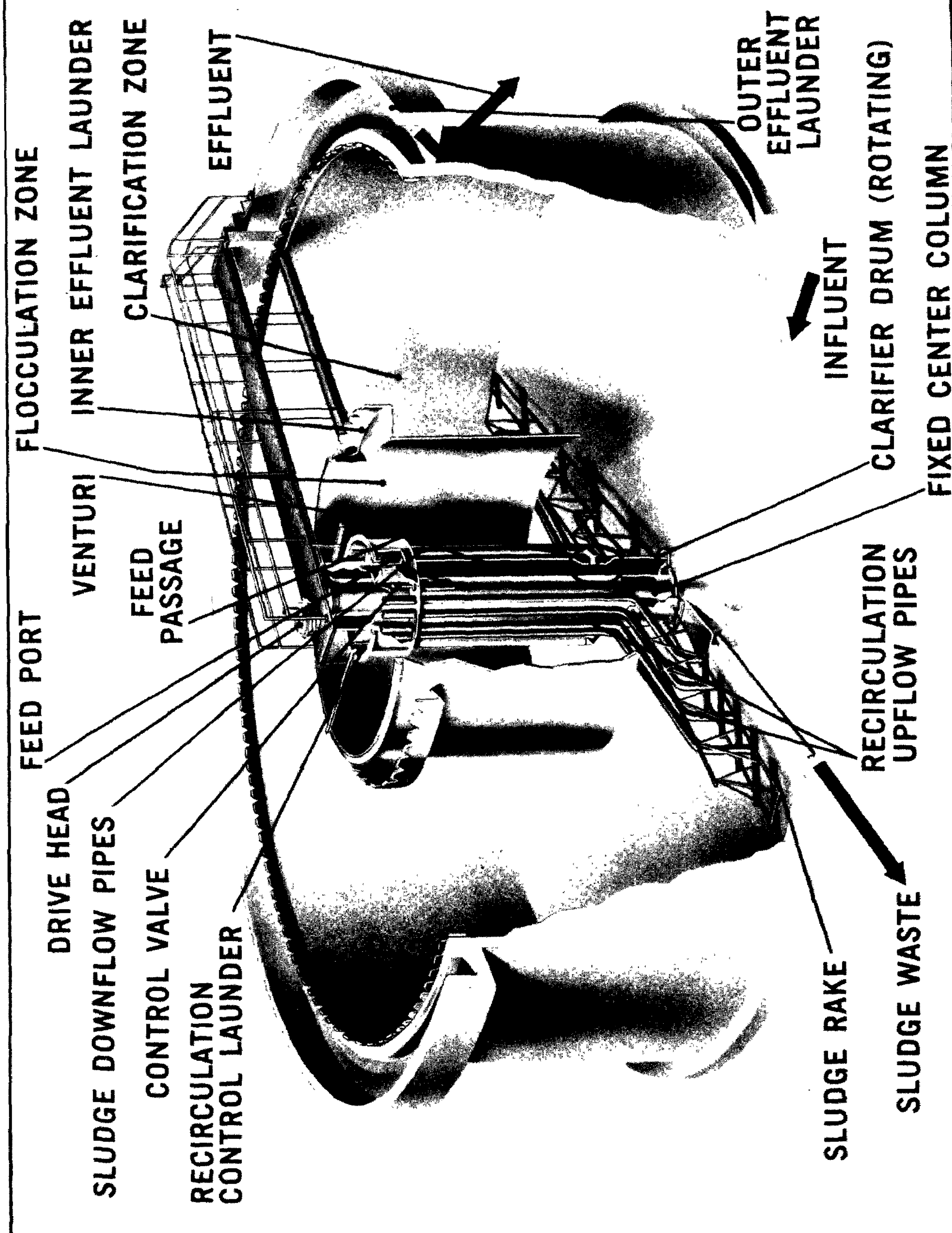
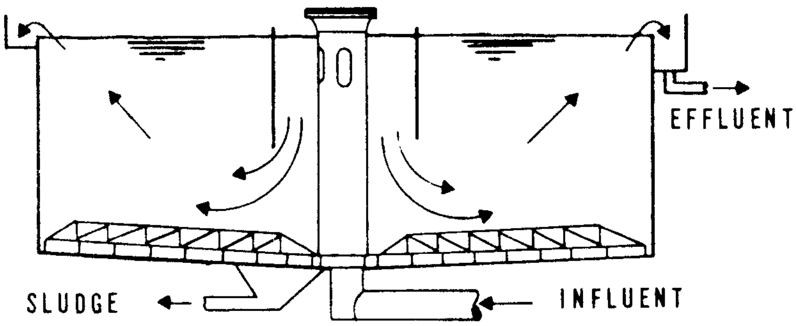
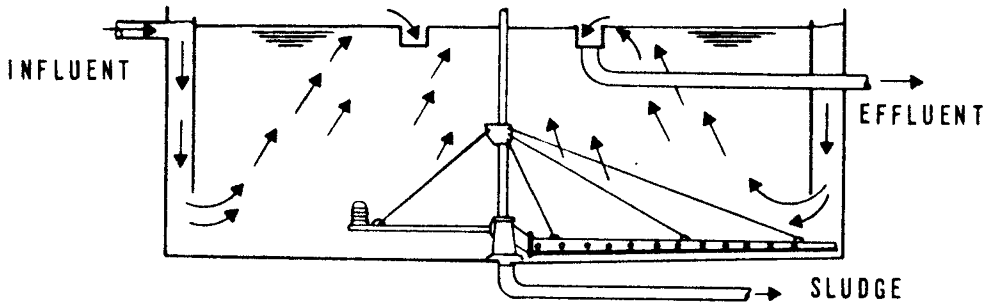


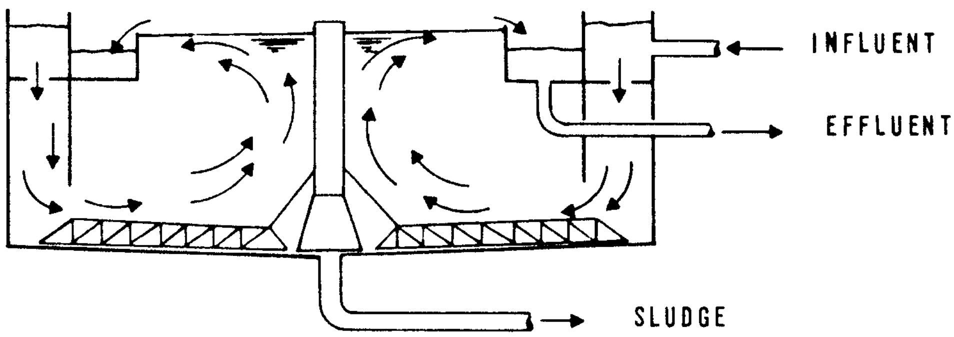
Figure 42. Secondary sedimentation tank.



(a) CIRCULAR CENTER-FEED CLARIFIER WITH A SCRAPER REMOVAL SYSTEM



(b) CIRCULAR RIM-FEED, CENTER TAKE-OFF CLARIFIER WITH A HYDRAULIC SUCTION SLUDGE REMOVAL SYSTEM



(c) CIRCULAR RIM-FEED, RIM TAKE-OFF CLARIFIER

Figure 43. Typical clarifier configurations.

TABLE 6. TYPICAL DESIGN PARAMETERS FOR SECONDARY CLARIFIERS

Type of treatment	Overflow rate Average	Peak	Solids loading[1] Average	Peak	Depth
	gpd/sq ft		lb solids/day/sq ft		ft
Settling following trickling filtration	400-600	1,000-1,200	- -	- -	10-12
Settling following activated sludge	400-800	1,000-1,200	20-30	<50	12-15
Settling following oxygen-activated sludge with primary settling	400-800	1,000-1,200	25-35	<50	12-15

[1] Allowable solids loadings are governed by sludge settling characteristics.

effluent is used for recirculation. Because the influent SS concentrations are low, tank solids loadings need not be considered.

Clarifiers in activated sludge systems must be designed not only for hydraulic overflow rates, but also for solids loading rates. This is because both clarification and thickening are needed in activated sludge clarifiers. When the MLSS concentration is less than about 3,000 mg/l, the clarifier size is normally based on hydraulic overflow rates. At higher MLSS values, the ability of the clarifier to thicken solids becomes more important, and the solids loading rate becomes more critical in determining tank size. As a result, the design of clarifiers following the activated sludge process should be based on average and peak overflow rates and solids loadings. The combination that gives the largest surface area should be used, so that good quality may always be obtained.

The performance of secondary wastewater treatment systems is determined by comparing the quality of the overflow from secondary clarifiers to that of the incoming wastewater. The biological treatment unit converts some of the soluble and insoluble organics to suspended organic solids. However, the treatment process is successful only if these organic solids are removed in the secondary clarifiers. Secondary clarifier design variables have the most critical effect on overall plant performance. Therefore, in order to have good quality plant effluent, the secondary clarifier must be properly designed.

<u>Control Considerations</u>

As with most wastewater treatment equipment, the efficient operation of secondary clarifiers depends on the proper operation of other plant processes. For example, in many treatment plants, the MLSS concentration will be changed to achieve a desired operating condition in the aeration tanks without considering the possible adverse effects on the secondary clarifiers. It is common practice among many operators to carry high MLSS concentrations to increase SRT, so that more organic matter is oxidized and sludge mass is reduced. In many cases, the high solids loading rate associated with high MLSS concentrations will cause the sludge blanket to rise to a level where solids will be swept over the effluent weirs. Thus, it is most important that a proper solids balance be kept between the aeration tank and clarifier.

Stability can be achieved by providing a large enough aeration basin to reduce changing oxygen demands and unusual shifts in solids inventory. When the recycle rate is constant, and plant inflow rates are low, the system solids will tend to shift to the aeration basin since the solids going to the clarifier is low. However, when the peak flows occur, the solids will shift to the clarifier. The most important thing is to keep the solids from filling the final clarifier and spilling over into the effluent.

In conventionally designed plants, the solids inventory can best be controlled during maximum and minimum flows, by varying the recycle rate to balance the shift in solids which occurs during changes in hydraulic load.

The secondary clarifier should not be used as a storage basin for activated sludge; the sludge should be removed and a portion of it returned to the aeration tanks as quickly as possible. Best return rates are often in the range of 25 to 30% of the secondary inflow rate for most systems. The sludge level in each clarifier should not be greater than ¼ the final basin depth. The sludge level is controlled by the sludge removal rate. Some of the removed solids are wasted from the system and the remainder is returned to the aeration basins. Excessive sludge inventory in the secondary clarifiers can lead to loss of sludge over the clarifier effluent weirs, causing high effluent solids. The earlier activated sludge section discusses control of the rate at which sludge should be removed from the secondary clarifier.

Scum should be properly removed from the secondary clarifier, since poor scum removal can have bad effects on plant performance. Excessive skimming will result in too much water being carried over with the scum. If insufficient scum is removed, it will flow around or under the baffle and leave the tank in the effluent.

Equal flow distribution should be provided among all available secondary settling tanks. Even with equal distribution of flow, some differences in efficiencies may be found between two or more units. With unequal flow, however, less SS and BOD will be removed overall.

In many cases, the addition of iron, aluminum salts, or polymers can greatly improve secondary clarifier performance. This depends on the amount, where it is added in the system, and the flocculant nature of the biomass. For example, in certain processes such as trickling filtration and extended aeration, solids may not flocculate and settle well in the secondary clarifier. In this case, the addition of iron or aluminum salts into the secondary clarifier may improve overall plant performance. Whenever chemicals are used in secondary processes, however, the dosage should be carefully controlled. When too much or not enough coagulant is added, poor clarification occurs. The addition of iron or aluminum salts can greatly increase the amount of sludge, so that other ideas for improved sedimentation should be studied first.

Good control of secondary clarifier operations is also important to the operation of downstream processes. An effective secondary clarifier allows better disinfection, reduces the frequency of cleaning chlorine contact tanks, and provides a clear effluent.

Common Design Shortcomings and Ways to Compensate

Shortcomings	Solutions
1. Clarifiers in activated sludge systems are sensitive to sudden changes in flow rate due to influent pumping.	1. Where flow equalization is not provided, install multispeed pumps for in-plant lift stations.
2. Poor hydraulic distribution of influent into several clarifier tanks will cause some tanks to become overloaded.	2. Provide sufficient head loss in the ports feeding the tanks, in order to eliminate the effect of water level variations in the distribution channel.
3. Inability to capture settleable solids at high overflow rates.	3. Use tube settlers to decrease the depth of settling or feed settling aid at high flows.
4. Poor sludge removal with conventional sludge scraping mechanism.	4. Use suction-type units which remove sludge from entire tank bottom in one revolution.
5. Clarifier too shallow, side walls less than 10 ft.	5. Use increased rates of return activated sludge to control sludge blanket.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Sludge floating to surface of secondary clarifiers.	1a. "Bulking Sludge" - Filamentous organisms predominating in mixed liquor.	1a. SVI - If less than 100, 1(a) is not likely cause; microscopic examination also can be used to determine presence of filamentous organisms.	1a. (1) Increase DO in aeration tank if less than 1 mg/l. (2) Increase pH to 7. (3) Supplement deficiency of nutrients so that BOD to nutrient ratio is no more than 100 mg/l BOD to 5 mg/l total nitrogen; to 1 mg/l phosphorus; to 0.5 mg/l iron. (4) Add 5-60 mg/l of chlorine to return sludge until SVI <150. (5) Add 50-200 mg/l of hydrogen peroxide to aeration tank until SVI <150. (6) Increase SRT. (7) Increase sludge return rate.
	1b. "Rising Sludge" - Denitrification occurring in secondary clarifiers; nitrogen gas bubbles attaching to sludge particles; sludge rises in clumps.	1b. Nitrate concentration in clarifier influent; if no measureable NO_3 then 1(b) is not the cause.	1b. (1) Increase sludge return rate (2) Increase DO in aeration tank. (3) Reduce SRT.
	1c. Broken or warped wooden flights.	1c. Visual inspection.	1c. Repair or replace flights.
	1d. Sludge collectors operating too slowly (septic sludge).	1d. Frequency and speed of sludge collection (sludge black with septic odor).	1d. (1) Increase speed or frequency of operation of sludge collectors. (2) Install skimming baffles to keep sludge from entering effluent weirs.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Sludge floating to surface of secondary clarifiers (cont'd)	1e. Over-aerated sludge		1e. Reduce turbulence in aeration tank.
2. Pin floc in secondary clarifier overflow - SVI is good but effluent is turbid.	2a. Excessive turbulence		2a. Reduce aeration agitation.
	2b. Long SRT	2b. MLSS	2b. Increase sludge wasting to decrease SRT
	2c. Anaerobic conditions in aeration tank.	2c. DO in aeration tank.	2c. Increase DO in aeration tank.
	2d. Toxic shock load.	2d. Microscopically examine sludge for inactive protozoa.	2d. Re-seed sludge with sludge from another plant if possible; enforce industrial waste ordinances.
	2e. Short-circuiting of flow allowing solids to pass over weirs.		2e. Level weirs to prevent short-circuiting.
	2f. Anaerobic side streams recycled.		2f. Identify and correct sources of anaerobic conditions.
3. Fouling of weirs.	3a. Accumulation of wastewater solids and/or aquatic plant growth on weirs.	3a. Visual inspection	3a. (1) More frequent and thorough cleaning on surfaces. (2) Pre-chlorination in addition to more frequent and thorough scrubbing.
4. Plugging of sludge ports.	4a. High content of heavy compacted material.	4a. Visual inspection.	4a. Loosen compacted material manually or with liquid or air pressure jetting.
	4b. Low velocity in with-drawal lines.	4b. Sludge withdrawal rate and resulting velocity.	4b. (1) Backflush clogged lines. (2) Pump sludge more frequently. (3) Revise sludge piping.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Short-circuiting of flow through clarifier	5a. Excessive hydraulic loading.		5a. Place more units in service.
	5b. Weir not level.	5b. Visual inspection.	5b. Level weir.
	5c. Equipment malfunction.	5c. Visual inspection.	5c. Replace or repair damaged scrapers etc.
	5d. Reduced detention time resulting from large solids and grit accumulation.	5d. Visual inspection.	5d. (1) Remove excessive solids accumulation. (2) Operate grit chamber.
6. Excess torque on rake mechanism.	6a. Excessive load on sludge scraper.	6a. Scrapers stop; motor overloading; torque meter indicating excessively high torque reading.	6a. (1) Inspect for and repair/ replace defective and worn parts. (2) Remove or break up ice formation on walls and surfaces. (3) Operate collector for longer period or pump sludge more often at a higher rate. (4) Drain and check basin for objects which may have fallen into basin.
7. Deflocculation in clarifier.	7a. Toxic or acid wastes.	7a. Supernatant above settled sludge is uniform in turbidity.	7a. Remove source of industrial waste.
	7b. Anaerobic conditions in aeration tank.		7b. Increase DO in aeration tank.
	7c. Aeration tank overloaded.		7c. Place more basins in service.
	7d. Inadequate nitrogen or phosphorus supply.		7d. Supplement deficiency in nutrients by chemical addition.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
7. Deflocculation in clarifier (cont'd)	7e. Excessive shear caused by turbulence.		7e. Reduce agitation.
8. Sludge blanket overflowing secondary clarifier weirs uniformly throughout basin.	8a. Inadequate rate of sludge return.	8a. Sludge return pump output, or depth of sludge blanket.	8a. (1) If return pump is malfunctioning, place another pump in service & repair. (2) If pump is in good condition increase rate of return and monitor sludge blanket depth routinely. Maintain 1-3 ft depth blanket. When blanket increases in depth, increase rate of return. (3) Clean sludge return line if plugged.
	8b. Unequal flow distribution to clarifiers causing hydraulic overload.	8b. Flow to each clarifier.	8b. Adjust valves and/or inlet gates to equally distribute flow.
	8c. Peak flows are overloading clarifiers.	8c. Hydraulic overflow rates at peak flows if >1,000 gpd/sq ft this is a likely cause.	8c. Install flow equalization facilities or expand plant.
9. Billowing sludge.	9a. Hydraulic surges.	9a. Visual inspection of sludge conditions.	9a. Eliminate hydraulic surges.
	9b. Density currents.		9b. Keep sludge depth as low as possible.
	9c. Stirring by sludge scrapers.		9c. Reduce scraper speed.

CHLORINATION

Process Description

The most common use of chlorine in sewage treatment is for disinfection, which usually is the last treatment step in a secondary plant. Where the treated effluent is fed into a stream to be used for water supply or for recreational purposes, chlorination is effective in destroying the disease-producing organisms (called "pathogens") found in treated wastewater. Other principal uses of chlorine are odor control and control of bulking in activated sludge.

Chlorine may be fed into the wastewater automatically, with the dosage depending on the degree of treatment previously given the sewage. The wastewater then flows into a tank, where it usually is held for about 30 mins to allow the chlorine to react with the pathogens (Figure 44). Chlorine often is used either as a gas, or a solid or liquid compound containing hypochlorite. Hypochlorite has been used mostly in small systems (less than 5,000 persons), or in large systems, where safety concerns related to handling chlorine gas outweigh economic concerns. The use of chlorine has proven to be a very effective means of disinfection.

Chlorine is also used in advanced wastewater treatment (AWT) for nitrogen removal, through a process known as "Breakpoint Chlorination". For nitrogen removal, enough chlorine is added to the wastewater to convert all the ammonium nitrogen to nitrogen gas. To do this, about 10 mg/l of chlorine must be added per mg/l of ammonia nitrogen in the wastewater - about 40 or 50 times more chlorine than normally used in a wastewater plant for disinfection only.

The facilities required for the process are simple. Wastewater (after secondary or tertiary treatment) flows into a mixing tank where the chlorine is added and complete mixing is provided. Because a large amount of chlorine is used and has an acidic effect on the wastewater, alkaline chemicals (such as lime) may be added to the same chamber to balance this effect. The nitrogen gas which is formed is then released to the atmosphere. The amount of chlorine used for nitrogen control provides very effective disinfection. Because the process is just as effective in removing 1 mg/l as 20 mg/l of ammonium, breakpoint chlorination often is used as a polishing step downstream of other nitrogen removal processes.

Typical Design Criteria and Performance Evaluation

Figure 45 shows how residual chlorine effects coliform number. The curves show the most probable number (MPN) of coliforms remaining

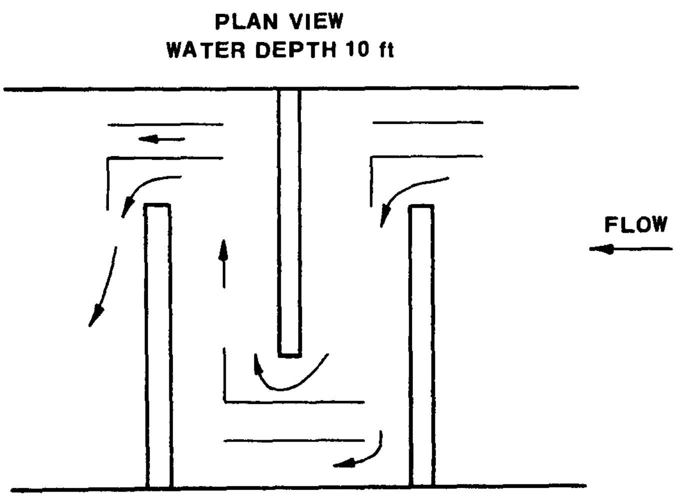


Figure 44. Chlorine contact chamber with end - around baffles and vanes.

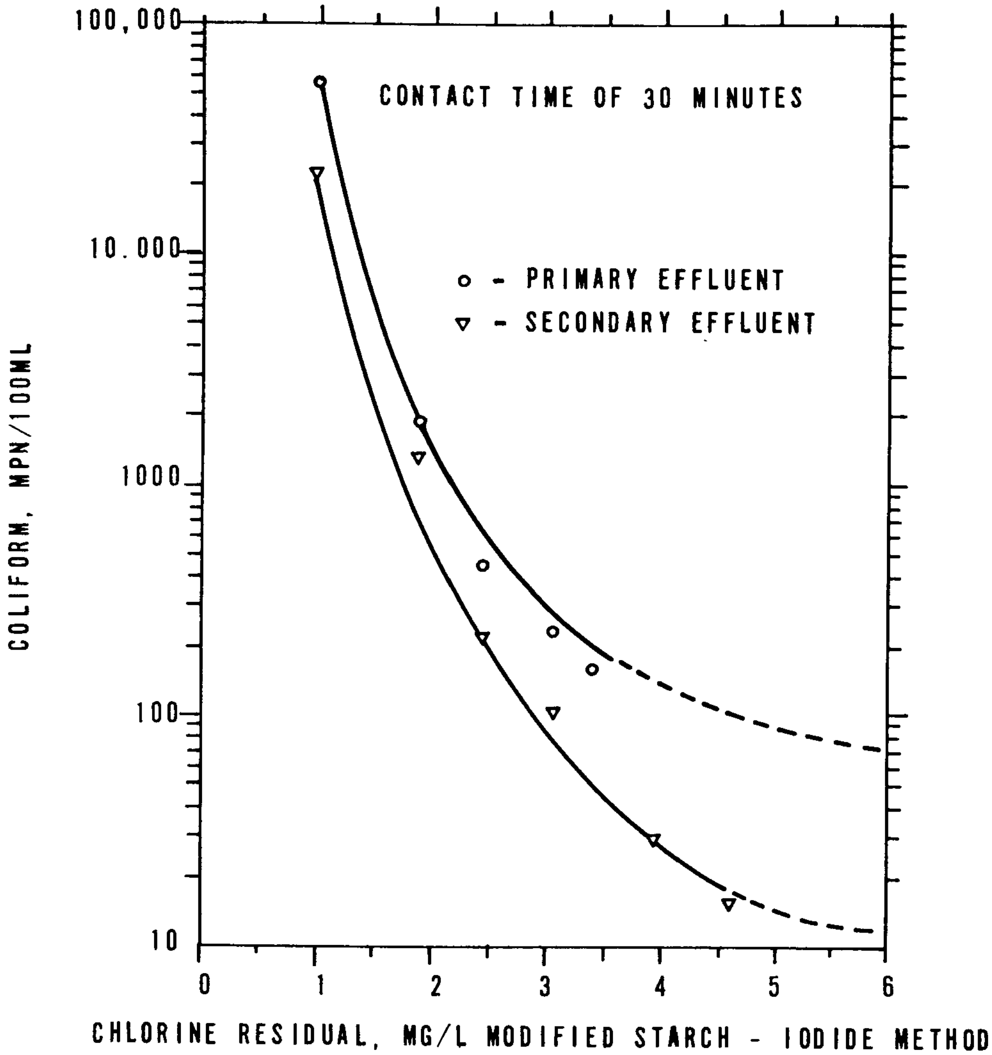


Figure 45. MPN Coliform vs. chlorine residual.

after 30 mins of chlorine contact in a well-designed chlorine contact tank. These results should not be considered as being exact.

Table 7 lists chlorine dosages often used for disinfection of raw and partially-treated sewage.

In breakpoint chlorination, about 10 mg/l of chlorine must be added for each mg/l of ammonia nitrogen present in the wastewater. Studies show that better pretreatment will reduce the amount of chlorine needed to reach breakpoint. Table 8 shows how different pretreatment processes affect the chlorine to ammonia-nitrogen ratio needed for breakpoint chlorination. The breakpoint process can result in 99+ percent removal of ammonium nitrogen, reducing concentrations to less than 0.1 mg/l (as N).

To evaluate the performance of a chlorination system, the evaluator should check the contact time, chlorine residual and MPN of coliform organisms after chlorination. This can be done easily in the following steps:

1. Obtain design and typical operating data for the chlorination system being studied.
   Example:

Type of effluent	Activated sludge
Peak plant flow	5.0 mgd
Volume of Cl contact tank, V	13,926 cu ft
Chlorine dosage	6.0 mg/l
Chlorine residual	1.0 mg/l

2. Determine the contact time for the chlorine contact tank based on peak flow.

$$\text{Contact time, hrs} = \frac{\text{V in cu ft} \times 7.48 \text{ gal/cu ft} \times 24 \text{ hrs/day}}{\text{Flow in gpd}}$$

$$= \frac{(13{,}926)\ (7.48)\ (24)}{5 \times 10^6}$$

$$= 0.45 \text{ hrs or } 27 \text{ min}$$

3. Examine the daily disinfection log sheet for chlorine feed rates and chlorine residual patterns. Compare both contact time and chlorine residual with those required by the proper regulatory agency. As a general rule, residuals between 0.2 and 1.0 mg/l after 15 to 30 min contact times provide good disinfection. As shown in the example the 27 min contact time and 1.0 mg/l residual should be generally sufficient.

4. If the chlorination system does not perform as expected, the shortcomings and troubleshooting guide should be studied.

TABLE 7. CHLORINE DOSAGE RANGES

Waste	Chlorine dosage mg/l
Raw sewage	6 to 12
Raw sewage (septic)	12 to 25
Settled sewage	5 to 10
Settled sewage (septic)	12 to 40
Chemical precipitation effluent	3 to 10
Trickling filter effluent	3 to 10
Activated sludge effluent	2 to 8
Sand filter effluent	1 to 5

TABLE 8. EFFECT OF PRETREATMENT ON $Cl_2:NH_4^+$-N BREAKPOINT RATIO

Sample	Breakpoint pH	Initial NH_4^+-N (mg/l)	Final NH_4^+-N (mg/l)	Irreducible minimum residual (mg/l as Cl_2)	Breakpoint ratio $Cl_2:NH_4^+$-N (weight basis)
			Laboratory Tests		
Buffered water	6-7	20	0.1	0.6	8:1
Raw wastewater	6.5-7.5	15	0.2	7	9:1-10:1
Lime clarified raw wastewater	6.5-7.5	11.2	0.1	7	8:1-9:1
Secondary effluent	6.5-7.5	8.1	0.2	3	8:1-9:1
Lime clarified secondary effluent	6.5-7.5	9.2	0.1	4	8:1
Ferric chloride clarified raw wastewater-carbon adsorption	3.2	10.2	0.1	20	8.2:1
			Pilot Plant Tests		
Filtered secondary effluent	6-8	12.9-21.0	0.1	2-8.5	8.4:1-9.2:1
Lime clarified raw wastewater-filtered	7.0-7.3	9.7-12.5	0.4-1.2	-	9:1
Alum clarified oxidation pond effluent-filtered	6.6	20.6	0.1	7.6	9.6:1

Control Considerations

In general, the better the treatment plant is operated, the easier it will be to disinfect the effluent. Any failure to provide adequate treatment will increase the bacterial count and the chlorine requirement. High solids content and soluble organic loads increase the amount of chlorine needed.

Effective chlorine disinfection is dependent upon the combined effect of chlorine dosage, mixing and contact time with the wastewater. Enough disinfectant should be added to always meet the bacterial quality required by the regulatory agency. Control of the disinfection process is accomplished by measurement of the chlorine residual.

Proper mixing is one of the most important factors in chlorine disinfection. Applying chlorine to wastewater in a well mixed system produces a much better effluent than a system where chlorine is fed without rapid mixing, even with adequate residual and contact time. However, sufficient contact time (usually 30 min) between the chlorine and the wastewater also is needed to provide good disinfection. Usually, longer contact times are more important than higher residuals in wastewater treatment.

In breakpoint chlorination, the system must be able to meet quick changes in ammonia nitrogen concentrations, chlorine demand, pH, alkalinity and flow. Failure to properly control chlorine dosage can result in poor nitrogen removal, and chlorine overdoses. Overdoses of chlorine are a direct waste of this chemical and cause problems in adjusting the operation of the dechlorination equipment. Overdoses also can cause the direct discharge of high concentrations of chlorine residuals to the receiving water, and can result in the undesirable formation of NCl_3.

Usually, a base chemical is added to the breakpoint process to neutralize some of the acidity resulting from the chlorine addition. The base requirements depend on wastewater alkalinity, individual treatment processes used before breakpoint chlorination as well as effluent pH or alkalinity restrictions by regulatory agencies.

Another consideration in breakpoint chlorination is dechlorination to remove the chlorine residual from the final effluents before it is discharged. Very often, dechlorination using sulfur dioxide or activated carbon may be needed when the breakpoint chlorination process is used.

In most cases, control of breakpoint chlorination requires the use of accurate and reliable automatic equipment to reduce the need for manual process control by operators. However, the operator must give special attention to this equipment and monitoring devices in order to insure their proper operation.

Common Design Shortcomings and Ways to Compensate

Shortcomings	Solution
1. Big changes in effluent chlorine residual when chlorine flow proportioning control device is operating properly.	1. Install a continuous chlorine residual analyzer to control the feed rate automatically, or use a closed loop system.
2. Short-circuiting in chlorine contact tank.	2. Make channels very narrow or provide thorough baffling in channel to insure complete mixing and a sufficient contact time.
3. High residual chlorine concentrations in the effluent toxic to aquatic life.	3. Install dechlorinating systems (activated carbon, hydrogen peroxide, sulfur dioxide, sodium metabisulfite).
4. Sodium hypochlorite cannot be stored for long periods of time without deteriorating.	4. If long storage periods cannot be avoided, dilute the sodium hypochlorite to slow down the rate of deterioration, or use liquid (gas) chlorine as an alternate source.
5. Lack of mixing.	5. Install mechanical mixer.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Low chlorine gas pressure at chlorinator.	1a. Insufficient number of cylinders connected to system.	1a. Reduce feed rate and note if pressure rises appreciably after short period of time. If so, 1a is the cause.	1a. Connect enough cylinders to the system so that chlorine feed rate does not exceed the withdrawal rate from the cylinders.
	1b. Stoppage or flow restriction between cylinders and chlorinators.	1b. Reduce feed rate and note if icing and cooling effect on supply lines continues.	1b. Disassemble chlorine header system at point where cooling begins, locate stoppage and clean with solvent.
2. No chlorine gas pressure at chlorinator.	2a. Chlorine cylinders empty or not connected to system.	2a. Visual inspection.	2a. Connect cylinders or replace empty cylinders.
	2b. Plugged or damaged pressure reducing valve.	2b. Inspect valve.	2b. Repair the reducing valve after shutting off cylinder valves, and decreasing gas in the header system.
3. Chlorinator will not feed any chlorine.	3a. Pressure reducing valve in chlorinator is dirty.	3a. Visual inspection	3a. 1. Disassemble chlorinator and clean valve stem and seat. 2. Precede valve with a filter-sediment trap.
	3b. Chlorine cylinder hotter than chlorine control apparatus.	3b. Cylinder area temperature.	3b. 1. Reduce temperature in cylinder area. 2. Do not connect a new cylinder which has been sitting in the sun.
4. Chlorine gas escaping from chlorine pressure reducing valve (CPRV).	4a. Main diaphragm of CPRV ruptured due to: 1. Improper assembly or fatigue. 2. Corrosion	4a. Place ammonia bottle near termination of CPRV vent line to confirm leak.	4a. 1. Disassemble valve and diaphragm. 2. Inspect chlorine supply system for moisture intrusion.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Inability to maintain chlorine feed rate without icing of chlorine system.	5a. Insufficient evaporator capacity.	5a. Reduce feed rate to about 75% of evaporator capacity. If this eliminates problem 5a is the cause.	
	5b. External CPRV cartridge is clogged.	5b. Inspect cartridge.	5b. Flush and clean cartridge.
6. Chlorination system unable to maintain water-bath temperature sufficient to keep external CPRV* open.	6a. Heating element malfunction.	6a. Evaporator water-bath temperature.	6a. Remove and replace heating element.
7. Inability to obtain maximum feed rate from chlorinator.	7a. Inadequate chlorine gas pressure.	7a. Gas pressure.	7a. Increase pressure - replace empty or low cylinders.
	7b. Water pump injector clogged with deposits.	7b. Inspect injector	7b. Clean injector parts using muriatic acid. Rinse with fresh water and replace in service.
	7c. Leak in vacuum relief valve.	7c. Disconnect vent line at chlorinator; place hand over vent connection to vacuum relief valve, observe if this results in more vacuum and higher chlorine feed rate.	7c. Disassemble vacuum relief valve and replace all springs.
	7d. Vacuum leak in joints, gaskets, tubing, etc. in chlorinator system.	7d. Moisten joints with ammonia solution, or put paper containing orthotolidine at each joint in order to detect leak.	7d. Repair all vacuum leaks by tightening joints, replacing gaskets, replacing tubing and/or compression nuts.

*Chlorine Pressure Reducing Valve

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
8. Inability to maintain adequate chlorine feed rate.	8a. Malfunction or deterioration of water supply pump.	8a. Inspect pump.	8a. Overhaul pump (if turbine pump is used, try closing down needle valve to maintain proper discharge pressure).
9. Wide variation in chlorine residual produced in effluent.	9a. Chlorine flow proportion meter capacity inadequate to meet plant flow.	9a. Check chlorine meter capacity against plant flow meter capacity.	9a. Replace with higher capacity chlorinator meter.
	9b. Malfunctioning automatic controls.	9b.	9b. Call manufacturer's field service personnel.
	9c. Solids settled in chlorine contact chamber.	9c. Solids in contact chamber.	9c. Clean chlorine contact chamber.
	9d. Flow proportioning control device not zeroed or spanned correctly.	9d. Check zero and span of control device on chlorinator.	9d. Re-zero and span the device in accordance with manufacturer's instructions.
10. Chlorine residual analyzer recorder controller does not control chlorine residual properly.	10a. Electrodes fouled.	10a. Visual inspection.	10a. Clean electrodes.
	10b. Loop-time too long.	10b. Check loop-time.	10b. Reduce loop time by doing the following: 1. Move injector closer to point of application. 2. Increase velocity in sample line to analyzer cell. 3. Move cell closer to sample point. 4. Move sample point closer to point of application.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
10. Chlorine residual analyzer recorder controller does not control chlorine residual properly (Cont'd)	10c. Insufficient potassium iodide being added for amount of residual being measured.	10c. Potassium iodide dosage.	10c. Adjust potassium iodide feed to correspond with residual being measured.
	10d. Buffer additive system malfunctioning	10d. See if pH of sample going thru cell is maintained.	10d. Repair buffer additive system.
	10e. Malfunctioning of analyzer cell.	10e. Disconnect analyzer cell and apply a simulated signal to recorder mechanism.	10e. Call authorized service personnel to repair electrical components.
	10f. Poor mixing of chlorine at point of application.	10f. Set chlorine feed rate at constant dosage and analyze a series of grab samples for consistency.	10f. Install mixing device to cause turbulence at point of application.
	10g. Rotameter tube range is improperly set.	10g. Check tube range to see if it gives too small or too large an incremental change in feed rate.	10g. Replace with a proper range of feed rate.
11. Coliform count fails to meet required standards for disinfection.	11a. Inadequate chlorination equipment capacity.	11a. Check capacity of equipment.	11a. Replace equipment as necessary to provide treatment based on maximum flow through plant.
	11b. Inadequate chlorine residual control.	11b. Continuously record residual in effluent.	11b. Use chlorine residual analyzer to monitor and control the chlorine dosage automatically.
	11c. Short-circuiting in contact chamber.	11c. Contact time.	11c. 1. Install baffling in contact chamber. 2. Install mixing device in contact chamber.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
11. Coliform count fails to meet required standards for disinfection (Cont'd)	11d. Solids build-up in contact chamber. 11e. Chlorine residual too low.	11d. Visual inspection. 11e. Chlorine residual.	11d. Clean contact chamber to reduce solids build-up. 11e. Increase contact time and/or increase chlorine feed rate.
12. Chlorine residual too high in plant effluent to meet requirements.	12a. Chlorine residual too high.	12a. Determine toxicity level by bioassay procedures.	12a. Install dechlorination facility (See Shortcomings).

OZONATION

Process Description

Ozone has been used for disinfection of water since 1900 and has recently found increased use for disinfection of wastewaters. Some of the advantages of using ozone rather than chlorine include:

- its high germicidal effectiveness, even against resistant organisms such as viruses and cysts;
- on decomposition, the only residual material is more dissolved oxygen;
- no dissolved solids, such as chlorides, are added;
- its disinfecting power is not affected by pH or ammonia content.

Ozone has also been used to control odors from treatment units. In these cases, ozone is applied to the exhaust air, given a short period of contact, and then discharged to the atmosphere. The reaction takes place very quickly, and is effective in destroying organic odors. Doses usually are between 1 and 2 mg/l by volume, with a contact time ranging from a few seconds to half a minute.

There are three basic ways to generate and use ozone in wastewater treatment: (1) generation from air, (2) generation from oxygen and recycle oxygen to the ozone generation system, and (3) generation from oxygen used for oxygen activated sludge system and recycle oxygen to the activated sludge system. Figure 46 pictures these different methods.

The once-through air approach uses conventional air drying techniques such as compression and refrigeration, followed by desiccant drying. Ozone generated from air is usually 0.5 to 2.0% by weight, but is usually produced at 1.0 weight percent. Ozone is typically mixed with wastewater in a contact basin as shown in Figure 47. Fine bubble diffusers are used to feed the ozone into the basin. Packed beds have also been used as contactors. Following treatment in the covered ozone contactor, the gas is decomposed to prevent high concentrations of ozone from being released to the atmosphere.

The oxygen recycle approach may be used to recover valuable oxygen-rich off-gas from the contractor when very pure oxygen is fed to the ozone generator. High-purity oxygen gas sometimes is used since it

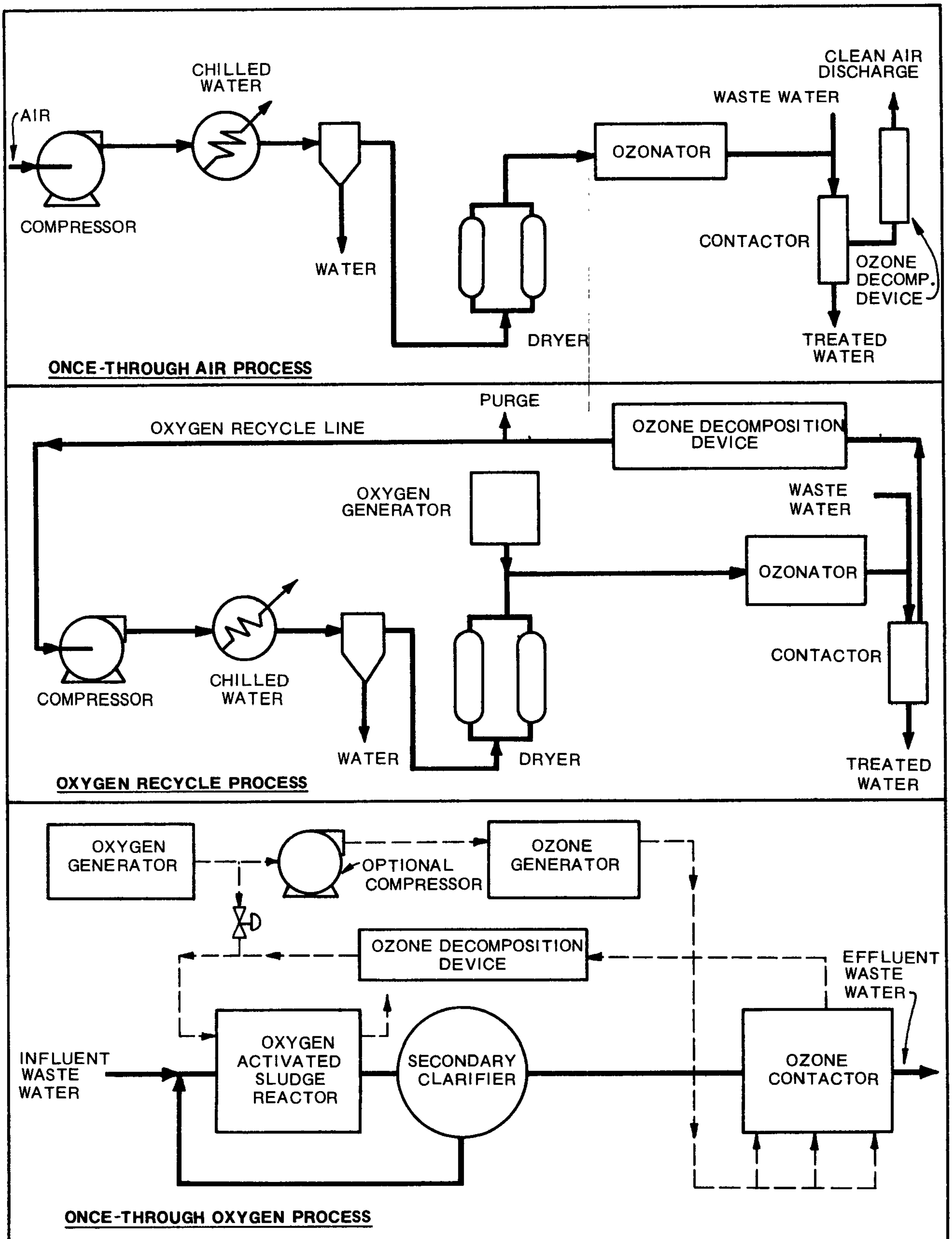


Figure 46. Alternative ozonation systems.

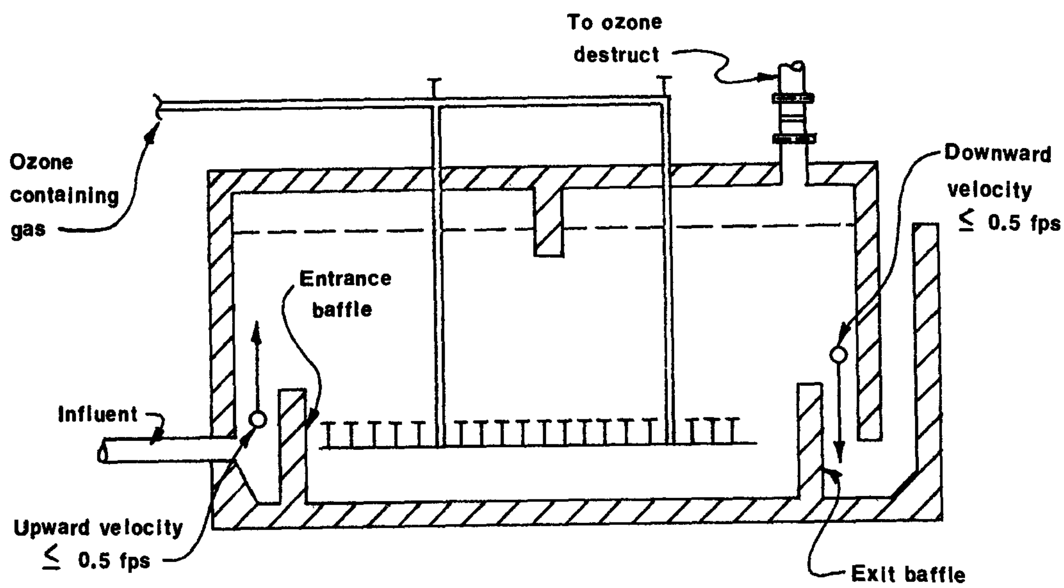


Figure 47. Typical ozone contact basin using porous diffusers.

enables the generator to produce two to three times as much ozone per unit time, and uses only about half as much generator power per pound compared to ozone produced from air.

Once-through oxygen is the simplest method of ozone wastewater disinfection. Dry oxygen is produced on-site by a cold air separation process or by pressure-swing adsorption and then fed to the ozone generator. Wastewater is next treated by ozonation in the contactor and, after destruction of the unreacted ozone, the off-gas is used elsewhere in the plant. It may, for example, be used in a biological reactor or fed into incinerators for sludge disposal.

There are three basic types of commercially available ozone generators: The Otto plate, the tube and the Lowther plate (Figure 48). While there may be some differences in these units, the following describes the basic systems.

1. Otto Plate Type: The ozonator has several parts arranged as follows: a cast-aluminum, water-cooled block that acts as the ground electrode, a glass plate dielectric, an air space, another glass dielectric and a high voltage stainless steel electrode. A complete "unit" would include the mirror image of dielectrics, air space and a grounded, water-cooled electrode.

Air is blown into the ozonator and enters the discharge gap where the air turns into ozone. The ozonized air is drawn through a manifold pipe with holes cut in the center of each of the electrodes and dielectrics. One drawback of the Otto plate-type generator is that operation is limited to low pressure.

2. Tube Type: The tube type generator consists of several tubular units. The outer electrodes are stainless steel tubes fastened into stainless steel tube spacers and surrounded by cooling water. Centered inside the stainless steel tubes are tubular glass dielectrics whose inner surfaces are coated with a conductor which acts as the second electrode. The stainless steel outer tubes are arranged in parallel and are sealed into a cooling water distribution system.

3. Lowther Plate-Type: This generator is very different from the Otto plate-type. The Lowther generator is air cooled, and operates on either air or oxygen feed.

The basic unit is a gas-tight "sandwich" made up of an aluminum heat dissipator, a steel electrode coated with a ceramic dielectric, a glass spacer to set the discharge gap, a second ceramic coated steel electrode with an oxygen inlet and an ozone outlet which exists through a second aluminum heat dissipator. These basic units are pressed together in a frame and manifolded for oxygen and ozone flow. Cooling is accomplished by a fan moving outside air across the heat dissipators. This is the most commonly used system in the U.S.

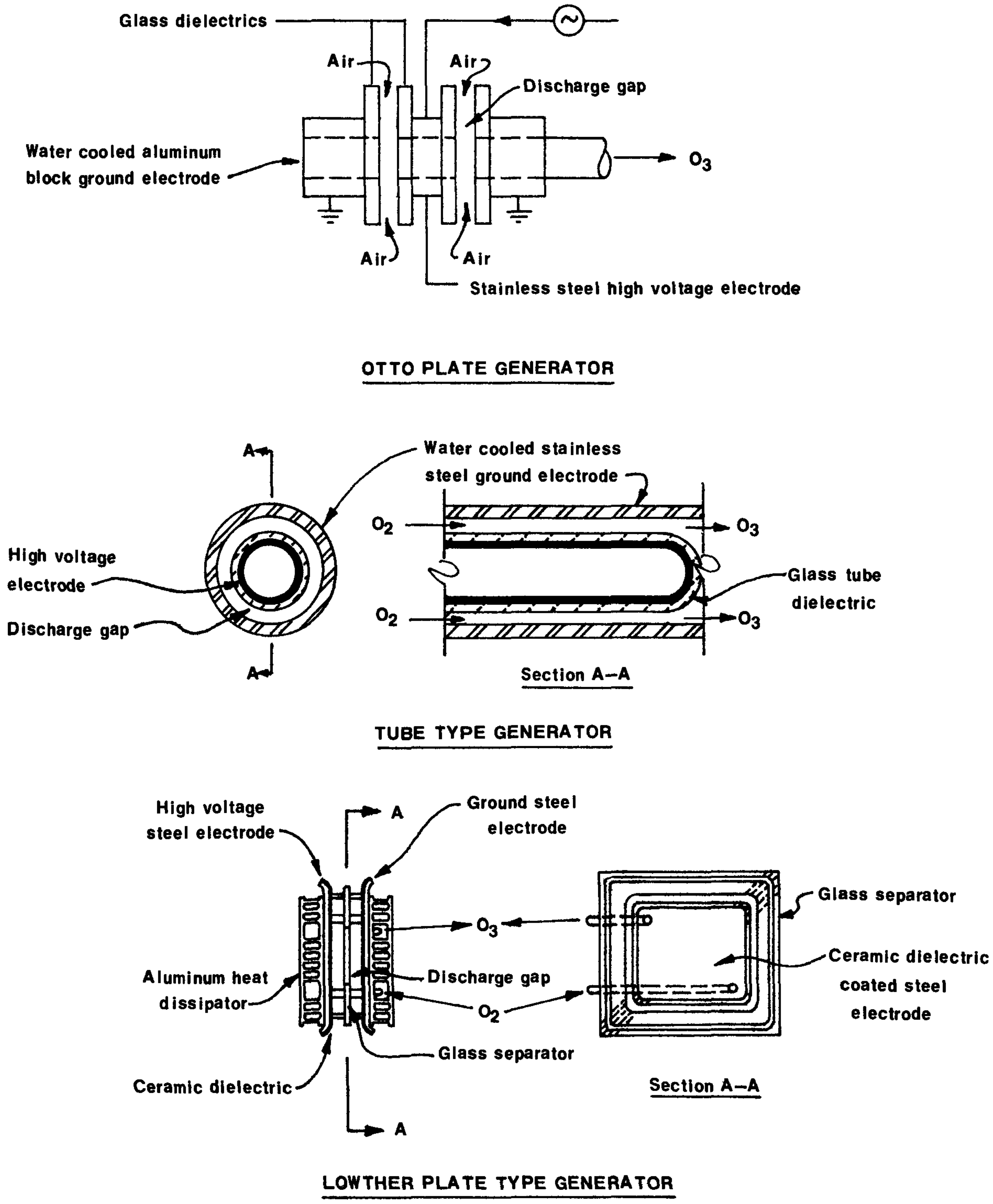


Figure 48. Ozone generator types.

Thus, the equipment required for ozonation falls into three major parts: air preparation, ozone generation, and ozone injection.

Typical Design Criteria and Performance Evaluation

Coliform standards of 200 fecal coliform/100 ml can usually be met in secondary effluents by ozone dosages of about 5 mg/l. Standards calling for almost complete coliform removal (to 2/100 ml total coliform) may require dosages of 15 mg/l or more. As with any disinfectant, exact dosages are a function of secondary effluent quality, efficiency of mixing, and contact time.

Key design variables related to ozone generators are summarized in Table 9. Ozone contact systems are typically designed for a minimum ozone utilization of 90% and disinfection contact time of about 15 min. Methods used for feeding ozone into water include porous diffusers, emulsion turbines, and injectors working on the venturi principal.

Besides being used as a disinfectant, ozone may also produce an effluent with less color and turbidity.

As with chlorine disinfection, the performance evaluation of ozonation systems should involve contact time and MPN of coliform in the effluent just before discharge. The best indicator of performance is the MPN of coliforms in the effluent as it compares to requirements of the regulatory agency. If the system does not provide acceptable treatment, the troubleshooting guide on ozonation should be reviewed.

Control Considerations

Ozone is a highly toxic gas and the manufacturer's safety instructions should be carefully followed.

To get the most ozone from the ozone generator:

1. The voltage should be kept relatively low while reasonable operating pressures are maintained. Keeping voltage low protects the dielectric and/or the electrode surfaces from the high voltage failure.

2. High frequency a-c should be used. High frequency is less damaging to the dielectric surfaces than high voltage. This decreases maintenance requirements and increases the useful life of the machine, while producing increased ozone yields.

3. Heat removal should be as efficient as possible.

Ozone generation rates are determined by the feed gas oxygen content, the feed gas flow rate, and the corona power. The feed gas oxygen content usually cannot be changed. Gas flow rate can usually be varied within a pressure range of about 8-15 psig. The corona power is determined by the

TABLE 9. OZONE GENERATOR DESIGN CRITERIA

Comparison of Commercial Ozonators-Typical Ozonator Operating Characteristics

Type	Feed	Dew Point of feed, °F	Cooling	Pressure psig	Discharge gap, in.	Voltage kv, peak	Frequency Hz	Dielectric thickness, in.
Otto	air	-60	water	0	0.125	7.5-20	50-500	0.12-0.19
Tube	air oxygen	-60	water	3-15	0.10	15-19	60	0.10
Lowther	air oxygen	-40	air	1-12	0.05	8-10	2000	0.02

Ozone Generator Power Requirements*

Type	Air feed kwhr/lb	Oxygen feed kwhr/lb
Otto	10.2	-----
Tube	7.5-10	3.75-5.0
Lowther	6.3-8.8	2.5-3.5

*for 1 percent ozone, higher ozone concentrations require greater power per lb.

frequency of the electrical pulses which trigger the corona cells. A balance must be kept between ozone concentration and operating costs. The loser ozone concentrations (1-2%) are less costly to produce, but higher concentrations usually give the best results.

The volts, amps, cell temperature, line pressure, gas flow rate should be recorded each shift with daily determination made of ozone production using calibrated ozone monitors and dew point of feed gas.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. No scum removal or foam control installed in contact basin.	1. Install skimmer.
2. No self-contained breathing apparatus provided near but outside ozone generator area.	2. Purchase self-contained breathing apparatus for safety - do not use chemical cartridge respirators.
3. Ozone concentration indicator/recorder not provided for gas exiting the ozone generators and on off-gas from contactor.	3. Install indicator/recorders with range of 0-6% ozone.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Ozone generator overheats and shuts down.	1a. Fan or cooling system malfunction.	1a. Fan louvers for obstruction.	1a. Clean louvers.
		1b. Fan for free rotation	1b. Lubricate fan bearings or remove obstructions hampering rotation.
		1c. Fan belts for tightness and condition.	1c. Tighten or replace belts.
2. No voltage or current to generator.	2a. Silicon controlled Rectifier (SCR) fuse blown.		2a. 1. Replace SCR fuse. 2. Replace surge arrestor. 3. Replace SCR's.
	2b. Control circuit blown.		2b. 1. Find and repair fault. 2. Replace control fuses.
	2c. Interlock circuit failure.	2c. 1. Make sure all doors or panels with interlocks are closed. 2. Check interlock switches such as gas flow.	2c. 1. Replace panel or door interlock switches. 2. Check reset mechanisms, establish proper gas flow.
	2d. No main power.	2d. Remote, main breakers.	2d. Reset main breaker.
3. Full voltage, no current.	3a. Master oscillator malfunction.	3a. Fuses.	3a. 1. Locate fault & repair. 2. Replace fuses.
	3b. Control circuit malfunction.	3b. 1. Relays & heaters. 2. Fan rotation.	3b. 1. Reset relays. 2. See 1b.
4. Low ozone production.	4a. Feed gas dew point high.	4a. Check dew point.	4a. Find leak in feed gas system and repair.
	4b. Decreased oxygen purity of feed gas.	4b. Feed gas oxygen content.	4b. Find leak in feed gas system and repair.
	4c. Significant number of cell fuses blown.	4c. Check fuses.	4c. Check fuses.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
4. Low ozone production (Cont'd)	4d. Cell exteriors dirty.	4d. Cell modules and cleanliness of cooling air.	4d. Clean cell modules in accordance with manufacturers instructions; insure cooling air is clean.
	4e. Low gas flow.	4e. Check gas flow rate and pressure.	4e. Establish proper feed pressure.
5. Ozone odor detectable.	5. Ozone leak.	5a. Manifold and flange connections - paper towels soaked with potassium iodide will turn purple when held next to ozone leak.	5. Tighten or repair faulty connection.
6. Low voltage which falls to zero when operation starts.	6. Blown rectifier fuses.	6. Fuses.	6a. Find/repair fault. 6b. Replace fuses.
7. Full voltage, 1/2 current, increased noise level.	7. Master oscillator malfunction.		7. Shut down at once and replace with spare units.
8. Inadequate disinfection achieved.	8a. Low ozone dosage.	8a. Ozone generator output.	8a. Increase dosage (see item 4).
	8b. Secondary effluent quality has degraded.	8b. Secondary effluent turbidity.	8b. Improve operation of secondary plant.
	8c. Diffusers partly plugged.		8c. Clean diffusers or replace as necessary.

FILTRATION

Process Description

In the filtration process, wastewater is passed through a filtering medium, such as fine sand or coal, in order to remove suspended or colloidal matter. The main purpose of filtration in tertiary treatment is to remove suspended solids from a secondary effluent or from effluent following the coagulation - sedimentation process. Filtration reduces turbidity and improves the chlorine disinfection process.

The two most commonly used types of filters in wastewater treatment are the gravity and pressure filters. Figures 49 and 50 show these two types of filters and their major parts.

Usually, wastewater is passed downward through the filter medium. After sometime, the filter becomes plugged with material removed from the wastewater, and the filter must be cleaned by reversing the flow ("backwashing"). The upward backwash rate must be high enough that the media particles are suspended and the wastewater solids are washed from the bed. These backwash wastewaters (usually less than 5% of the wastewater flow treated) must be recycled to the wastewater treatment plant for processing.

Filter beds usually are 30-36 in deep and made of relatively small particles (less than 1.5 millimeters in size). However, some filters use deeper beds and more coarse materials. Modern wastewater filters usually are made up of a mixture of two or three different media (coal, sand, and garnet are commonly used) of varying sizes and specific gravities. These materials form a filter (called a "multimedia" or "mixed media" filter), which is coarse at the top of the filter and becomes more fine with depth. This coarse to fine mixture allows solids removed from the water to be stored throughout the bed, rather than only at the top surface. Also, this design requires less frequent backwashings than single media beds.

Typical Design Criteria and Performance Evaluation

The major design variables are:

- Filter configuration (gravity or pressure)
- Media type, size, and depth
- Filtration rate
- Backwash system

Closed type filters allow influent pressures above atmospheric, while open filters have only the water pressure over the bed to overcome

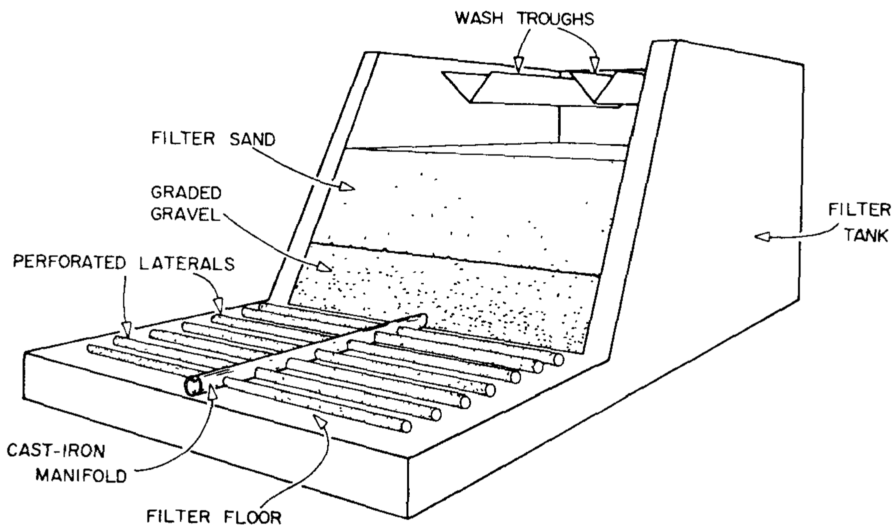


Figure 49. Typical gravity filter.

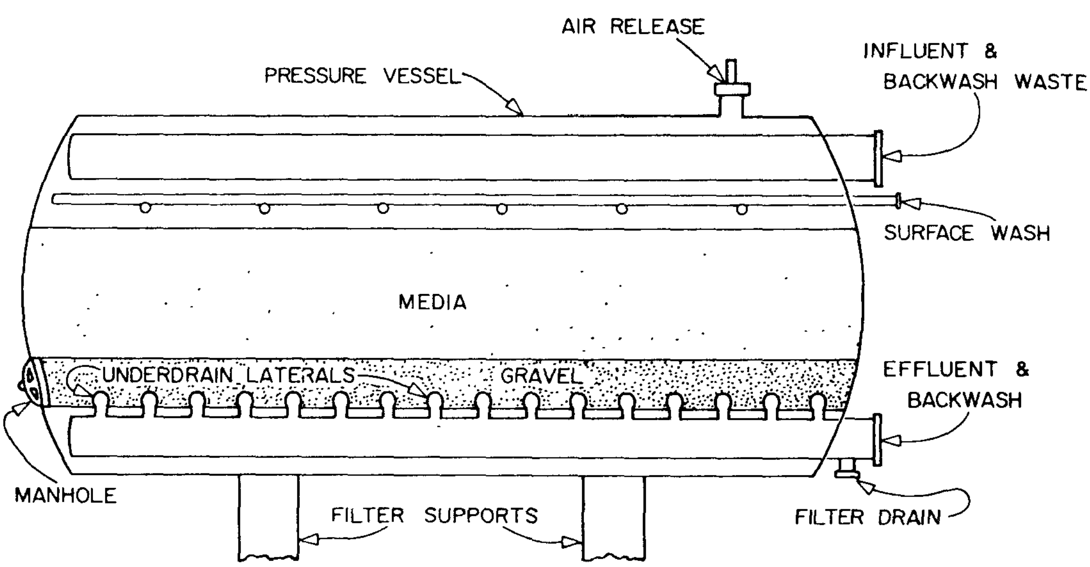


Figure 50. Typical pressure filter.

filter headlosses. Pressure units are generally used where high final headlosses are expected or where the added head will allow effluent to pass through downstream units without repumping. They are most often used in small-to-medium-sized treatment plants where steel-shell package units are economical.

Filter media designs usually consist of dual media filters with 15 in of coal (about 1.8 mm in diameter) over 15 in of sand (0.55 mm) or mixed media with about 16 in of coal, 9 in of sand, and 4 in of garnet. Design criteria used for a typical mixed media system are shown in Table 10.

The most common filtration rates used in wastewater treatment range from 3 to 6 gpm/sq ft of filter area.

Backwash systems for filters usually are operated at rates of about 15 gpm/sq ft for 5-10 min. To insure complete cleaning, filters often have rotary surface wash devices which are operated for 1 to 2 min before the backwashing flow is started. Many surface wash systems have a revolving pipe with several nozzles attached. These units are set 1 to 2 in above the normal surface of the filter. Washwater under 50 to 100 psi pressure is fed through the nozzles, causing the pipe to rotate during the backwash cycle. The amount of water needed for these devices usually is in the range of 0.75 to 1.0 gpm/sq ft. Rather than use surface wash devices, some systems inject air into the backwashing system.

Some of the major items that determine actual filter performance include:

- maximum available headloss
- filtration rate
- influent characteristics
- media characteristics
- design of backwash system

Of these, the single most important factor is the quality of the influent to the filter. When filtering secondary effluent, if the biological system always operates very well, good filter performance can be expected. However, if the biological system often is upset, filtration will be much more difficult. Because filter performance is affected so much by the quality of its influent, a simple performance evaluation may be determined as follows:

1. Calculate the filter area and maximum filter rate: (using the filters in Table 10).

   $$\text{Maximum flow rate} = \frac{15 \text{ mgd}}{1440 \text{ min}} = 10{,}417 \text{ gpm}$$

   Filter Area = 4 x 22 ft x 24 ft = 2112 sq ft
   Max Filter Flow Rate = 4.93 gpm/sq ft

   This filter rate falls within the normal range of 3-6 gpm/sq ft.

TABLE 10. DESIGN CRITERIA FOR ORANGE COUNTY WATER DISTRICT OPEN GRAVITY, MIXED MEDIA FILTER SYSTEM

Dimensions: 4 filters each
22 ft x 24 ft (plan area)
media depth = 30 in

Bed construction:

Media	Depth (in)	Specific gravity	Grain size range (mm)
Anthracite Coal	16.5	1.6	0.84-2.00
Silica sand	9	2.6	0.42-0.84
Garnet sand	4.5	4.0	0.18-0.42
Garnet gravel	1.5	4.0	1
Garnet gravel	1.5	4.0	2.00-4.76
Silica gravel	2	2.6	3.18-6.36
Silica gravel	2	2.6	6.36-12.72
Silica gravel	2	2.6	12.72-19.08
Leopold blocks	-	-	

Surface hydraulic loading rate: 4.93 gpm/sq ft at 15 mgd (2604 gpm per filter)

Max operating headloss: 10 ft

2. Calculate the amount of backwash water that is being used.

   Four filters in operation, each at 2640 gpm
   One backwash/filter/day of 7 min duration at 7920 gpm rate/filter
   Volume of backwash water = 7920 gpm x 7 min x 4 filters
   = 221,760 gal
   Filter Throughput = (1440 min - 7 min) x 2640 gpm x 4
   = 15.13 mg
   Percent backwash water $= \frac{221,760}{15,130,000} \times 100 = 1.5\%$

   A backwash water percentage of greater than 3% indicates that the system performance is questionable and that either:

   1) The solids being applied to the filter are excessive,
   2) Filter aid dosages are excessive, reducing filter runs,
   3) The filter surface wash system is not working or not being operated long enough per backwash cycle, or
   4) Excessively long backwash is being used.

3. Identify the type of process (activated sludge, trickling filters or chemical coagulation) that comes before filtration.

4. From operational data, determine the average BOD and SS concentrations in the filter influent and effluent.

5. Using the information gathered in steps 1 and 2, refer to Table 11 for activated sludge plants, and Table 12 for trickling filter plants. Compare the expected filter performance shown in these tables with the actual filter data collected in step 2. When treating chemically coagulated and settled effluent, the filter effluent should be less than 1 turbidity unit. If the filter does not provide acceptable treatment, the shortcomings and troubleshooting guide on filtration should be checked for more details.

Control Considerations

Modern filter systems usually have equipment for feeding polymers as filter aids, and instruments that continuously monitor and record the turbidity of the filter effluent. Filter operation depends on the flow rate through the filter, which, in turn, is related to the filtered wastewater pressure differential. Control should be based on effluent quality and differential pressure.

Filter Aid Dosage Control--

Filter performance can be improved by adding filter aids such as polymer and/or alum. The process is improved by:

TABLE 11. EXPECTED FILTER PERFORMANCE FOR ACTIVATED SLUDGE PLANTS

Type of activated sludge process	Filter influent BOD mg/l	Filter influent SS mg/l	Filter effluent BOD mg/l	Filter effluent SS mg/l	Run time hr
	Good biological treatment				
Conventional and extended aeration	12-15	15-25	2-5	1-4	16-24
Contact stabilization	15-20	15-25	5-10	1-5	12-20
	Fair biological treatment				
Conventional and extended aeration	20-35	30-50	5-10	5-10	6-12
Contact stabilization	30-45	25-50	20-25	5-10	6-10

TABLE 12. EXPECTED FILTER PERFORMANCE FOR TRICKLING FILTER PLANTS

% soluble BOD removed in secondary process

85% Filter influent BOD mg/l	85% Filter influent SS mg/l	85% Filter effluent BOD mg/l	85% Filter effluent SS mg/l	85% Run time hr	80% Filter influent BOD mg/l	80% Filter influent SS mg/l	80% Filter effluent BOD mg/l	80% Filter effluent SS mg/l	80% Run time hr
30-40	30-40	20-30	15-20	6-11	40-50	35-45	30-40	20-25	5-9

- Strengthening the floc
- Controlling the depth of floc penetration into the beds
- Improving the clarity of the filtered water
- Increasing the maximum allowable flow rate through the bed

The amount of filter aid needed increases with lower water temperature, higher flow rates through the filters, and higher turbidities. The optimum dose of filter aid should be based on the desired filter headloss when turbidity breakthrough is about to happen. Too much filter aid shortens the length of filter runs by increasing the rate of headloss too quickly. If not enough filter aid is added, turbidity breakthrough occurs before maximum allowable headloss is reached.

Filter aid coats the grains of fine filter media. In placing a new filter into service, it may take 3 or 4 filter runs to get the best coating. Also, 3 or 4 filter backwashes may be needed to reduce the coating in a filter if the dosage is reduced. The operator should be careful in reducing filter aid dosages because of the left-over effects of previous coats on the bed, and the time lag before the full effect of the reduced dosage is noticed.

Turbidity, Flow and Headloss Monitoring--

The effluent turbidity of each individual filter should be continuously recorded, and the results used to control the rate of filter aid added to each unit. Also, if the effluent turbidity is too high, the filter should be taken out of service and backwashed. However, this should not happen too often since high headloss through a filter bed usually is the basis for backwashing.

The rate of flow through each filter unit should be monitored, and the total plant flow divided equally among all filter units in service. It is good practice to use all available filters regardless of flow. Sudden changes in filter flow should be avoided, since hydraulic surges tend to let particles pass through the bed. As a result, changes in flow should be made slowly.

Filter Backwashing--

Effective cleaning of the filter media during backwash is very important to successful plant operation. If the bed is not cleaned well, a large collection of biological organisms could cause plugging problems. Good backwashing aided by surface wash or air water backwash can prevent plugging. The length of time needed for backwashing usually is about 5 to 8 mins. Because all filter backwash wastewater must be reprocessed, the percentage of recycled backwash water is checked to see how well the system operates. When the backwash water percentage is greater than 3%, system performance is not good and the troubleshooting guide should be checked to identify and correct the problem.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Air introduced into the gravel support bed can overturn the gravel and disrupt filter operation. This may occur when air collects in the pump column between back-washings.	1. Air can be eliminated by: 1) Starting the pump against a closed backwash valve and releasing the air through a pressure release valve in the backwash line. 2) Placing an air release valve at the high point in the washwater line with a separate pressure water connection to the washwater line at the high point to keep it full of water and expel the air.
2. Operating difficulties resulting from surging wastewater flows.	2. Provide flow equalization among all available filters.
3. When a single-media sand filter is used, more frequent backwashing is required than for multi-media filters.	3. Replace sand filter bed with multi-media bed.
4. Inadequate filter cleaning results in plugging.	4. Provide adequate backwashing assisted by surface wash or air-water backwash.
5. Significant hydraulic surges result if filter backwash wastewater is recycled directly back to the rapid mix basin.	5. Collect flows in a backwash water receiving basin and recycle flows at controlled rate.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Effluent turbidity too high.	1a. Filter needs backwashing.	1a. Turbidity in excess of 1 JTU.	1a. Remove filter from service and backwash it.
	1b. Inadequate upstream chemical coagulation.	1b. Run jar tests, determine proper coagulant dosage.	1b. Feed proper coagulant dosage.
2. High headloss through filter bed.	2. Filter needs backwashing.	2. High headloss through filter.	2. Remove filter from service and backwash it.
3. High headloss through a filter just backwashed.	3a. Insufficient backwash time to thoroughly clean the filter media.	3a. Initial headloss greater than normal (1-2 ft).	3a. Increase the setting on the backwash timer to provide longer backwash period.
	3b. Inoperative surface wash arm or air scouring system.	3b. Visually inspect surface wash arm.	3b. Repair surface wash arm or air scouring system.
4. Percentage of backwash water recycled exceeds 5%.	4a. Solids carryover to filter basin is too high.	4a. SS concentration.	4a. Provide better treatment in settling tanks by improving solids settling characteristics.
	4b. Filter aid dosages too high.	4b. Filter aid dosage.	4b. Reduce filter aid dosage.
	4c. Surface wash system not working.	4c. Visual inspection of surface wash system.	4c. Repair surface wash system.
	4d. Surface wash system not being operated long enough per backwash cycle.	4d. Length of surface wash cycle.	4d. Increase surface wash system time.
	4e. Backwash used is too long.	4e. Length of backwash	4e. Reduce length of backwash cycle.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Clogging of filter surface indicated by very rapid increase in headloss after backwash.	5. Rapid accumulation of solids on the top surface of the media due to:	5. Rate of headloss buildup.	
	a. Inadequate prior clarification for single-media sand filters.		5a. Improve pretreatment or change to dual or mixed-media filters to provide greater porosity at the top of the filter.
	b. Excessive filter aid dosages in dual or mixed - media filters.		5b. Reduce or eliminate filter aid dosage to allow particles to penetrate deeper into the bed.
	c. Surface wash or backwash is in-adequate.		5c. Provide adequate surface wash and backwashing.
6. Short filter runs.	6a. High headloss caused by surface clogging.	6. Visual inspection, headloss through filter.	6a. Replace sand media, with dual or mixed-media.
	6b. (See item 4a)		6b. Reduce filter aid dosage.
			6c. Use polymer as a filter aid to control rate of headloss buildup.
			6d. Be sure adequate surface wash and backwash is provided.
7. Filter effluent turbidity increases suddenly but filter headloss is low.	7a. Inadequate dosage of polymers as filter aid.	7a. Excessive turbidity.	7a. Increase polymer dosage.
	7b. Coagulant feed system malfunction.	7b. Chemical feeders.	7b. Repair feeders.
	7c. Change in coagulant demand.	7c. Run jar tests.	7c. Adjust coagulant dosage.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
8. Mud ball formation.	8. Inadequate backwash flow rate and surface wash.	8. Visual inspection.	8. Provide backwash flow rate up to 20 gpm/sq ft, and maintain proper auxiliary scour (surface wash).
9. Gravel displacement.	9. Introduction of air into filter under-drain in the back-wash water.	9. Visual inspection of gravel bed.	9. If displacement is severe, filter media may have to be replaced. Limit the total flow and head of water avail-able for backwash (also see shortcomings).
10. Loss of media during backwashing.	10a. Excessive flows used for backwashing	10a. Backwash rate.	10a. Reduce rate of backwash flow.
	10b. Auxiliary scour excessive.	10b. Backwash program.	10b. Cut off the auxiliary scour 1 to 2 min before the end of the main backwash.
	10c. Air bubbles attach-ing to coal causing it to float. - (See item 12).		
11. Difficult to clean filter adequately in warm weather at normal backwash rates.	11. Decreased viscosity of backwash water due to higher temperatures.		11. Increase backwash rate until desired bed expansion during backwash is achieved.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
12. Air binding causing headloss to increase prematurely.	12. Air bubbles accumulate within bed due to: a) Filter influent containing dissolved oxygen at or near saturation levels being subjected to less than atmospheric pressure in filter. b) Lowered water level and stoppage of flow through filter during preparation for backwashing reduces pressure and releases gases.	12. Rapidly increasing headloss through filter.	12a. Provide more frequent backwashing to prevent bubbles from accumulating as quickly. 12b. Maintain maximum water depths above the beds.

MICROSCREENING

Process Description

The most common type of microscreen used in wastewater plants is the horizontal rotating drum. The variable speed drum is shaped like a cylinder and made of finely woven stainless steel or synthetic cloth. It is mounted in a tank so that wastewater enters the inside of the drum from one end and flows outward through the straining fabric, as shown in Figure 51.

The drum is usually about two-thirds underwater. Solids are stored on the inner surface of the drum as the flow passes through the drum. These solids are then backwashed with screened effluent into a trough inside the drum, where the solids are then returned to the head of the works.

Most meshes are woven type 316 18/8 stainless with openings ranging from 23 to 60μ. The microscreen usually is used to remove suspended solids from secondary effluent. They also have been used successfully on combined sewer overflows. Microscreens are not effective for removal of chemical floc nor are they used on raw sewage due to problems with grease buildup on the screen.

Typical Design Criteria and Performance Evaluation

The hydraulic capacity of the microscreen depends on the rotational speed (50-150 fpm peripheral) of the drum, the area of which is submerged; head applied across the screen (about 12 in in tertiary treatment); rate of mesh clogging; and backwash efficiency. Generally, loading rates in tertiary applications are 5-10 gpm/sq ft of submerged area with 6-12 in of headloss. When applied to combined sewer overflows, rates as high as 20-40 gpm/sq ft with heads of 48 in are used. Backwash flow requirements are usually about 5% of the influent flow, but may range from 3-25%. Detailed design information may be found in the article "Designing Microscreens? Here's Some Help" in the April, 1976 issue of Water and Wastes Engineering. Information also may be obtained from the manufacturers of these systems.

Where the influent is less than 35 mg/l, microstraining can produce an effluent with less than 10 mg/l of solids. The throughput rates are very dependent on changes in influent solids. Increases from 35 mg/l to 200 mg/l would probably reduce the throughput rate by a factor of 4 or 5. Thus, it is important to keep a fairly constant concentration of SS in the influent. The performance of the screen will be affected by the following:

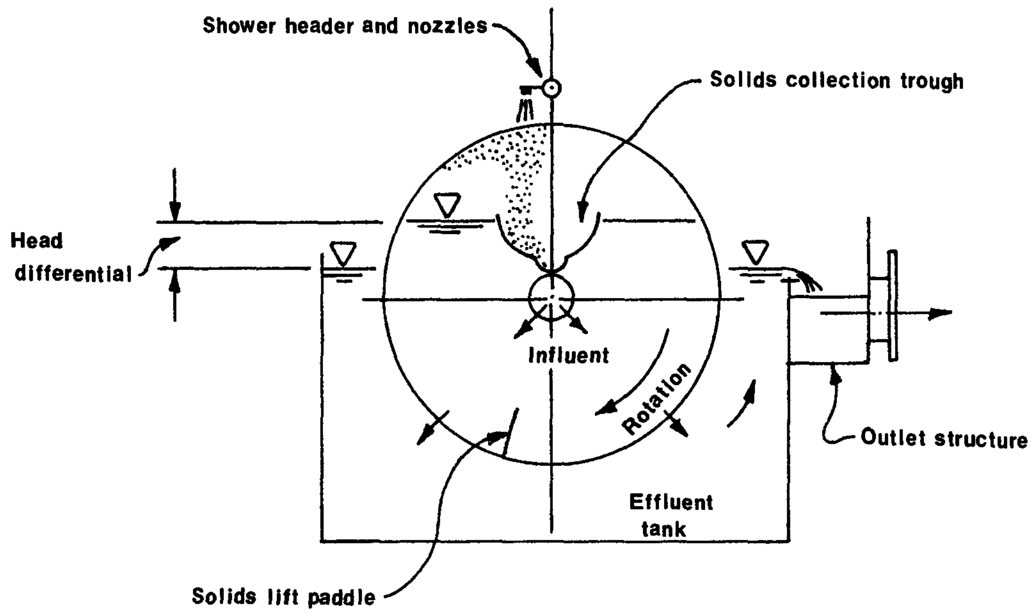


Figure 51. Schematic of typical microscreen.

1. Biological Loading of the Upstream Process - Highly loaded plants (for example, in activated sludge, a sludge retention time (SRT) of three days or less) would provide less removal at the screen and higher screen effluent suspended solids concentration.

2. Final Clarifier Hydraulic Loading - Higher clarifier loadings often result in poorer screen effluent quality, but higher percentage removal of solids at the screen.

3. Hydraulic Head Across Screen Media - As the head increases from hydraulic or solids loading, removal efficiency and effluent quality suffer. The additional head forces some of the particles through the media that otherwise would have been strained out.

4. Upstream Hydraulics - Excessive headloss or velocity in the hydraulic passages just before the screen may result in the breakup of agglomerated particles, causing effluent quality and removal efficiency to be reduced.

5. Effectiveness of Solids Collection System - Since many of the screened particles are composed of several smaller particles that have been agglomerated, the force of the spray water may break up some of the particles small enough to let them pass through the media. If these particles go to the drum pool rather than the collection trough, they may pass through the media causing a poor effluent quality.

6. Media Aperture - A small amount of the total suspended solids are within the size range of 20 to 36μ, and because of this,effluent quality is reduced slightly.

7. Screen Peripheral Speed - Increases in speed often cause decreases in head across the media, and improve the effluent quality and removal efficiency. Beyond a certain speed however, the head across the media increases because of reduction in efficiency of the solids collection system at the higher speed. Also, floc breakup becomes more of a problem at the higher speed. Best effluent quality is possible at speeds ranging from 70 to 140 fpm.

Control Considerations

Except for drum speed there are not many things the operator can control with the microscreening process. If the drum travels too fast, it will not do an effective screening job and may cause excess wear on the mechanical parts. If it runs too slowly, the fabric will become clogged and the water level difference between the influent and the effluent may become so great that the fabric breaks. A clogged screen may also cause the influent to bypass the microscreen. There are units which automatically increase drum speed as the headloss across the screen increases. General guidelines for good control of operation are:

> Operate the microscreens at the slowest possible speed or at a rate with the manufacturers' recommendations for water level

differential between influent and effluent.

- Ensure that the microscreen receives the best quality influent that can be produced by secondary treatment.
- Provide good preventive maintenance on mechanical equipment.
- Provide daily inspection of the operating units.

Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Accumulation of settled solids in influent chamber which can become anaerobic and float to the surface temporarily overloading unit.	1. Reduce size of influent chamber.
2. Grease frequently plugging the screen.	2. Clean screen according to manufacturers instructions and improve scum removal in primary settling tank.
3. No flow measurement installed on shower water line making it difficult to determine effectiveness of screen cleaning.	3. Install flow meter on shower line.
4. Screen capacity marginal.	4. Increase available head to maximum allowable for specific screen. Increases in screen opening size or increases in submerged depth usually do not help significantly.
5. High pressure (60-120 psi) shower system installed causing shortened media life.	5. Operate system normally at 30 psi, but once per week operate at 60-120 psi.
6. Constant speed drive motor used on screen making it difficult to cope with variations in influent solids.	6. Convert to variable speed to allow speeds of 80-150 fpm to be used.
7. Large objects inadvertently entering and damaging screen.	7. Install one-inch square mesh ahead of microscreen.

Shortcomings	Solution
8. Solids loading to screens too high to achieve desired throughput.	8. Install added secondary clarifier capacity or system to use chemical coagulation/flocculation/sedimentation ahead of screen.
9. Persistent problem with slime accumulations on screen surface.	9. Install ultra-violet light irradiation unit directed at screen exposed after backwashing. Special filters are used to eliminate ozone-producing wavelengths which could cause metal corrosion.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Gradual decrease in throughput rate due to slime growths on screen.	1. Inadequate cleaning.	1a. Backwash pressure low (≤ 30 psi). 1b. Spray nozzles partly plugged.	1a. Increase backwash pressure to 60 to 120 psi until cleaned or add hypochlorite ahead of screen. 1b. Clean nozzles and convert to automatic, self-cleaning nozzles.
2. Leakage at ends of drum causing poor efficiency.	2. Seals leaking.	2. Seals.	2. Increase tension on sealing bands gradually until leakage is eliminated; replace bands if work excessively.
3. After shutdown period screen capacity is low.	3. Screen fouled.		3. Never allow screen to dry out in dirty condition; clean with sodium hypochlorite solution to restore capacity.
4. Drive system running hot or noisy.	4. Inadequate lubrication.	4. Oil level.	4. Fill to required level with recommended oil.
5. Drum rotation erratic.	5. Drive belts not adjusted properly or worn out.	5. Drive belt tension and condition.	5. Adjust drive belt to proper tension.
6. Sudden increase in screen effluent solids.	6a. Hole in screen or fabric securing screws loose. 6b. Solids collection trough overflowing.	6a. Surface of screen.	6a. Repair screen fabric per manufacturer's instructions or tighten screws as appropriate. 6b. Reduce wastewater flow rate.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
7. Screen capacity cannot be restored by high pressure flushing or hypochlorite treatment.	7. Film of iron or manganese oxide has accumulated.	7. Screen surface.	7. Clean screen with inhibited acid cleanser per manufacturer's instructions.

ACTIVATED CARBON ADSORPTION

Process Description

The activated carbon process is almost always a part of some larger wastewater treatment operation. The main purpose of activated carbon adsorption is the removal of soluble organics. There are two ways to use activated carbon: (1) as advanced wastewater treatment (AWT), or (2) as independent physical-chemical treatment (IPC).

As an AWT process, activated carbon is used after secondary treatment, and sometimes after coagulation, sedimentation and filtration, in order to remove soluble organic material which is difficult to remove biologically. These "difficult to remove" materials are often called "refractory organics" and are measured by the COD (chemical oxygen demand) test.

In the IPC processes, biological secondary processes are not used at all, and the carbon is the only way of removing soluble organics. In the IPC system, the raw wastewater is usually coagulated and settled (and sometimes filtered) before it is passed through the carbon system. This process removes more organics than biological secondary, but not as much as biological secondary followed by carbon adsorption.

Wastewater treatment with activated carbon involves two process operations, a contact system, and a regeneration system. The water passes through a container filled either with carbon granules or with a carbon slurry. Impurities are removed from the water by adsorption when there is enough contact time. The carbon system usually has several columns or basins used as contactors. Most contact columns are either open concrete gravity-type systems, or steel pressure containers applicable to either upflow or downflow operation (Figures 52 and 53).

After a while, the carbon loses its adsorptive capacity. The carbon must then be regenerated by taking the contactor out of service and connecting it to the regeneration system. Fresh carbon is sometimes added to the system to replace carbon lost during hydraulic transport and regeneration. The regeneration process is explained in a later section of this manual.

Activated carbon used for wastewater treatment may be either in a granular form (about 0.8 millimeter in diameter, the size of a fairly coarse sand) or in a powdered form. Granular carbon adsorption is used by passing the wastewater through beds of the carbon housed in columns. These carbon beds usually provide 20-40 mins contact between the carbon and the wastewater.

Because powdered carbon is very fine, it is not used in columns, but

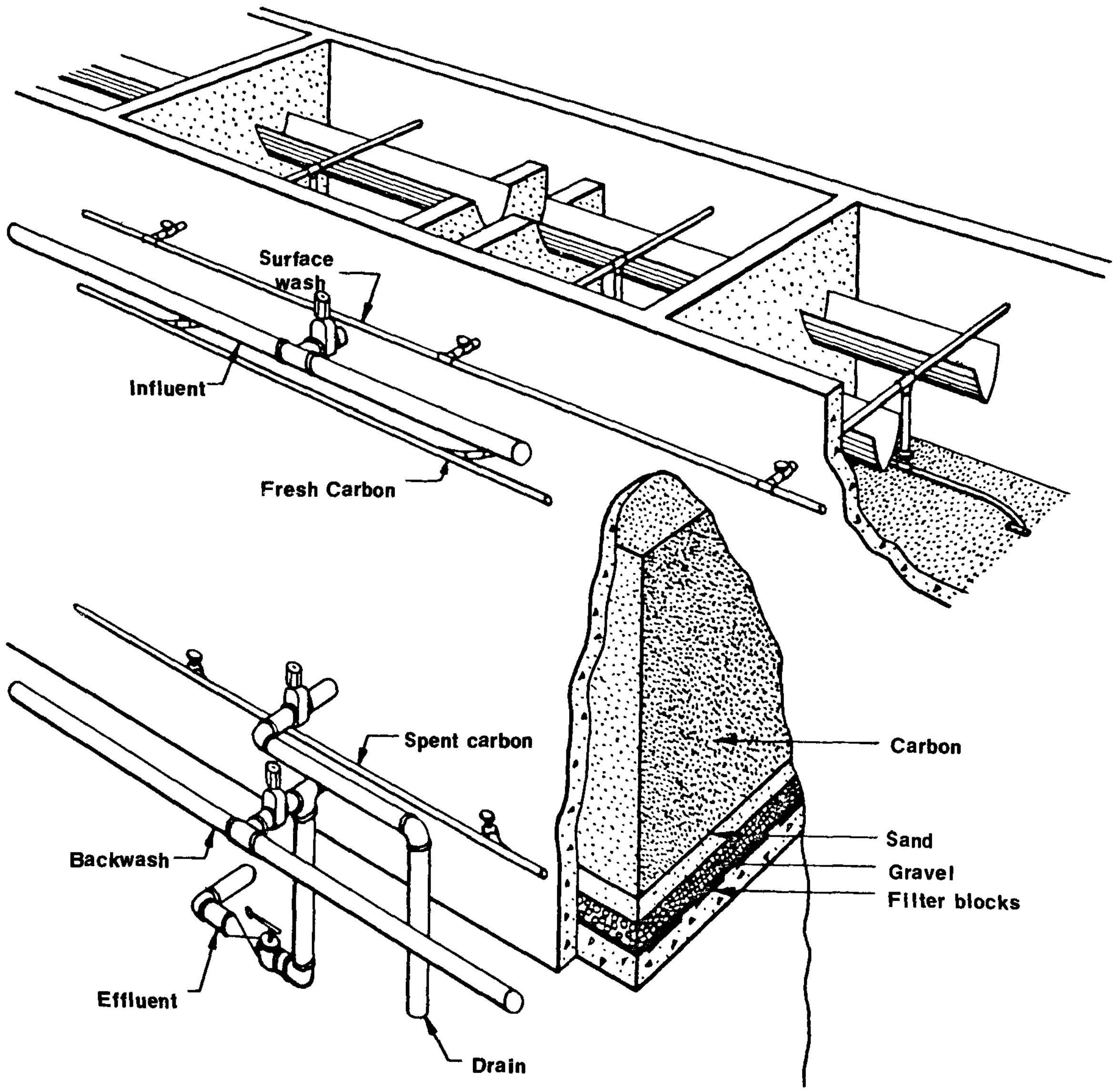


Figure 52. Gravity contactor.

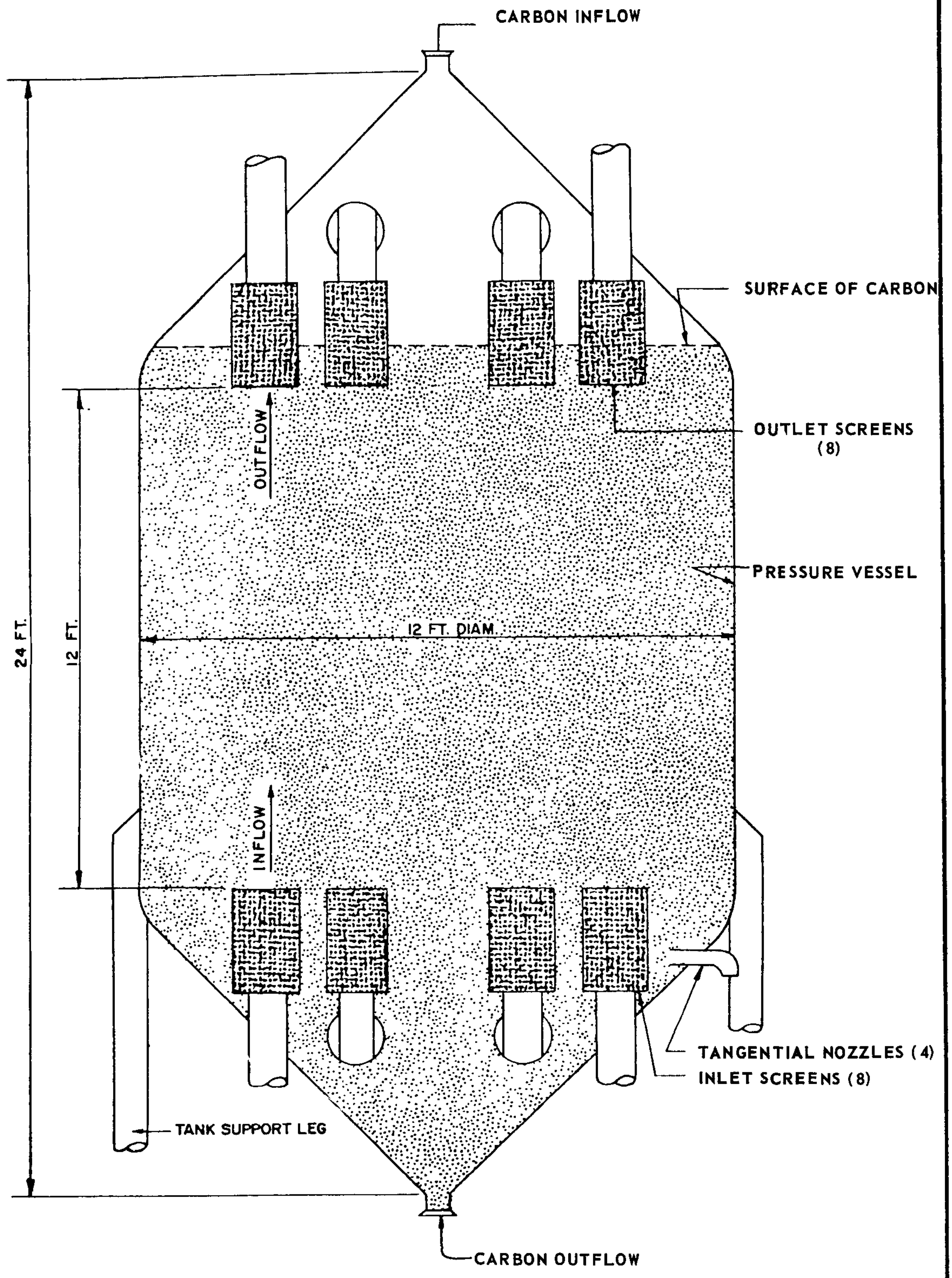


Figure 53. Pressurized contactor capable of using upflow or downflow operation.

instead is added to the wastewater and removed by coagulation and settling. Because of difficulties in powdered carbon regeneration and recovery, it is not used in wastewater treatment as often as granular carbon.

Typical Design Criteria and Performance Evaluation

Table 13 and 14 show design parameters from several activated carbon systems. Table 13 shows design specifications for IPC plants (secondary plants, replacing biological processes) and Table 14 shows the same type of data for AWT plants (tertiary plants).

The most important things that affect activated carbon performance are contact time and pretreatment. Longer contact times and greater amounts of pretreatment usually result in higher effluent quality and lower carbon dosage requirements. Table 15 compares dosages and carbon effluent quality for various kinds of pretreatment. Performance data from one plant designed to treat secondary effluent is shown in Table 16.

COD removals in the carbon columns may vary from 40 to 75% from day to day. The absolute value of the effluent COD in milligrams per liter is a more important measure of process efficiency, however. The lbs of COD removed per lb of carbon (ranges from 0.5 to 2.0 lbs) is the most useful measure of efficiency because it shows the whole operation of the carbon adsorption and regeneration systems.

Principals for evaluating the performance of activated carbon systems should involve contact time, hydraulic loading, and pretreatment effects. The following will serve as an example of step-by-step procedures for evaluating the performance of an activated carbon adsorption system:

1. Define the dimensions and design data for the carbon system.
   Upflow Contactor
   Pretreatment: Filtered Secondary Effluent

Column Flow Rate	=	650 gpm
Column Diameter, dia	=	12 ft
Column Area, $A = (\pi/4)\ dia^2$	=	113 sq ft
Carbon Depth	=	26'2"
Column Volume, V=A x Depth	=	22,140 gal

2. Determine the contact time of the carbon column and compare it to the designed contact time.

$$\text{Contact time (min)} = \frac{\text{Carbon column volume in gal}}{\text{Flow rate in gpm}} = \frac{22{,}140}{650} = 34 \text{ min}$$

In general, contact times should range between 20 and 40 min. Longer contact times may produce a lower effluent COD, color and perhaps, a lower carbon dosage. However, contact times can

TABLE 13. DESIGN SPECIFICATIONS OF SOME IPC PLANTS
(Secondary plants, replacing biological plants)

	Rocky River, Ohio	Owosso, Michigan	Garland, Texas	Niagara Falls, New York
Carbon requirements	500 lbs/MG	600 lbs/MG	1800 lbs/MG	750 lbs/MG
Plant size	10 MGD	6 MGD	30 MGD	60 MGD
Hydraulic loading	4.3 gpm/sq ft	6.2 gpm/sq ft	2.4 gpm/sq ft	1.5 gpm/sq ft
Contact time	26 minutes	36 minutes	30 minutes	40 minutes
Bed depth	15 ft	30 ft	10 ft	8 ft
Contactor size	16 ft dia x 25.3 ft	12 ft dia	20 x 47.5 ft	40 x 20 x 18 ft
Carbon size	8 x 30 mesh	12 x 40 mesh	--	--
Carbon inventory	736,870 lbs	246,480 lbs	2,600,000 lbs	--
Backwash rate	15-20 gpm/sq ft	N/A	N/A	--
Surface wash	stainless steel, rotating spray	N/A	N/A	--
Air scour	none	N/A	N/A	--
Vessel type	pressure-downflow	pressure-upflow	gravity-upflow	gravity-downflow
Regeneration rate	500 lbs/hr	416 lbs/hr	--	--
Furnace*	72 OD 8	54 ID 6	--	--
Corrosion protection	rubber lining	--	concrete and stainless steel	concrete
After burner	yes	--	no	yes
Wet scrubber	no	--	yes	no

*72 OD 8 means 72" outer diameter and an 8-hearth furnace

TABLE 14. DESIGN SPECIFICATIONS OF SOME AWT PLANTS
(Tertiary plants, upgrading biological plants)

	Colorado Springs, Colorado	Pomona, California	South Lake Tahoe, California
Carbon requirements	250 lbs/MG	350 lbs/MG	250 lbs/MG
Plant size	3 MGD	0.3 MGD	7.5 MGD
Hydraulic loading	5 gpm/sq ft	7 gpm/sq ft	6.2 gpm/sq ft
Contact time	30 minutes	40 minutes	17 minutes
Bed depth	20 ft	38 ft	14 ft
Contactor size	20 ft dia x 20 ft	6 ft dia x 16 ft	12 ft dia x 14 ft
Carbon size	8 x 30 mesh	12 x 40 mesh	8 x 30 mesh
Carbon inventory	250,000 lbs	--	500,000 lbs
Backwash rate	20 gpm/sq ft	12 gpm/sq ft	N/A
Surface wash	--	--	N/A
Air scour	--	--	N/A
Vessel type	pressure-downflow	pressure-downflow	pressure-upflow
Regeneration rate	75 lbs/hr	110/hr	250 lbs/hr
Furnace*	30 ID 6	30 ID 6	54 ID 6
Corrosion protection	--	coal tar epoxy	coal tar epoxy
After burner	yes	yes	available
Wet scrubber	--	yes	yes

*30 ID 6 means 30" inner diameter and a 6-hearth furnace.

TABLE 15. THE EFFECTS OF PRETREATMENT ON CARBON DOSAGE AND CARBON COLUMN EFFLUENT QUALITY

Pretreatment	Primary		Secondary, plus-plain filtration	Chemically flocculated and filtered secondary effluent
Carbon contact	Downflow series 2 beds 15 min	Downflow series 4 beds 30 min	Downflow 4 series bed 20 min	Upflow countercurrent 17 min
Carbon dosage lb/MG	1,200	800	500	250
SS, mg/l	10	5	<1	<1
BOD, mg/l	20	10	<1	<1
COD, mg/l	65	45	12	12
TOC, mg/l	20	10	3	3
Color, units	---	---	4	4
Turbidity, JU	---	---	1.5	0.5

TABLE 16. TYPICAL WATER QUALITY BEFORE AND AFTER GRANULAR ACTIVATED CARBON TREATMENT AT SOUTH TAHOE

Quality parameter	Carbon column Influent	Carbon column Effluent
BOD (mg/l)	3	<1
COD (mg/l)	24	12
TOC (mg/l)	12	3
MBAS (mg/l)	0.85	0.13
Color (units)	15	4

become so long as to cause anaerobic conditions (no oxygen) in the carbon columns. Anaerobic conditions in a carbon contactor can cause odors.

3. Determine the hydraulic loading rate and note if the calculated loading is within the typical range of 2 to 8 gpm/sq ft.

$$\text{Hydraulic loading rate} = \frac{\text{Flow rate in gpm}}{\text{Surface area of column}} = \frac{650}{113} = 5.75 \text{ gpm/sq ft}$$

Numerous tests have shown that the efficiency of the carbon is not affected by hydraulic loading rate (at a given contact time) for rates in the range of 2 to 8 gpm/sq ft.

4. Review available effluent quality data and, if needed, collect samples from the carbon column influent and effluent, and analyze the samples for the following:

- TOC
- Soluble Organic Carbon
- SS
- BOD
- COD
- Color
- Turbidity

The results should be compared to those shown in the following table or Table 15, taking into account pretreatment considerations.

Description	Filtered Secondary Effluent	Unfiltered Secondary Effluent
TOC Removed, percent	45 - 55	50 - 60
Soluble Organic Carbon Removal, %	40 - 45	45 - 50
Soluble Organic Carbon Removed per lb Active Carbon, lb	0.19 - 0.20	0.22 - 0.23

5. If carbon effluent quality is not acceptable, the troubleshooting and shortcomings section should be read.

Control Considerations

The rate of adsorption of organics found in municipal wastewater usually increases as the pH of the water decreases. Adsorption is very poor at pH values above 9.0. High pH wastewaters should be neutralized before carbon adsorption, and the influent pH should be kept fairly constant. A sudden, upward shift in pH can lead to desorption of organics and an increase in effluent COD.

Treating water that has high turbidity or high organic content will plug carbon pores and result in the loss of carbon capacity. Thus, special attention should be given to the control of processes upstream of the carbon columns. The adsorptive capacity and service life of the carbon can be maximized by applying to the carbon, water that has been carefully pretreated to the highest practical clarity.

The regeneration process requires careful operator control. A later section describes carbon regeneration in detail.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. BOD removal is poor.	1. Provide biological pretreatment prior to activated carbon application.
2. Carbon adsorptive capacity is poor and carbon must be regenerated often.	2. Pretreat the water to the highest practical quality.
3. Effluent suspended solids are too high when column is operated in expanded, upflow mode.	3. Operate as upflow, packed bed or provide filtration to remove solids downstream of carbon process.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Excessive headloss.	1a. Highly turbid water being applied to carbon.	1a. Turbidity, SS concentration.	1a. Vigorously backwash to restore headloss. Improve turbidity of applied water by improved pretreatment.
	1b. Growth and accumulation of biological solids in contactor.	1b. Visual inspection, hydrogen sulfide (rotten egg) odor in effluent.	1b. Operate carbon contactor as expanded upflow beds so solids are flushed continuously; backwash downflow beds more frequently and improve upstream removal of soluble BOD.
	1c. Carbon deteriorating during handling and large amounts of carbon fines accumulating.	1c. Run gradation analysis of carbon and compare with original specification.	1c. Remove carbon and wash fines from system. It may be necessary to replace carbon with a different brand of greater hardness.
	1d. Inlet or outlet screens plugged.		1d. Backflush screens.
2. Hydrogen sulfide in carbon contactor.	2a. Low concentration or absence of DO and nitrate in carbon contactor influent.	2a. DO of influent.	2a. Add oxygen, air or sodium nitrate to influent, in case of upflow operation.
	2b. High BOD concentrations in influent.	2b. BOD in influent.	2b. If possible, maintain aerobic conditions in carbon column to prevent H_2S formation by addition of ozone, nitrates, or oxygen to carbon influent. Improve upstream soluble BOD removal to remove sulfides already formed, precipitate with iron or add chlorine.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	2c. Long detention time in carbon columns.	2c. Detention time of 30-60 mins is a typical maximum.	2c. 1. Reduce the detention time by removing some of the carbon contactors from service. 2. Backwash columns more frequently and violently by use of air scour or surface wash.
3. Large decrease in COD removed per lb of carbon regenerated.	3. Carbon fouled and losing efficiency.	3. COD removal efficiency (COD removed/lb carbon).	3. Evaluate and adjust regeneration system to provide increased efficiency (see carbon regeneration section).
4. Corrosion of metal and damage to concrete in carbon contactors.	4a. H_2S present in carbon contactors (anaerobic conditions).	4a. H_2S concentration, low DO.	4a. See solution 2.
	4b. Holes in metal coatings permitting partially dewatered carbon to contact metal.		4b. Recoat metal surfaces.

NITRIFICATION

Process Description

The biological processes (activated sludge, trickling filters, ABF process, and rotating biological contactors) described in earlier sections may all be used to convert ammonia nitrogen to nitrate nitrogen. Basic process descriptions and troubleshooting guidance for each process presented earlier will not be shown again here. This section will present some added guidance directly related to the nitrification process.

The form of nitrogen that is in raw sewage may be biologically oxidized to nitrate after the carbonaceous oxygen demand is met. But this can only happen if the proper aerobic conditions are maintained in the process. Nitrification may be done in either one or two stages. In single-stage, the carbon and nitrogen oxidation steps are combined in a single unit. In two-stage systems, the carbonaceous oxidation is first carried out in a separate unit, followed by nitrification in another unit.

Typical Design Criteria and Performance Evaluation

Activated Sludge--

In the activated sludge process, the degree of nitrification depends on the sludge retention time (SRT - see activated sludge chapter). Figure 54 shows the effects of SRT on nitrification, oxygen requirements, and the aeration time needed to obtain different SRT values. For single-stage nitrification, temperatures of 18°C and a sludge age of at least 10 days or an aeration basin loading ratio less than 0.25 lbs of BOD_5 /day/lb of MLVSS will usually work. In two-stage systems, the first stage activated sludge system often is designed to produce an effluent BOD of less than 50 mg/l. Detention times of 4-5 hrs are common for the second stage basins.

Trickling Filters--

Nitrification in trickling filters depends on organic loading. Results from several rock trickling filters are pictured in Figure 55. For good nitrification, loadings should be less than 5 lbs BOD/1000 cu ft/day.

Oxidation-nitrification can be done in a single-stage system using synthetic-media trickling filters. BOD loading is the limiting factor in this application. The following are common design and operating data for this type of system:

Influent Ammonia-Nitrogen	=	25 mg/l
Media Area	=	27 sq ft/cu ft (94% void volume)

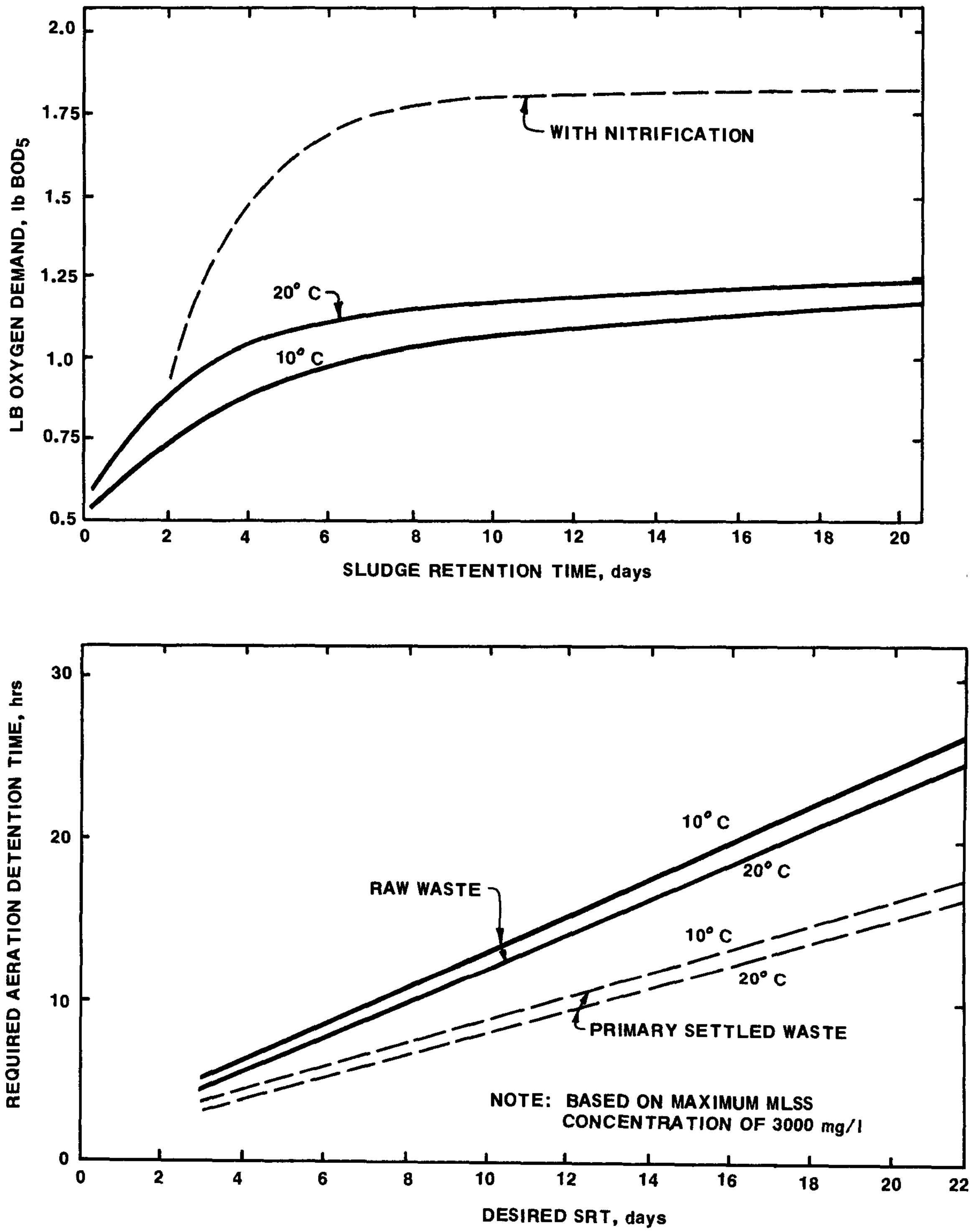


Figure 54. Required aeration time for varying SRT values.

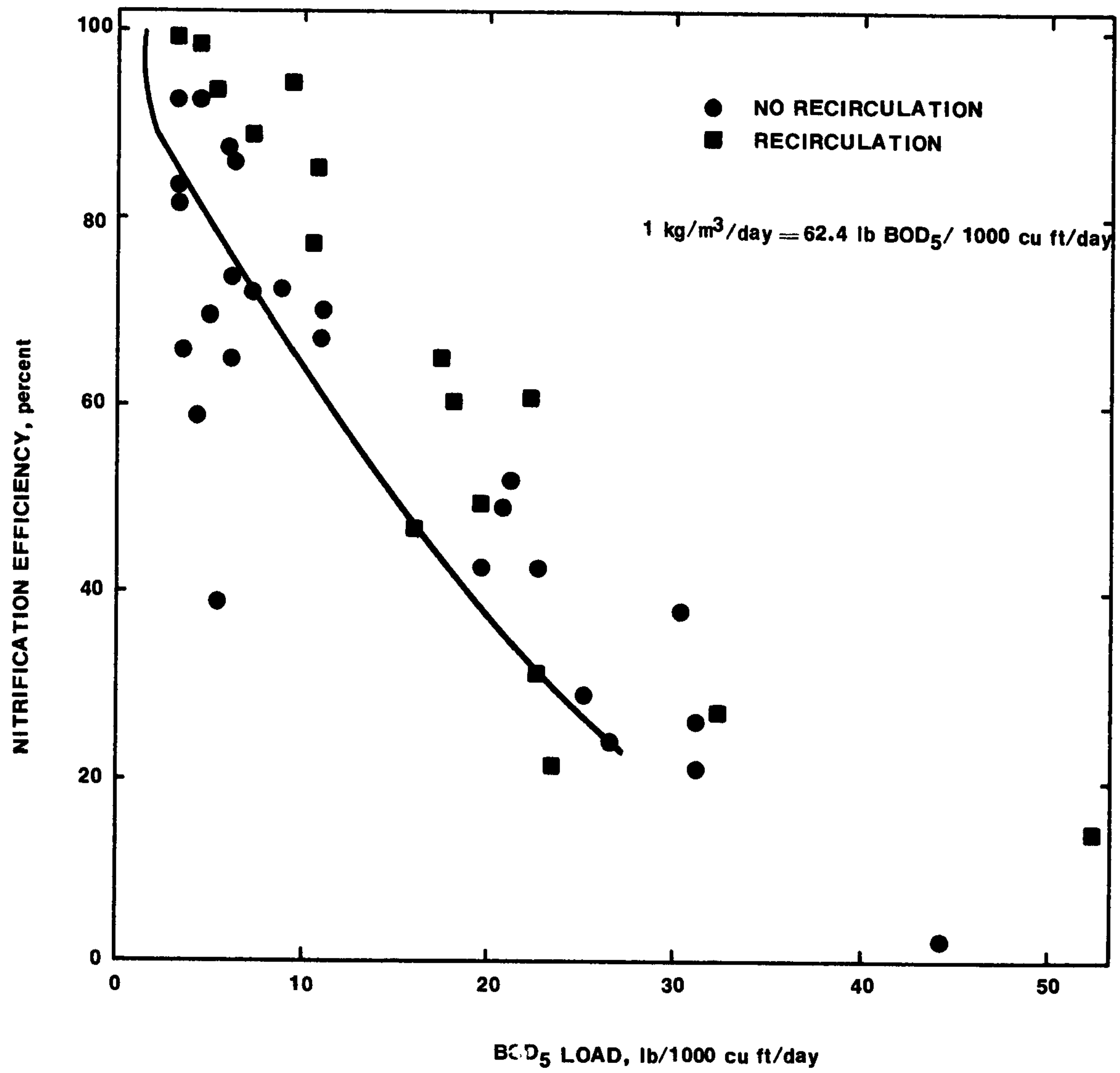


Figure 55. Effect of organic load on nitrification efficiency of rock-media trickling filters.

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Maximum BOD loading	=	25 lb/1,000 cu ft/day
Recycle to maintain minimum flow of to keep media from drying out		0.5-1 gpm/sq ft

For nitrification of secondary effluents in a two-stage system, the contact time in the filter becomes most important. For this type of system, following are typical criteria:

Influent BOD_5	=	50 mg/l
Influent Ammonia-Nitrogen	=	25 mg/l
Media Area	=	27 sq ft/cu ft (94% void volume)
Recycle to maintain constant flow for media depth of		21.5 ft

The following flow rates may be used to obtain the desired performance:

Nitrification Performance	Flow Rate @ Wastewater Temp. Shown	
	$65^{o}F$	$44^{o}F$
90%	0.5 gpm/sq ft	0.5 gpm/sq ft
85%	0.75	0.65
80%	1.0	0.75
75%	1.5	0.85

The ABF system can provide complete nitrification at average loadings of 200-250 lbs BOD/1,000 cu ft/day (with peaks of 450 lbs BOD/1,000 cu ft/day) with an aeration basin detention time of 3-4 hrs. Common design data are listed in Table 17.

Rotating biological contractors (RBC) also may be used in single-stage or two-stage nitrification systems. As the rotating discs operate in series, organic matter is removed in the first disc stages and following stages are used for nitrification. Figure 56 shows design based on hydraulic loading. When the ammonia concentration exceeds the maximum ammonia concentration on the appropriate BOD curve, the curve for the ammonia concentration is used. The nitrifying ability of the discs is relatively constant when the temperature is between 15 and $26^{o}C$. Temperature correction factors are used to adjust the hydraulic loadings in Figure 57 for any wastewater temperature lower than $13^{o}C$. The RBC process may also be used to nitrify secondary effluents. Figure 58 shows design and performance for nitrification systems using 4 stages of discs. This is the most common type of system used for nitrification of secondary effluents.

The final clarifier overflow rate usually is kept at a peak hourly rate of no more than 1,000 gpd/sq ft with a minimum depth of 12 ft and equipped with a surface skimmer. Sludge return usually should not be greater than 100% of the average daily flow. Rising sludge caused by denitrification has

TABLE 17. GENERAL DESIGN PARAMETERS FOR NITRIFICATION OF DOMESTIC WASTEWATER WITH ABF PROCESS

Parameter	Units	Typical value	Range
Effluent criteria			
5-day BOD	mg/l	15	5-30
Suspended solids	mg/l	20	15-30
NH_3-N	mg/l	1.0	0.5-2.5
Bio-cell parameters			
Organic load	lb BOD_5/day/1000 cu ft	200	100-350
Media depth	ft	14	5-22
BOD_5 removal	%	65	55-85
Hydraulic parameters			
Bio-cell recycle	*	1.5 Q	0.5-2.0 Q
Sludge recycle	*	0.5 Q	0.3-1.0 Q
Bio-cell flow	*	3.0 Q	2.3-4.0 Q
Bio-cell hydraulic load	gpm/sq ft	3.5	1.5-5.5
Aeration parameters**			
Detention time*	hr	3.5	2.5-5.0
Organic load	lb BOD_5/day/1000 cu ft	25	20-40
Ammonia load	lb NH_3-N/day/1000 cu ft	10	5.0-15.0
F/M	lb BOD_5/day/lb MLVSS	0.13	0.1-0.2
MLVSS concentration	mg/l	3000	1500-4000
MLSS concentration	mg/l	4000	2000-5000
Carbonaceous oxygen***	lb O_2/lb BOD_5	1.4	1.2-1.5
Clarifier parameters			
Overflow rate	gpd/sq ft	600	300-1200
Solids loading	lb/hr/sq ft	1.0	0.5-2.0
Return sludge concentration	%	1.5	1.0-3.0
Sludge production	lb VS/lb BOD_5 removed	0.45	0.30-0.55

* Based on design average flow and secondary influent BOD_5 = 150 mg/l.

** Based on aeration BOD_5 loading after bio-cell removal.

*** Total oxygen utilization = carbonaceous oxygen + 4.6 lb O_2/lb NH_3-N oxidized.

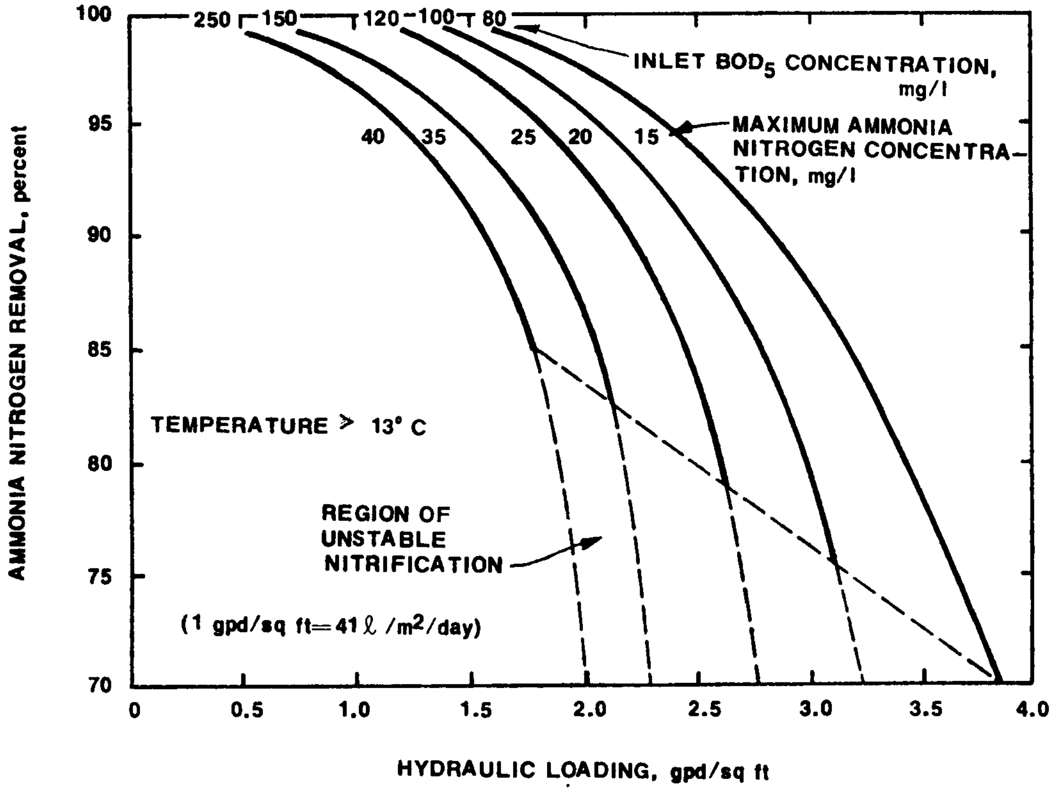


Figure 56. Design criteria for single-stage nitrification with rotating biological discs.

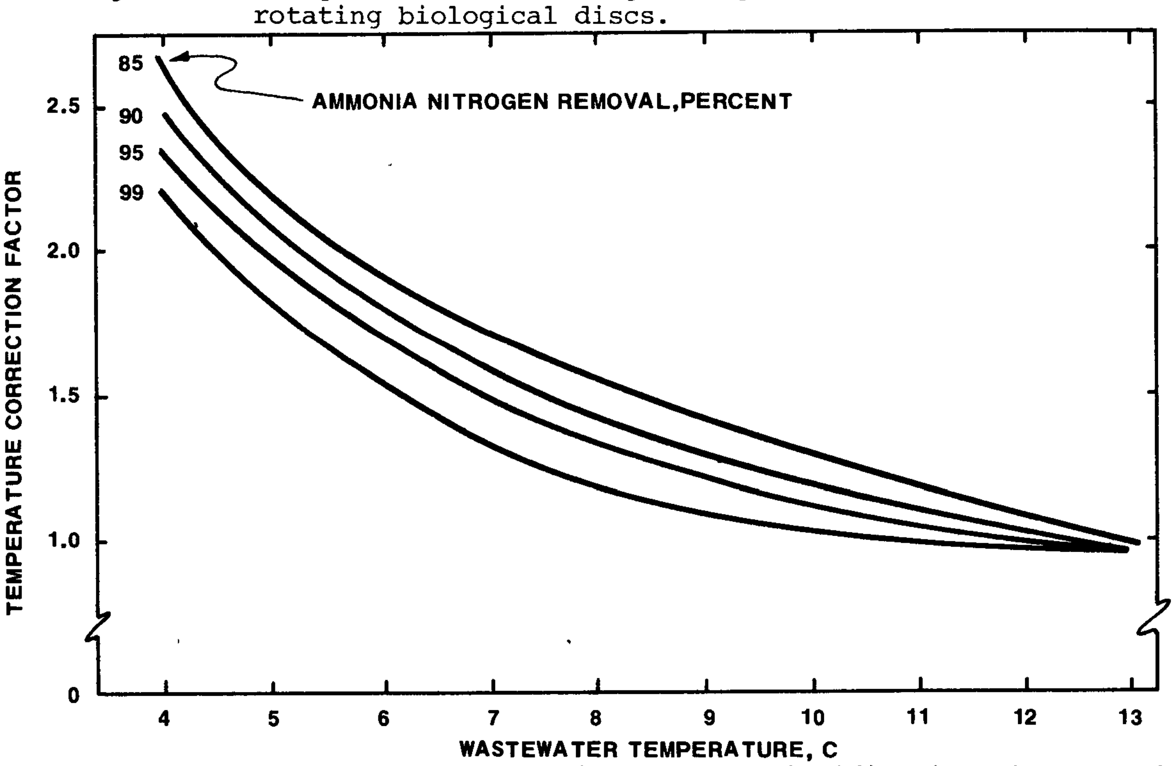
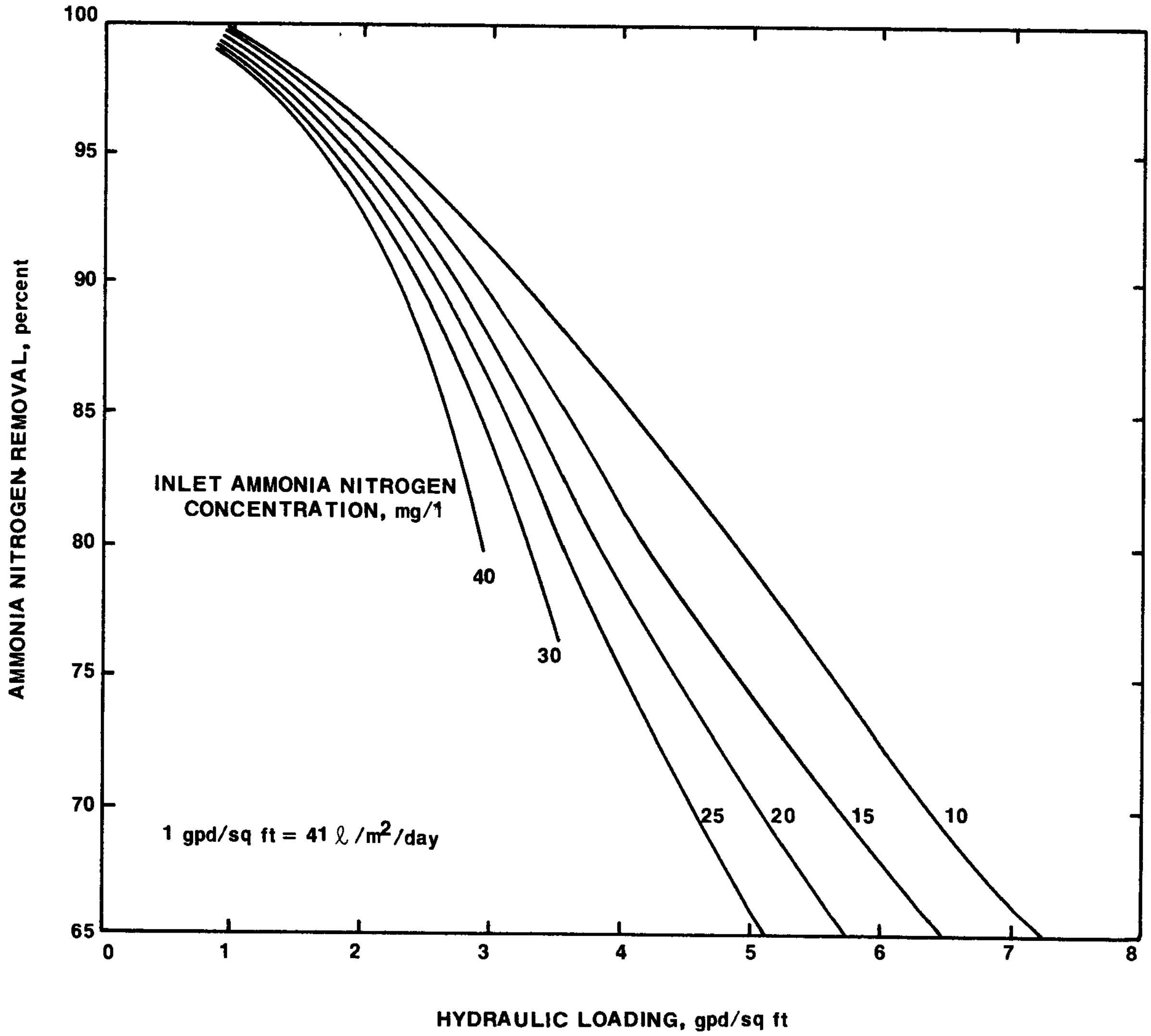


Figure 57. Temperature effects on single-stage nitrification with rotating biological discs.



RELATIVE CAPACITIES FOR STAGED OPERATION (90–95% Nitrification)

No. Stages	Relative Capacity
1	0.60
2	0.80
3	0.90
4	1.00
6	1.07

Conditions

Temperature > 13° C
BOD_5 < 20 mg/l

Figure 58. Design relationships for a 4-stage RBD process treating secondary effluent.

sometimes been a problem in nitrification systems, especially with warm wastewaters. The following are control measures for preventing floating sludge:

- provide rapid sludge removal in clarifier tank design to prevent bubbles from forming,
- provide flexibility in influent feed points (e.g., change from step aeration to plug flow in warm weather periods),
- chlorinate the return activated sludge to control sludge bulking and to reduce the sludge volume index. This will allow more rapid sludge removal from the clarifier.

The following is an example of how to evaluate the performance of different nitrification systems using the information just provided:

1. Define the type of biological system used at the treatment plant and any necessary design information.

Type of Plant	Rock Media Trickling Filter
No. of Stages	1
BOD_5 Loading	10 lb/1000 ft^3/day
Ammonia Nitrogen Content	
Influent	25 mg/l
Effluent	10 mg/l

2. Determine the nitrification efficiency of the system.

$$\% \text{ Nitrification} = \frac{(\text{Influent } NH_3 - \text{Effluent}) \times 100}{\text{Influent } NH_3}$$

$$= \frac{(25-10)}{25} \times 100$$

$$= 60\%$$

3. Compare the 60% removal with the average performance curve in Figure 55. The actual nitrification is very close to the expected value. This would mean that the nitrification system is working very well.

The evaluator should refer to the section of this manual about the process used for nitrification (activated sludge section, for example) for detailed information on process evaluation.

Control Considerations

There are several very important factors controlling the nitrification process.

pH has a major effect on the rate of nitrification, with values of about 8.5 usually best. At pH 7, nitrification rates are often 50% of those at pH 8.5. Sudden decreases in pH also produce bad effects on nitrification. The nitrification process itself can lower the pH to undesirable levels. About 7.14 mg of alkalinity as $CaCO_3$ is removed per mg of ammonia nitrogen oxidized. In many wastewaters there is not enough alkalinity to leave a good residual for buffering the wastewater during the nitrification process. Because of the effect pH has on nitrification, it is very important to provide enough alkalinity in the wastewater to balance the acid produced by nitrification. Caustic or lime addition may be needed to help add alkalinity to moderately alkaline wastewaters.

The rate of nitrification is also affected by temperature. The rate at $10^{o}C$ is about one-half of the nitrification rate at $20^{o}C$.

The concentration of dissolved oxygen (DO) also has a major effect on the rates of nitrification. Nitrification can occur at DO levels of 0.5 mg/l, but at much lower rates than at higher DO levels.

The following heavy metals and organic compounds are toxic to nitrifying bacteria:

Organics	Inorganics
Thiourea	Zn
Allyl-thiourea	OCN^{-1}
8-hydroxyquinoline	ClO^{-1}
Salicyladoxine	Cu
Histidine	Hg
Amino acids	Cr
Mercaptobenzthiazole	Ni
Perchloroethylene	Ag
Trichloroethylene	
Abietec acid	

Common Design Shortcomings and Ways to Compensate

Shortcomings	Solution
1. Aeration system not sized for maximum hourly ammonium load with resultant loss of nitrification efficiency during peak load periods.	1. Install flow equalization facilities to moderate peak conditions or install added aeration capacity to meet peak hourly BOD and nitrogenous load.
2. Drop in pH because no means provided for addition of alkalinity to aeration basins to offset loss of alkalinity from nitrification reaction.	2. Install lime or sodium bicarbonate feeders and pH probes in aeration basin.

Shortcomings	Solution
3. No means provided to return secondary clarifier skimmings to aeration (nitrification) basin.	3. Add line to return skimmings as required to maintain adequate nitrifier population.
4. Inadequate sludge return capacity to prevent denitrification in final clarifier with resultant rising sludge.	4. Increase sludge return capacity.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Decrease in nitrification unit pH with loss of nitrification	1a. Need more alkalinity to offset nitrification acidic effects.	1a. Alkalinity in effluent from nitrification unit.	1a. If alkalinity less than 30 mg/l start addition of lime or sodium hydroxide to nitrification unit.
	1b. Addition of acidic wastes to sewer system.	1b. Raw waste pH and alkalinity.	1b. Initiate source control.
2. Inability to completely nitrify.	2a. Oxygen concentrations are limiting nitrification.	2a. Minimum DO in nitrification unit should be 1 mg/l or more.	2a. Increase aeration supply or decrease loading on nitrification unit.
	2b. Cold temperatures are limiting nitrification.		2b. Decrease loading on nitrification unit or increase biological population in nitrification unit.
	2c. Increases in total daily influent nitrogen loads have occurred.	2c. Current influent nitrogen concentrations.	2c. Place added nitrification units in service or modify pretreatment to remove more nitrogen.
	2d. Biological solids too low in nitrification unit.	2d. SRT should be greater than 10 days and in cold temperatures may need to be greater than 15 days.	2d. 1. Decrease loading on nitrification unit and decrease wasting or loss of sludge from nitrification unit. 2. Add settled raw sewage to nitrification unit to generate biological solids.
	2e. Peak hourly ammonium concentrations exceed available oxygen supply.		2e. Install flow equalization system to minimize peak concentrations or increase oxygen supply.
3. In 2-stage act. sludge system, SVI of nitrification sludge is very high (>250).	3. Nitrification is occurring in first stage.	3. Nitrates in first stage effluent.	3. Transfer sludge from first stage to second and maintain lower SRT in first stage.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
4. Loss of solids from final clarifier.	4. (See activated sludge and secondary clarifier sections).		
5. Loss of solids from trickling filter or RBC.	5. (See trickling filter and RBC sections).		

DENITRIFICATION

Process Description

If bacteria come in contact with a nitrified element, and there is no oxygen, nitrates are reduced to nitrogen gas ("denitrification"). In this form, the nitrogen will escape as a gas from the wastewater.

Denitrification can be done either in an anaerobic activated-sludge system (suspended growth system) or in a columnar system (fixed-film system). With good biological treatment upstream, there is not much oxygen-demanding material left in the wastewater by the time it reaches denitrification. The denitrification will occur only if there is an oxygen demand when no oxygen is present in the wastewater. Usually, an oxygen-demand source must be added to reduce the nitrates quickly. The most common method of supplying the needed oxygen demand is to add methanol. About 3 mg/l of methanol are added per 1 mg/l of nitrate-nitrogen.

Suspended growth reactors used for denitrification are mixed mechanically only enough to keep the bio-mass from settling. Too much mixing will add unwanted oxygen.

Submerged filters using different kinds of media may be used for denitrification. Usually, a fine media (2-4 mm) is used in a downflow, packed bed. This system not only denitrifies the wastewater, but also filters the effluent. Another system uses a fluidized sand bed where wastewater flows upwards through a bed of small media such as activated carbon or sand at a rate which causes the bed to fluidize. The small media provides a large surface for the denitrifying bacteria to grow on.

Typical Design Criteria and Performance Evaluation

Suspended growth reactors are usually designed as plug-flow units to prevent short circuiting. Submerged mechanical mixers (0.25-0.5 hp/1000 cu ft) are usually used for mixing. Detention times often range from 1-3 hours, depending upon cold weather conditions and nitrogen concentrations.

About 3 mg/l of methanol usually is fed per mg/l of nitrate-nitrogen. Other materials also have been used, but some cause greater sludge production than others. For example, about twice as much sludge is produced per mg of nitrogen reduced when saccharose is used instead of methanol. On the other hand, acetone and acetate produce about the same amount of sludge as methanol. Low-nitrogen industrial wastes (such as brewery wastes) also have been used when available. The amount of methanol fed (or other oxygen demand source) must be carefully controlled since too much would result in a residual BOD in plant effluent. The feed rate should be automatically controlled by the incoming nitrate concentration. Flow pacing usually doesn't work because of changes in nitrate concentrations. Unless methanol removal is provided, excess methanol doses will cause methanol to appear in the effluent. It may be necessary to provide a methanol removal system as backup to provide fail-safe operation. Figure 59 shows one system used for removal of excess methanol. After denitrification, the mixed liquor passes to an aerated stabilization tank. In this tank, facultative organisms use up any remaining methanol. In fixed-film denitrification systems, this type of system would not work because there are not enough organisms in the column effluent to accomplish the biological oxidation.

There is a fixed-film filtration system using 6 ft of uniformly graded sand 2 to 4 mm in size. To remove 20 mg/l NO_3^- nitrogen, filtration rates of 2.5 and 1.0 gpm/sq ft are needed for minimum wastewater temperatures of 21°C and 10°C respectively. Mixed-media filters (coal, sand, garnet) have also been used as downflow, packed beds for denitrification. Using a 36-inch mixed-media filter (3 inches of 0.27 mm garnet, 9 inches of 0.5 mm sand, 8 inches of 1.05 mm coal, and 16 inches of 1.75 mm coal), almost complete denitrification is possible at 1.5 gpm/sq ft at temperatures of 10°C, and at 3 gpm/sq ft at temperatures of 20° C.

Settling basins downstream of denitrification units usually are designed with overflow rates less than 1,000 gpd/sq ft at peak hour. They are equipped with surface skimmers that return the scum to the denitrification tank. Waste sludge quantities depend on the oxygen-demand source fed to the system. For methanol, waste sludge quantities will be about 0.2 lbs/lb of methanol fed.

Control Considerations

Like nitrification, pH and temperature will effect the rate of denitrification. Denitrification rates are much less when pH is below 6.0 or above 8.0. Highest rates occur between 7.0 and 7.5. Denitrification rates at 15°C are often about 50% of those at 20°C. Fixed film beds using 2-4 mm sand are backwashed with one or two minutes of air agitation followed by ten to fifteen minutes of air and water scouring and finally five minutes of water rinse. Nitrogen gas may accumulate in such a filter during a filter run. These gas bubbles must be removed at certain times to prevent too much loss of head on the filter. A "bumping" procedure may be used consisting of a short backwash cycle lasting one or two minutes, after four to twelve hours of operation. When several filters are used, backwashed filter effluents are blended with other operating filters in order to reduce the effects of any initial nitrate leakage.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. No provision for removal of excess methanol from	1. Add aerated stabilization unit.

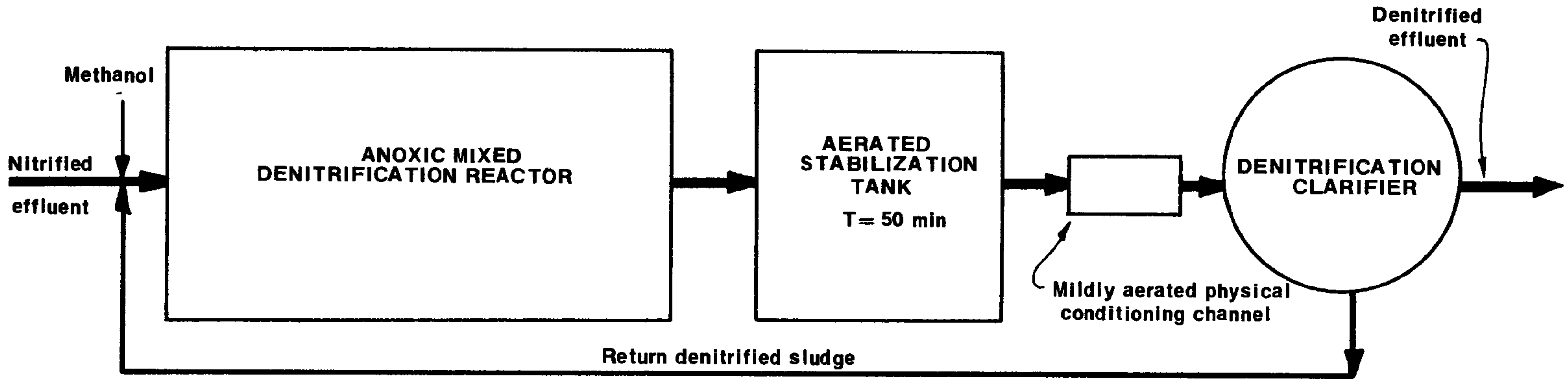


Figure 59. Process for removal of excess methanol.

Shortcoming	Solution
1. (continued) mixed denitrification reactor effluent.	
2. Short circuiting in mixed reactor is causing nitrate leakage.	2. Install baffles in mixed reactor to provide plug flow conditions.
3. Coarse rock-media in downflow fixed-film reactor cannot be backwashed.	3. Replace media with media finer than 0.5 inches.
4. Methanol feed pumps erratic due to pump materials not being compatible with methanol.	4. Replace pump heads (or pumps) with appropriate materials.
5. Packed bed denitrifiers backwashed with nitrate containing effluent causing high nitrate leakage at start of run.	5. Change source of backwash water to denitrified effluent.
6. Inadequate methanol storage provided causing outages due to shipping delays.	6. Install added storage to provide a total of at least two weeks storage.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Effluent BOD shows sudden increase.	1. Excessive addition of methanol (or other oxygen demanding material used).	1. Methanol to nitrate-nitrogen ratio should be 3:1.	1a. Reduce methanol addition. 1b. Install automated methanol feed system. 1c. Install aerated stabilization unit for removal of excess methanol per Figure 59.
2. Effluent nitrates show sudden increase	2a. Inadequate methanol addition.	2a. Methanol feed system malfunction.	2a. Correct malfunction
	2b. pH has drifted outside 7-7.5 range due to low pH in nitrification stage.	(See Nitrification Section)	
	2c. Loss of solids from denitrifier due to failure of sludge return.	2c. Denitrifier unit solids and clarifier effluent	2c. Increase sludge return; decrease sludge wasting; transfer sludge from carbonaceous unit to denitrifier.
	2d. Excessive mixing is introducing DO	2d. Denitrifier DO, should be as near zero as possible (<0.5 mg/l).	2d. Turn some mixers off or reduce speed.
3. High headloss across packed bed denitrification units.	3a. Excessive solids accumulation in filter.	3a. Length of filter run - if 12 hrs or more, this is the probable cause.	3a. Initiate full backwash cycle.
	3b. Nitrogen gas accumulating in filter.	3b. Run times or less than 12 hrs indicates this may be the cause.	3b. Backwash bed for 1-2 mins and return to service.
4. Packed bed denitrifier which has been out of service blinds immed. upon start-up	4. Solids have floated to top of bed and blind filter surface		4. Backwash beds before removing them from service and immediately before starting them.

AMMONIA STRIPPING

Process Description

The ammonia stripping process removes gaseous ammonia from water by agitating the water-gas mixture in the presence of air. Ammonium in secondary effluent can be converted to ammonia gas by raising the pH of the wastewater to 10.8 to 11.5. The gaseous ammonia can then be released by passing the high pH effluent through a stripping tower. In the tower, large amounts of air are mixed with the water flowing through the tower which releases the ammonia. Lime used in coagulation-sedimentation process not only removes suspended solids and phosphorus, but also raises the pH for the stripping process.

The three basic steps in ammonia stripping are (1) raising the pH of the water to at least 10.8 with the lime added in the chemical clarifier, (2) cascading the water down through a stripping tower to release the ammonia gas, and (3) forcing large amounts of air through the tower to carry the ammonia gas out of the system.

The towers used for ammonia stripping (Figure 60) look much like cooling towers. The Orange County facility in Figure 60 pictures a common ammonia stripping tower design. In this facility, clarifier effluent is pumped to the top of the towers where the flow is distributed through spray nozzles to the cells. Each tower has cells equipped with sections of fill material. These sections are separated by inside and outside access areas. Water flows down through the fill bundles into catch basins where the effluent may flow to recarbonation basins.

Each cell in each tower has a two speed fan. Air is drawn into the tower through the separate cooling sections which are located on the outside faces of the towers. The air passes up through the packing, (opposite in direction to water flow) stripping the ammonia from the water droplets as they are formed by the splash bar packing. The air leaves through the fan stacks on top of the tower structure.

Typical Design Criteria and Performance Evaluation

Tables 18 and 19 show the major design data for the ammonia stripping towers at the Orange County Water District Facility, and at the South Tahoe Facility.

Air temperature is the major element which can effect the performance of the ammonia stripping process. As the air temperature drops, efficiency also drops. For example, stripping removes about 95% of the ammonia in warm

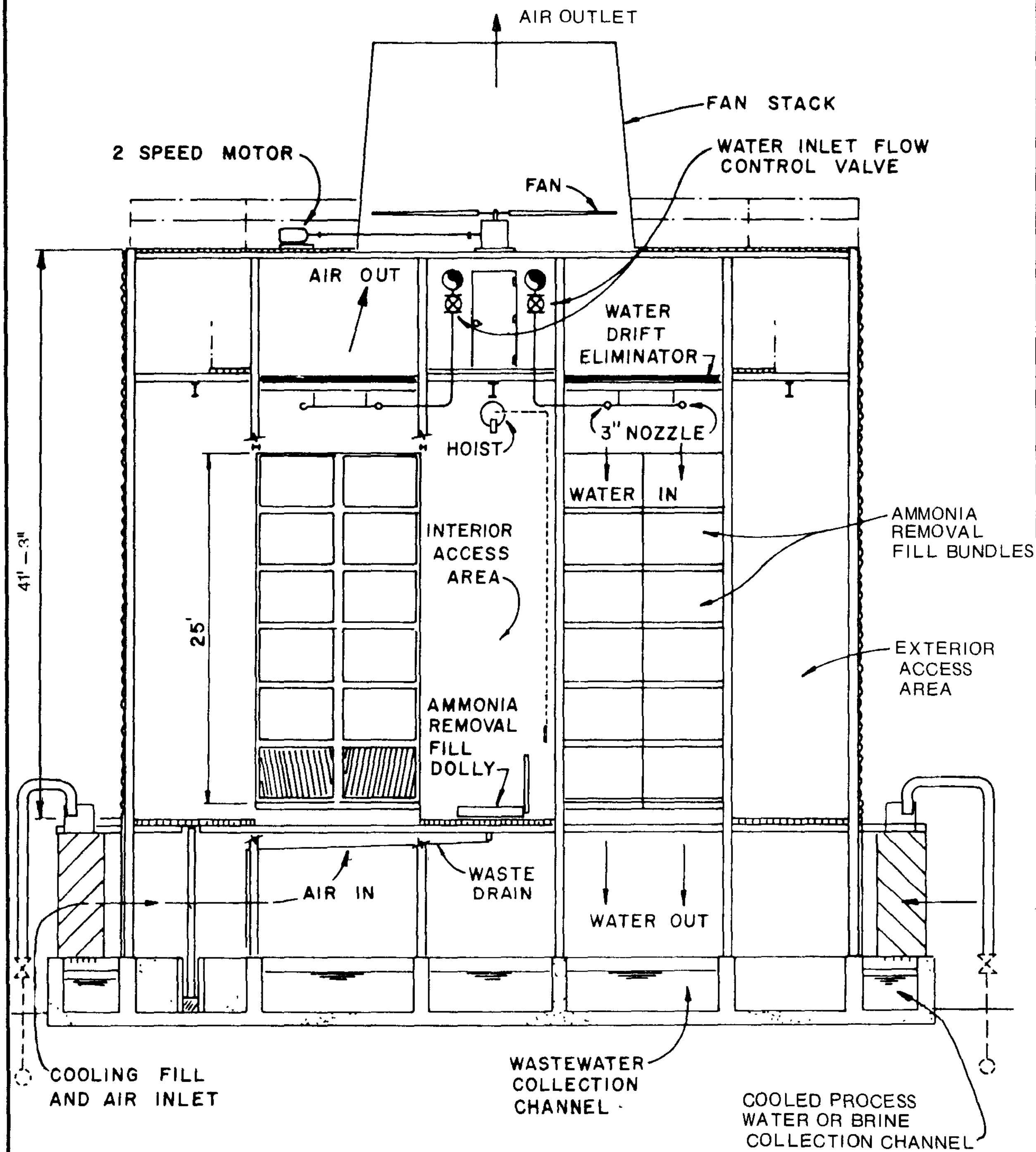


Figure 60. Typical ammonia stripping tower.

TABLE 18. DESIGN DATA FOR ORANGE COUNTY WATER DISTRICT AMMONIA STRIPPING TOWER

Number of towers:	2
Dimensions:	Overall length = 207 ft, width = 61 ft, height of main tower structure = 55 ft, depth of packing = 25 ft; plan area of ammonia stripping fill material = 4752 sq ft per tower; fill bundles are removable for cleaning.
Capacity:	5200 gpm each tower
No. of fans:	6 per tower, 18 ft diam, two speed 125/155 hp, electric motors (1800/1200 rpm).
Air capacity:	350,000 cfm per fan at static pressure of 1.1 in water (400 cfm/gpm @ design loadings)
Hydraulic loading rate:	1.1 gpm/sq ft of packing plan area @ 15 mgd
Cooling fill:	9 ft high, 200 ft long per tower at air inlet plenum.

weather (70°F air temperature) but only about 75% of the ammonia when the temperature falls to 40°F. The process becomes impossible because of frost inside the stripping tower when the air temperature falls very far below freezing. Performance also is affected by pH, hydraulic loading and the quantity of air circulating through the tower. These factors are described in more detail under the section on "Control Considerations".

The following steps can be used to check performance:

1. Determine influent pH - it should be above 10.8.

2. Check the tower hydraulic loading rate:

   Area covered by tower packing = 4752 sq ft
   Flow to tower = 5200 gpm

   $$\text{Hydraulic loading} \quad \frac{5200 \text{ gpm}}{4752 \text{ sq ft}} = 1.1 \text{ gpm/sq ft}$$

   Loadings should be less than 2 gpm/sq ft to keep water from moving through the tower in sheets rather than in drops.

TABLE 19. DESIGN DATA FOR TAHOE AMMONIA STRIPPING TOWER

Capacity:	Nominal, 3.75 mgd
Type:	Cross flow with central air plenum and vertical air discharge through fan cylinder at top of tower.
Fill:	Plan area, 900 sq ft Height, 24 ft Splash bars: material, roug-sawn treated hemlock size, 3/8 x 1-1/2 in spacing, vertical 1.33 in horizontal 2 in
Air flow:	Fan, two-speed, reversible, 24-ft diameter, horizontal

Water Rate		Air Rate	
gpm	gpm/ft^2	cfm	cfm/gpm
1,350	1.0	750,000	550
1,800	2.0	700,000	390
2,700	3.0	625,000	230

Tower structure:	Redwood
Tower enclosure:	Corrugated cement asbestos
Air pressure drop:	1/2 in of water at 1 gpm/ft^2

3. Check the tower packing to make sure it is not coated with calcium carbonate.

4. Calculate the removal of ammonia in the tower and check the air temperature:

   Influent = 20 mg/l
   Effluent = 2 mg/l
   Removal = $\frac{20 - 2}{20}$ = 90%
   Air Temperature = 65°F

   At 65°F, 90% removal is good. For every °F decrease in temperature, the efficiency will drop about 0.5%.

If performance is poor, refer to the troubleshooting guide.

Control Considerations

Influent pH--

The pH of the tower influent (chemical clarifier effluent) must be kept above 10.8 for efficient ammonia removal by air stripping. The pH usually is controlled in the chemical clarifier using lime addition.

Only the ammonia gas can be removed by stripping. At 20°C and pH 7.0 almost all of the ammonia nitrogen is present as ammonium ion and no ammonia can be removed by stripping. At a pH between 10.8 and 11.0 about 95 to 98% of the ammonia is present as dissolved gas and can be removed by stripping. It is important then to maintain the proper pH (at least 10.8) in the tower influent at all times for efficient ammonia removal.

Temperature--

The temperature of the air entering the tower is also a factor in ammonia removal efficiency. The removal efficiency is increased about 0.5% for each degree Fahrenheit increase in inlet air temperature.

In most cases, the operator has no control over the temperature of the air entering the tower. It is not practical to heat the large volumes of air needed for the stripping process.

Hydraulic Loading--

Removal efficiencies also vary with the hydraulic loading of the towers. Ammonia removals generally increase with decreased hydraulic loading. For best operation, this means that all sections of the tower should be used whenever possible. Loadings greater than 2 gpm/sq ft will probably result in sheets or streams of water flowing through the tower rather than in droplets. This will cause efficiency to drop.

The amount of droplets that form depends on the height and spacing of the packing and how evenly the flow is distributed. Spray inlet nozzles should be adjusted to give the best flow distribution possible.

Air Quantity--

Ammonia removal efficiency usually increases with increasing air flow in the stripping tower. Where the tower has variable speed fans, the lower speed can be used during low flow periods to reduce power consumption.

Scale Control--

When stripping lime-treated wastewater, high calcium and pH values make the water unstable, allowing the formation of calcium carbonate scale. Excessive scale must not be allowed to gather on the tower fill because air flow through the tower will be reduced and ammonia removal efficiency will drop. When scale first forms at pH values of 10.8 to 11.0, it is usually soft (the scale may be harder when formed at pH values of 11.5 to 12.0) and usually can be removed by hosing with a stream of water. If hard scale forms, it may be necessary to remove the fill bundles from the tower for cleaning.

Polymer Feed to Stripping Tower Influent--

There are polymers such as Cyanamer P-38 and Nalco Polyol-Ester, which are made especially to prevent calcium carbonate scale from forming at high pH. Polymer dosages of 0.5 to 5.0 mg/l are used to prevent scale from forming. Regular use of a polymer will depend on how bad the scale problem is, and how much the polymer costs. Sometimes it may be cheaper to manually remove the scale instead of adding polymer.

Common Design Shortcoming and Ways to Compensate

	Shortcoming		Solution
1.	Continuous formation of soft scale deposits on tower requiring frequent maintenance.	1.	Install a system of water sprays for automatic cleaning to be operated at a specific frequency.
2.	Noise complaint.	2.	Reduce fan speed to minimum speed compatible with removal of ammonia.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Scale build-up on ammonia stripping packing.	1a. Insufficient cleaning of tower (removal of scale).	1a. White coating accumulating on packing and reduction of air flow through the tower.	1a. Clean by hosing with a spray of water. 1b. Add a descaling polymer to the tower influent. 1c. Clean with a mixture of dilute sulfuric acid and an organic dispersant.
2. Scale build-up on pumping units feeding water into the tower.	2. Insufficient backwashing of pumping units.	2. Backwashing frequency.	2. Backwash pumps 2 or 3 times per day.
3. Ice build-up on outside of tower.	3. Freezing weather.	3. Air temperature.	3. Reverse draft fan to blow warm inside air to the frozen area to melt the ice.
4. Fan inoperable.	4a. Loose or damaged blade. 4b. Drive bearings overheating.	4a. Visual inspection.	4a. Repair or replace damaged or worn parts.
5. Loss of ammonia removal efficiency.	5a. Scale build-up on fill material. 5b. pH of tower influent too low. 5c. Excessive hydraulic loading. 5d. Insufficient air flow through tower.	5a. (See Item 1) 5b. pH 5c. Sheets or streams of water flowing through tower rather than in droplets. 5d. Air flow rate.	5a. (See Item 1) 5b. Increase pH to at least 10.8 by lime addition in chemical clarifier. 5c. (See Item 6) 5d. Increase air flow rate by operating fans at higher speed, or recycle air flow back through the tower.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
6. Sheets or streams of water rather than droplets flowing through tower.	6a. Excessive hydraulic loading rate.	6a. Flow rate should be less than 2 gpm/ft^2.	6a. 1. Decrease the flow rate or 2. Increase the number of units in service.
	6b. Non-uniform flow distribution.	6b. Spray inlet nozzle adjustment.	6b. Adjust or clean spray inlet nozzles to provide even flow distribution.
	6c. Scale build-up may be blocking a portion of the fill.	6c. (See Item 1)	6c. (See Item 1)

CHEMICAL FEEDING AND CONDITIONING

Process Description

Many different chemicals are used to treat municipal wastewaters. Some of the most often used chemicals are lime, aluminum sulfate (alum), ferric chloride, soidum hydroxide, and powdered activated carbon. The chemical used depends on what purpose is to be served, the quality of the wastewater, the type of handling and feeding equipment available, and chemical costs. Good feed control is important because of chemical costs, and to prevent excess chemicals from reaching the receiving stream. Table 20 lists some of the chemicals used in wastewater treatment, as well as the properties of each, and information on the feeding of each chemical.

Three basic types of chemical feed equipment are used: volumetric, belt gravimetric, and loss-in-weight gravimetric. The feeder must be chosen carefully, especially in the small facilities where a single feeder may be used for more than one chemical.

Volumetric feeders usually are used only where low feed rates are required. These feeders deliver a constant, preset amount of chemical. There are many types of volumetric feeders, but the screw type feeder is most often used (Figure 61). Gravimetric feeders, however, are more accurate and generally are used in larger plants. Both types of feeders can be used to feed in proportion to the flow of wastewater.

The loss-in-weight feeder should be used where accuracy or cost of chemical is important. This feeder only works for feed rates up to a rate of 4,000 lb/hour. The loss-in-weight type feeder has a material hopper and feeder set on enclosed scales. The feed rate controller is used to deliver the dry chemical at the desired rate.

Belt-type gravimetric feeders have a wide capacity range and usually can be sized for any use in a wastewater treatment plant. Belt-type gravimetric feeders use a basic belt feeder with a weighing and control system. Feed rates can be changed by adjusting the weight per foot of belt, the belt speed, or both.

Liquid feeders usually are metering pumps or orifices. These metering pumps usually are positive displacement, plunger, or diaphragm type pumps. The type of liquid feeder used depends on the viscosity, corrosivity, solubility, suction and discharge heads, and internal pressure-relief requirements. Some examples are shown in Figure 62. In some cases, control valves and rotameters may be all that is needed. For uses like lime slurry feeding, however, centrifugal pumps with open impellers are used.

TABLE 20. CHEMICALS COMMONLY USED IN WASTEWATER TREATMENT

1. Name 2. Formula 3. Trade name 4. Use	Available forms and appearances	Commercial strength	Properties likely to cause trouble	Storage container materials	Best feed regulation	Strength of solution or suspension (%) and properties	Suitable handling material for solutions
1. Aluminum sulfate 2. $Al_2(SO_4)_3$ 14 H_2O 3. Filter alum 4. Coagulation sludge conditioning	Light tan to gray-green lumps, granules, or powder Liquid alum also avail.	Powder - 17% Al_2O_3 Minimum Liquid - 8.3% Al_2O_3, 49% dry aluminum sulfate	Dusty	Concrete Steel Wood Moisture-proof	Dry or solution feed	0.25-6.0% - Acid and corrosive	Lead Rubber Acid-resisting tile Duriron Plastics Stainless steel 316 Asphalt Cypress
1. Calcium oxide 2. CaO 3. Quicklime 4. Coagulation, pH adjustment sludge conditioning	White powder	$Ca(OH)_2$ 97-99% CaO 71-74%	Dusty	Concrete Steel Wood	Dry feed or slurry	Up to 10% - alkali and prone to encrustment	Rubber Iron Concrete
1. Calcium oxide 2. CaO 3. Quicklime 4. Coagulation, pH adjustment sludge conditioning	White powder or porous white to light gray lumps	90-96% CaO below 88% is poor quality	Dusty, slakes upon standing long, causing expansion	Concrete Steel	Thin, milk-like slurry	Up to 25%, then dilute to 10% after slaking - alkali and prone to encrustment	Rubber Iron Cement
1. Ferric chloride, $FeCl_3$ solution 2. $FeCl_3$, $6H_2O$ crystal $FeCl_3$-anhydrous 3. Liquid ferric chloride Crystals, ferric chloride 4. Coagulation, sludge conditioning, odor control (H_2S)	Dark brown solution Yellow, brown crystals Green, black granules	Solution - 37-47% $FeCl_3$ Crystal - 60% $FeCl_3$ Anhydrous - 96-97% $FeCl_3$	Solution - acid, corrosive, stains Crystal - melts at 37°C, hygroscopic, corrosive, stains, Anhydrous - deliquescent, corrosive, stains	Rubber-lined steel, wood, or concrete	Solution feed only	Up to 45% $FeCl_3$-acid and corrosive	Acid-proof brick Ceramics Stoneware Rubber Glass Plastics Asbestos Teflon
1. Methanol 2. CH_3OH 3. Methanol 4. Denitrification	Colorless liquid	99.9% CH_3OH	Vapors toxic Toxic liquid Flammable Skim irritation	Steel tanks	Solution feed only	-	Steel
1. Sodium hydroxide 2. NaOH 3. Caustic soda 4. pH adjustment, acid neutralization	Liquid	50% NaOH 73% NaOH	Alkali burns	Steel	Solution feed only	Up to 20%	Stainless steel - 316 Rubber Nickel Nickel alloys Plastic

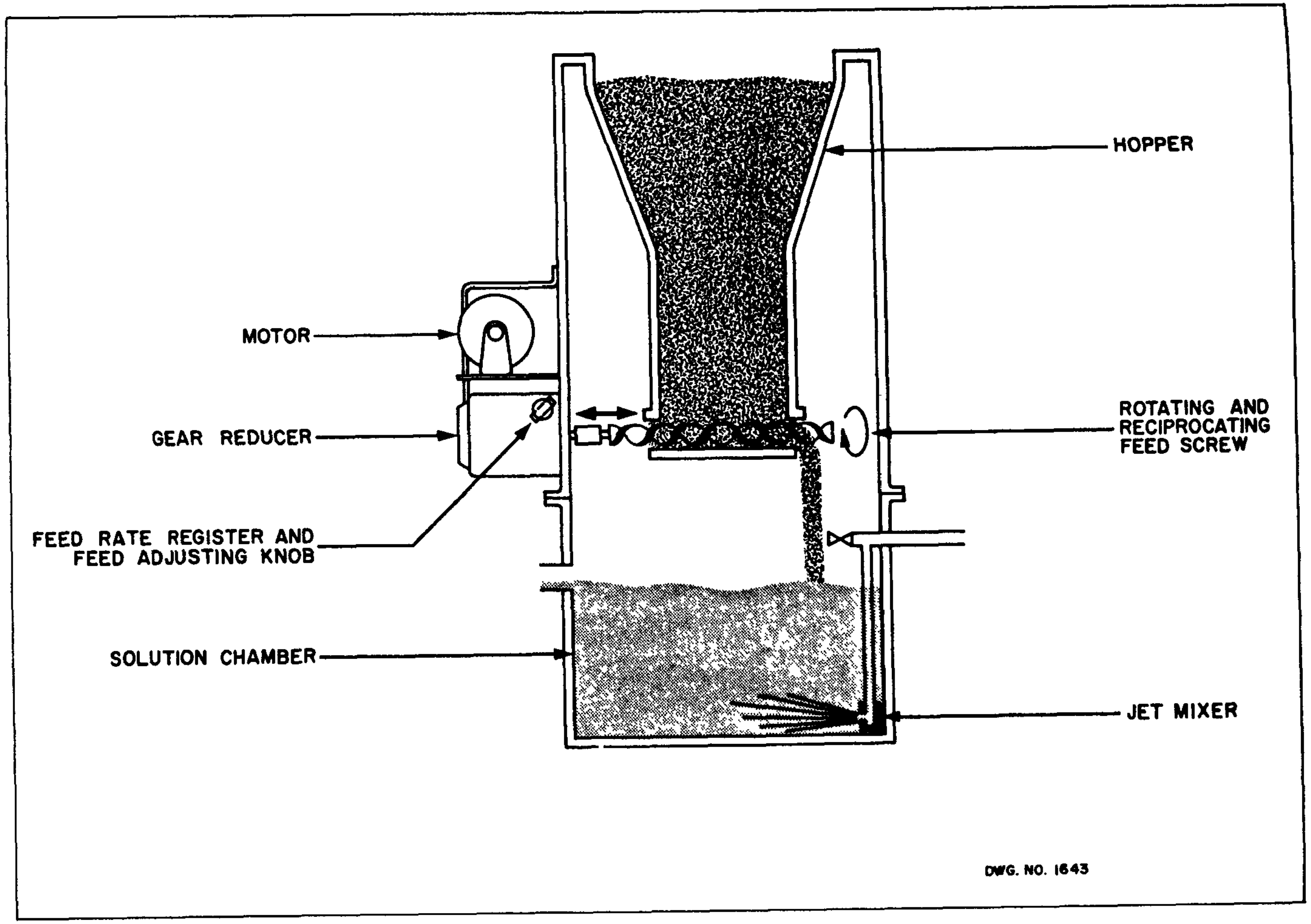
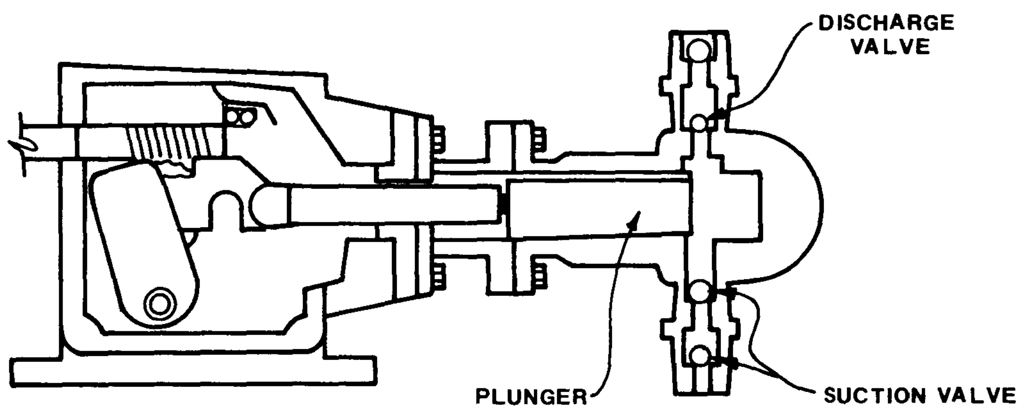
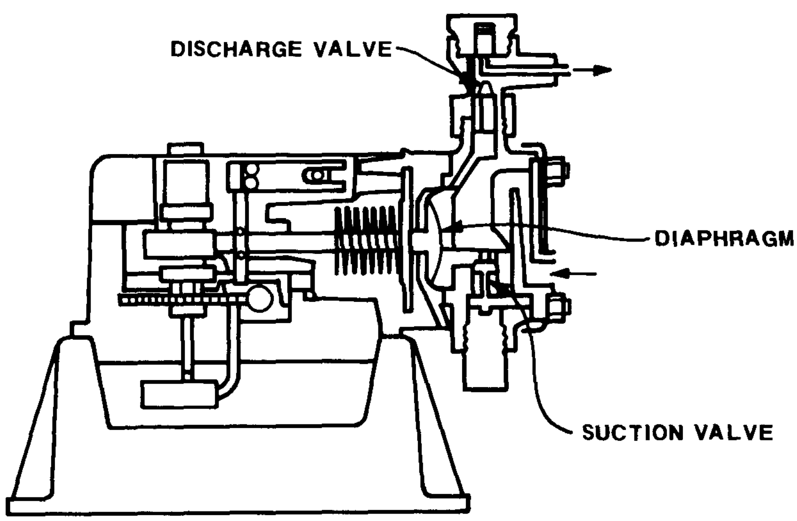


Figure 61. Typical screw type volumetric feeder
(courtesy of Wallace & Tiernan, division of Pennwalt Corporation)



PLUNGER PUMP



DIAPHRAGM PUMP

Figure 62. Positive displacement pumps.

Lime--

Lime can be added either before primary treatment or after secondary treatment (as part of an AWT process). As a coagulant used in primary treatment, lime helps to remove SS, phosphorus, heavy metals, grease and viruses. Lime also may be used to adjust the pH of the wastewater, or for sludge conditioning.

Although lime comes in many forms, quicklime and hydrated lime are used most often for wastewater coagulation. Quicklime (unslaked lime) is almost all calcium oxide (CaO), and first must be converted to the hydrated form ($Ca(OH)_2$). Hydrated or slaked lime is a powder obtained by adding enough water to quicklime to satisfy its affinity for water.

Lime may be unloaded using screw or bucket conveyors, or pneumatically as shown in Figure 63.

Lime is never fed as a solution because of its low solubility in water. Also, quicklime and hydrated lime usually are not applied dry directly to the wastewater for the following reasons:

- they are transported more easily as a slurry;
- the lime mixes better with the wastewater;
- pre-wetting the lime in the feeder with rapid mixing helps to make sure that all particles are wet and that none settle out in the treatment basin.

A schematic drawing of a lime feed system is shown in Figure 64 with details of gravimetric feeders and slakers shown in Figure 65. Quicklime feeders usually must be the belt or loss-in-weight gravimetric types because bulk density changes so much. Feed equipment usually has an adjustable feed range of at least 20:1 to match the operating range of the slaker. The main parts of a lime slaker for wastewater treatment usually include one or more slaking bins, a dilution bin, a grit separation bin, and a continuous grit remover.

Hydrated lime is slaked lime and needs only enough water to form milk of lime. Wetting or dissolving tanks usually are designed for 5 minutes detention with 0.5 lb/gal of water or 6% slurry at the highest feed rate. Hydrated lime often is used where maximum feed rates are less than 250 lb/hr.

Dilution is not too important in lime feeder, therefore, it is not necessary to control the amount of water used in feeding. Hydraulic jets may be used for mixing in the wetting chamber of the feeder, but the jets should be the right size for the water supply pressure.

Alum--

Aluminum sulfate may be added to wastewater for coagulation or phosphorus removal. It may be used as the primary coagulant instead of lime,

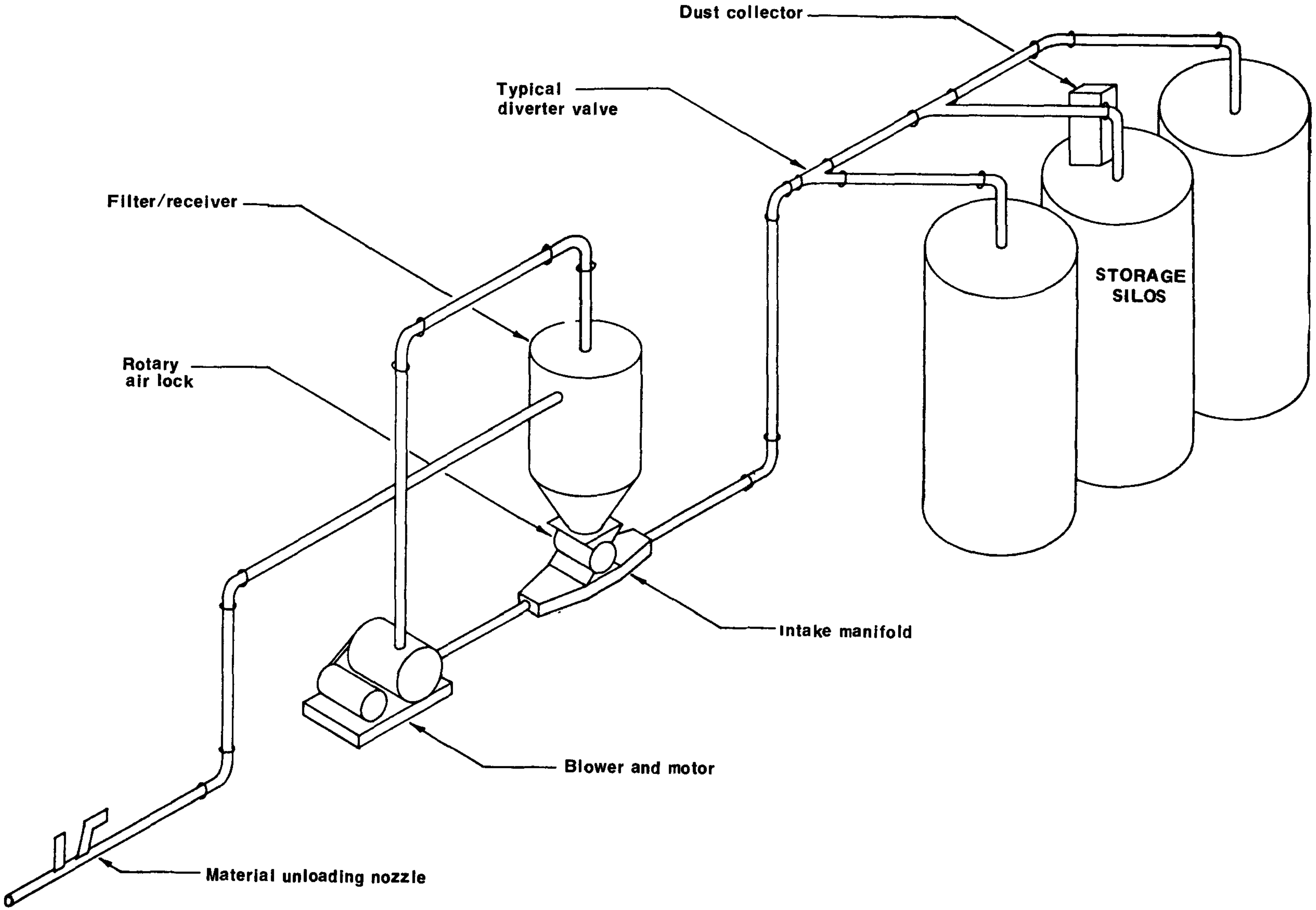


Figure 63. Typical positive-negative pneumatic conveying system.

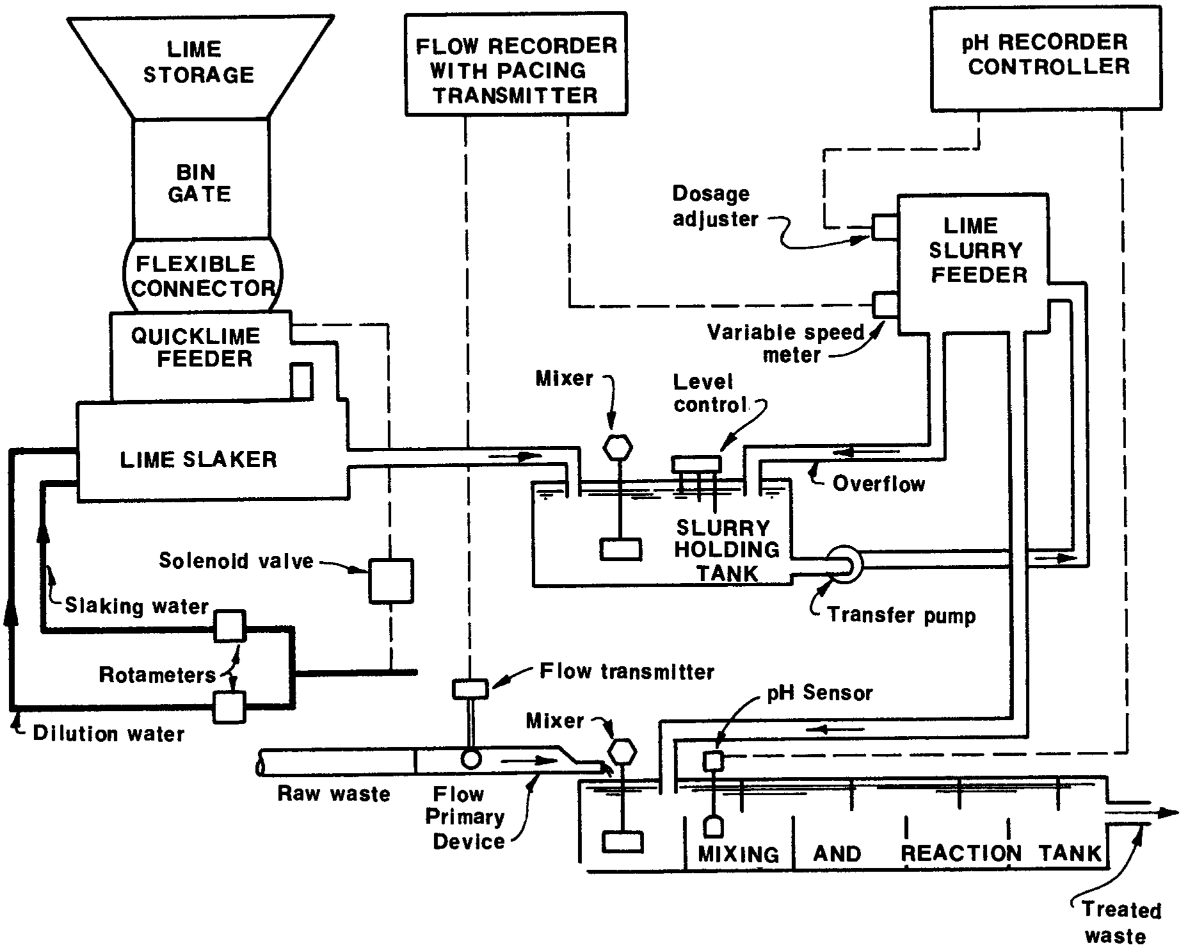


Figure 64. Illustrative lime feed system for wastewater coagulation.

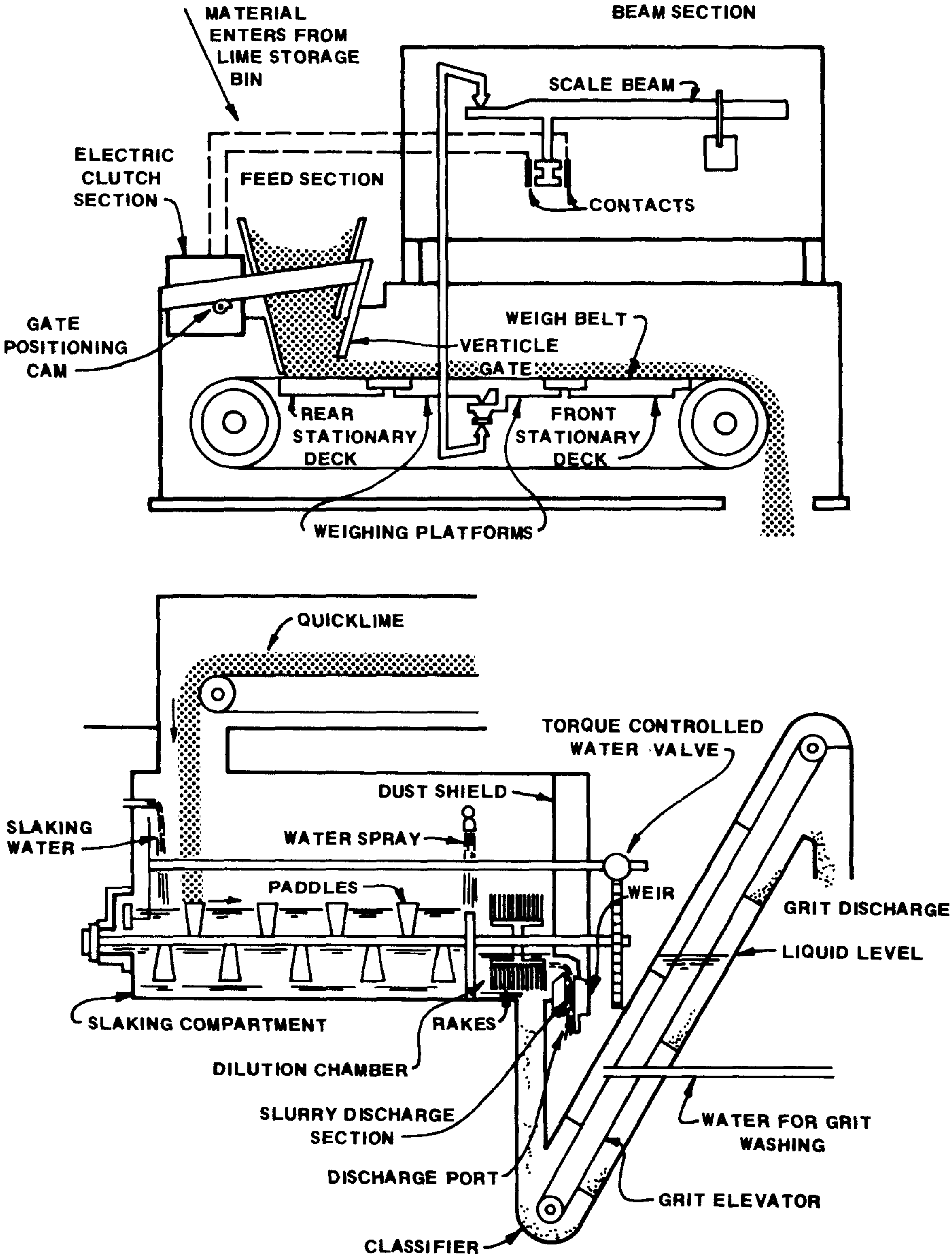


Figure 65. Typical lime feeder and lime slaker.

or along with lime. Alum may be added as a filter aid to the influent of a mixed-media filter. It may also be added at several other points in the wastewater treatment process including the primary influent, rapid mix basin, or first stage recarbonation basin.

Alum is available in either dry or liquid form. As a dry chemical, alum may be in the granular, powder, or lump form in bag, barrel or carload quantities. When the granular form is used, it is dry fed, and weighs 60 to 75 lb/cu ft. A common type of storage and feeding system for dry alum is pictured in Figure 66. Dry alum in bulk can be unloaded with screw conveyors, pneumatic conveyors, or bucket elevators made of mild steel. Pneumatic conveyor elbows should have a strong backing since the alum can contain harsh impurities.

The feed system for dry alum has all of the parts needed for good preparation of the chemical solution.

To prepare alum for feeding, dissolving tanks should be made of a non-corrosive material. Dissolvers should be the right size to get the desired solution strength. Most solution strengths are 0.5 lb of alum to 1 gal of water, or a 6% solution. The dissolving tank should be designed for a minimum detention time of 5 minutes at the maximum feed rate. Dissolvers should have water meters and mixers so that the water/alum mixture can be controlled.

Liquid alum is shipped in rubber-lined or stainless steel, insulated tank cars or trucks. The liquid form is delivered at a solution strength of about 8.3% as Al_2O_3, and contains about 5.4 lbs dry alum (17% Al_2O_3) per gal of liquid. Figures 67 and 68 show two common feed systems for liquid alum. The rotodip-type feeder or rotameter often is used for gravity feed and the metering pump for pressure feed systems. The pressure at the point of application often determines the type of feeding system used. Overhead storage can be used to gravity feed the rotodip as shown in Figure 67. A centrifugal pump may also be used, but needs an excess flow return line to the storage tank, as shown in Figure 68. Alum usually is fed by positive displacement metering pumps. Positive displacement pumps can be set to feed over a wide range by adjusting the pump stroke length. Dilution water usually is added to an alum feed pump discharge line to prevent line plugging, to reduce delivery time to the point of application, and to help mix the alum with the water being treated. The output of the pumps can be controlled automatically in proportion to plant flow. This is done by setting the alum dosage for the maximum flow rate. The controls are then set to automatically adjust the off-on cycle and the amount of alum pumped to the actual flow.

Polymers--

Polymers are used as an aid to flocculation, where a light or fine floc settles too slowly. The normal dose for this use is about 0.10 to 0.25 mg/l of polymer. It is almost impossible to overdose, but this may occur in the range of 1.0 to 2.0 mg/l. Polymers are also very useful as filter aids (common doses are 0.01 to 0.1 mg/l). By adding the right

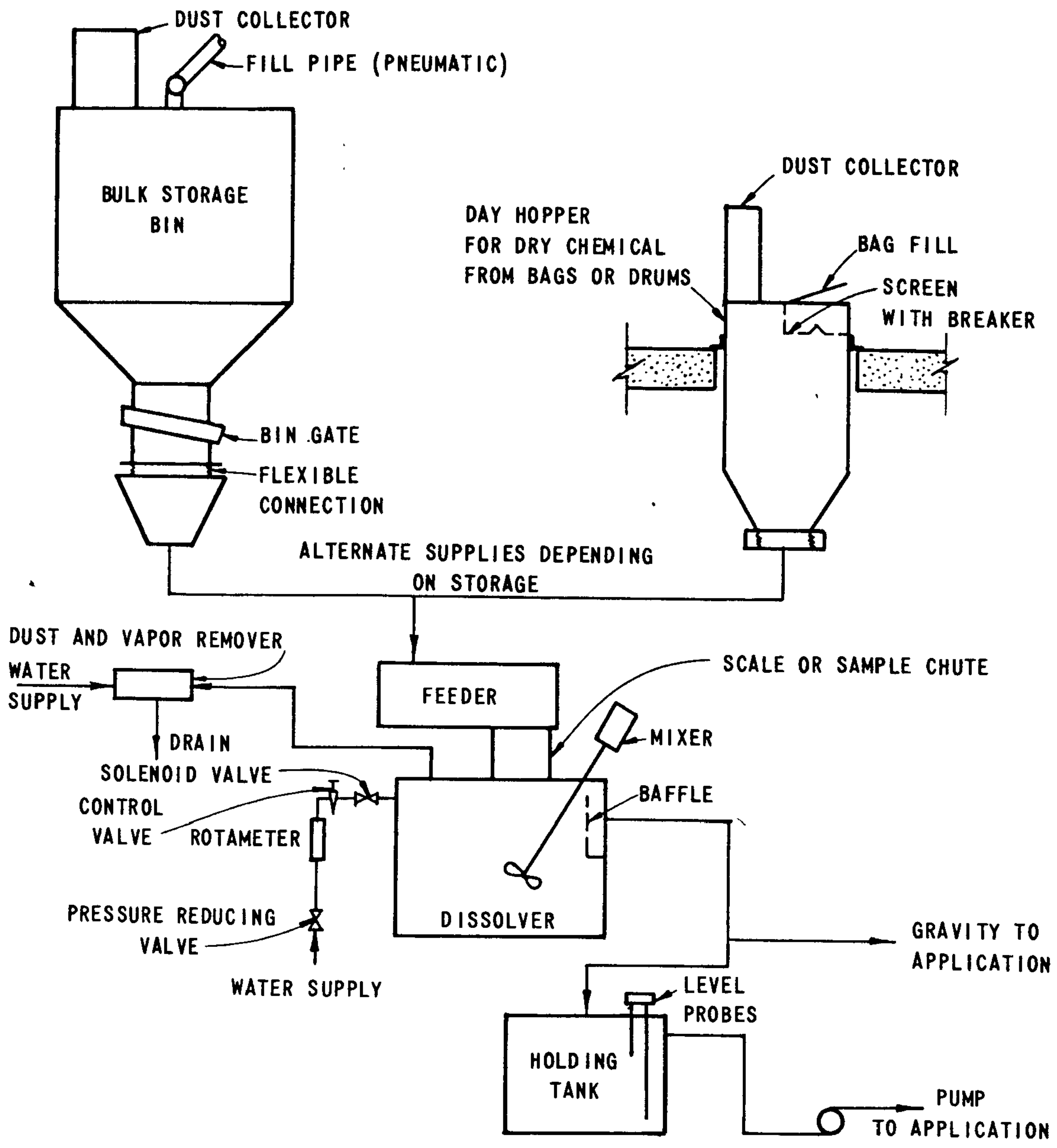


Figure 66. Typical dry feed system.

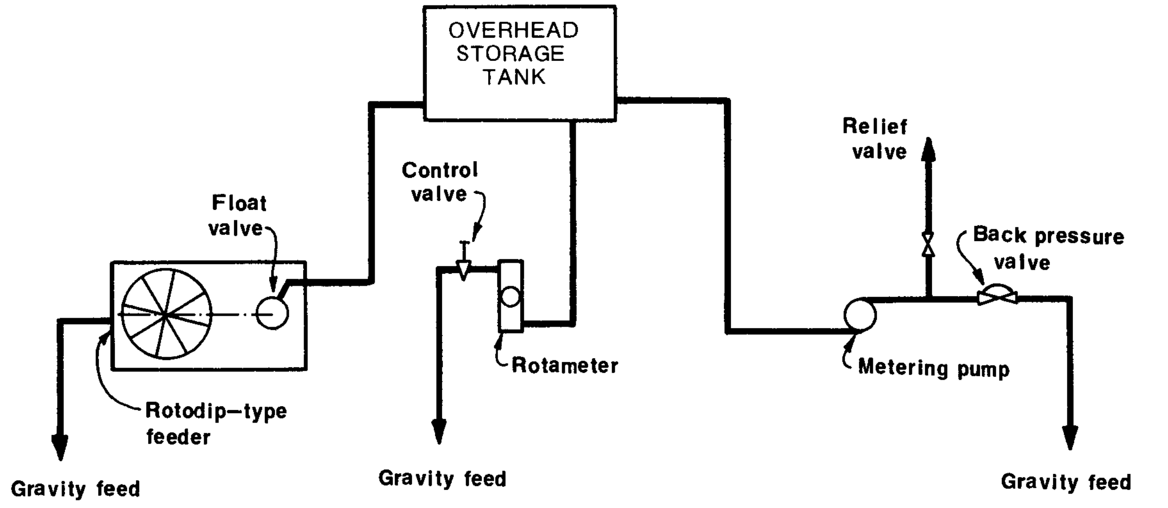


Figure 67. Alternative liquid feed systems for overhead storage.

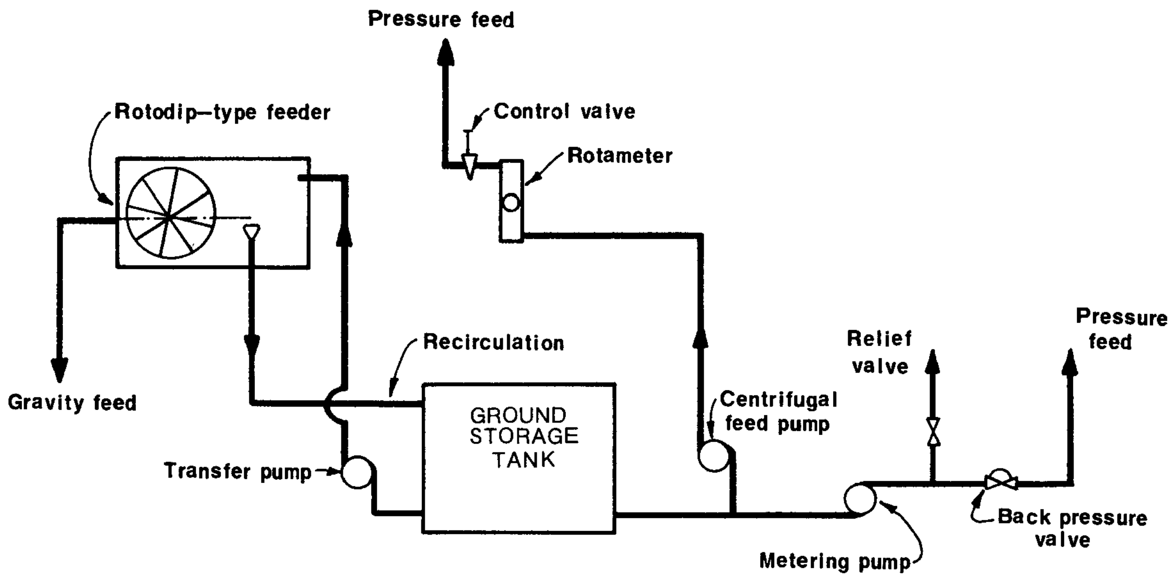


Figure 68. Alternative liquid feed systems for ground storage.

amount of polymer at the right point in treatment, both turbidity and phosphorus removal can be improved.

When polymers are used as a dry powder, complete wetting is necessary using a funnel-type aspirator. After wetting, warm water must be added and gently mixed for about 1 hr. Polymer feed solution strengths are usually in the range of 0.2 to 2.0%. Stronger solutions are often too viscous to feed. The solution usually is fed using positive displacement metering pumps. Dilution water is added to the feed discharge to reduce line plugging and to aid mixing. Like alum pumps, polymer feed pumps can be paced automatically for plant flow.

Polymer solutions above 1% in strength should not be used because they are very viscous and difficult to handle. Most powdered polymers are very stable, but even in cool, dry conditions, they should not be stored as powders for more than 1 yr. Once polymers are dissolved, they may become unstable within 1 or 2 weeks.

Ferric Chloride--

Ferric chloride is available in dry, liquid, or crystalline (hydrated) form. The crystalline form weighs 60 to 64 lb/cu ft and the anhydrous form weighs 85-90 lb/cu ft. Most liquid forms contain 35 to 45% ferric chloride and weigh 11.2 to 12.4 lb/gal. The liquid should be handled in rubber, glass, ceramics, or plastic. If iron salts are used for wastewater coagulation in softwaters, a small amount of base (such as sodium hydroxide or lime) is needed to neturalize the acidity of these strong acid salts.

Like alum and lime, ferric chloride is an effective coagulant used to remove phosphorus and to lower suspended solids. Ferric chloride also can be used as an oxidant to control odor problems coming from hydrogen sulfide. Since ferric chloride is always fed as a liquid, it is normally obtained as a liquid and unloaded pneumatically. The ferric chloride content of the solution is about 35 to 45% $FeCl_3$. It contains about 3.95 to 5.58 lb $FeCl_3$/gal.

Feeding systems for ferric chloride are much like those for liquid alum. The differences are the materials of construction, and the use of glass tube rotameters. Because of hydrolysis, it may not be a good idea to dilute the ferric chloride solution from its shipping concentration to a weaker feed solution. Ferric chloride solutions may be transferred from underground storage to day tanks with rubber-lined self-priming centrifugal pumps having teflon rotary and stationary seals. Because liquid ferric chloride can stain or deposit, glass-tube rotameters are not used for metering. Instead, rotodip feeders and diaphragm metering pumps made of rubber-lined steel and plastic often are used for ferric chloride feeding.

Methanol--

In the biological nitrification-denitrification process, an oxygen-demand source such as methanol often is added to the wastewater in order to reduce the nitrates quickly. Methanol may be used either in a column or in a 3-stage reaction basin. (See Denitrification Section of this manual)

Methanol is a colorless liquid, and non-corrosive (except to aluminum and lead) at normal atmospheric temperature. Transfer pumps should always have positive suction pressure and should be protected by a strainer. There are three basic pumping arrangements which can be used: (1) diaphragm chemical feed pumps using an adjustable stroke for volume control; (2) positive displacement pumps with variable speed drives controlled by either a flow meter or by counting revolutions; (3) centrifugal or regenerative turbine pumps with variable speed drives controlled by a flow meter.

Sodium Hydroxide--

Sodium hydroxide (NaOH) is a strong base used to neutralize an acidic wastewater. Without proper neutralization, acid wastewaters can damage treatment facilities and biological treatment processes. Sodium hydroxide also is used for pH adjustment along with other chemicals used in the treatment process.

Liquid caustic soda (sodium hydroxide) comes in two concentrations, 50% and 73% NaOH. The 50% solution contains 6.38 lb/gal NaOH and the 73% solution contains 10.34 lb/gal NaOH. Sodium hydroxide comes in bulk shipments, transferred to storage, and diluted just before feeding. Dilution of liquid caustic soda below the storage strength may be good when volumetric feeders are used. Feeding systems for caustic soda are about the same as for liquid alum except for materials of construction. A typical feeder system schematic is shown in Figure 69. Feeders often are made of ductile iron, stainless steels, rubber, and plastics.

Powdered Carbon--

Activated carbon most often is used to remove soluble organics. When the powdered form is used, it is mixed directly with the wastewater, fed as slurry, and removed by coagulation and settling. The carbon slurry is transported by pumping the mixture at a high velocity to keep the particles from settling and collecting along the bottom of the pipe. The velocity of the slurry should not be greater than 10 ft/sec in order to

- keep the pipe from wearing out,
- keep from losing carbon particles during transport,
- keep pressure at a good level.

Most plant feeding slurry concentrations around 10.7% or 1 lb carbon/gal water use either centrifugal pumps or a combination of centrifugal pumps and eductors. Diaphragm slurry pumps or double-acting positive displacement pumps are used for transporting higher concentrations. The carbon slurry may be fed using a rotodip feeder.

Typical Design Criteria

Table 21 lists several types of chemical feeders often used in wastewater treatment. The table also shows the use and limitations of each feeder. Chemical feed systems must be very reliable. The design of the system should depend on:

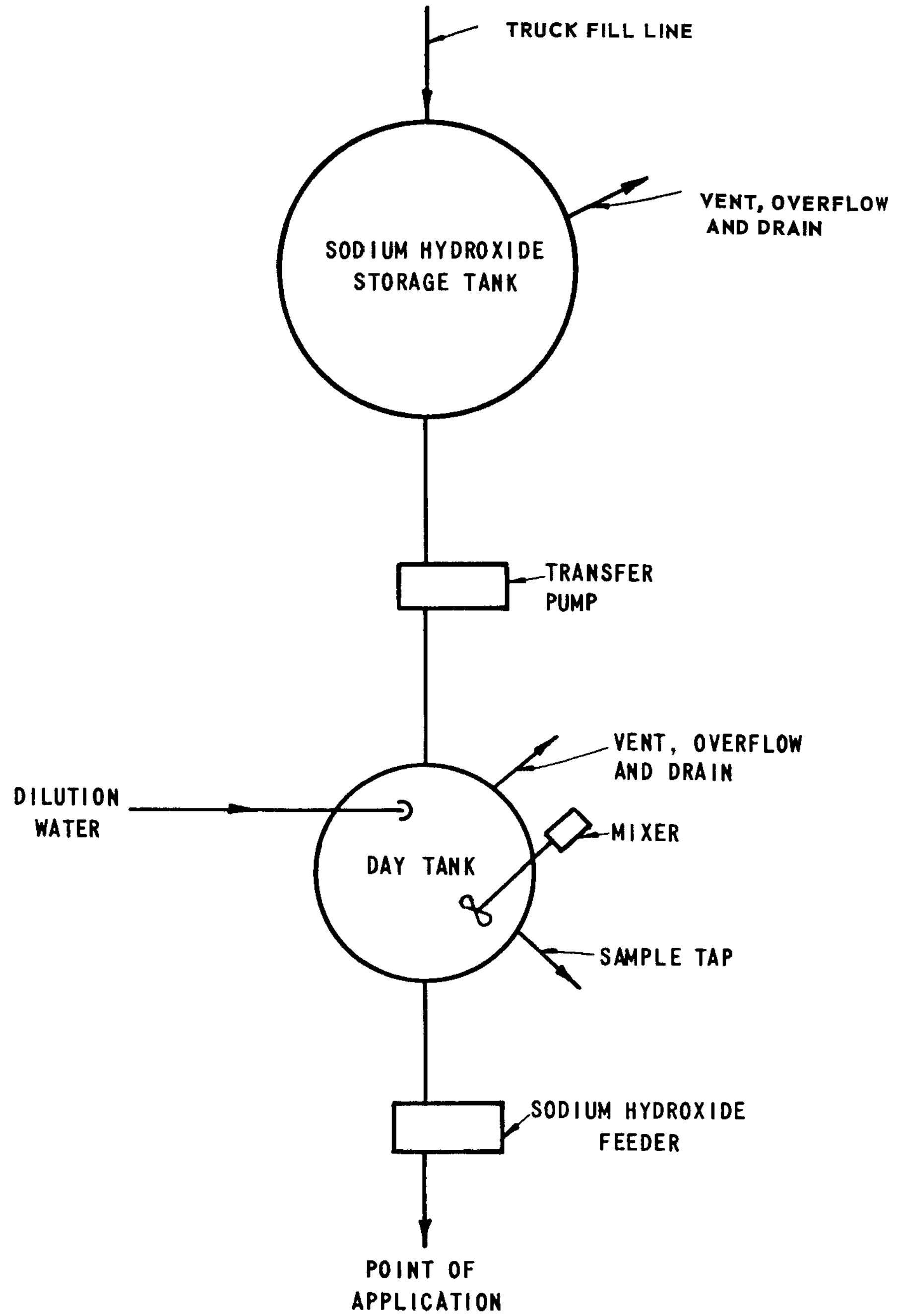


Figure 69. Typical caustic soda feed system.

TABLE 21. TYPES OF CHEMICAL FEEDERS

Type of Feeder	Use	Limitations: General	Limitations: Capacity cu ft/hr	Limitations: Range
Dry feeder:				
Volumetric:				
Oscillating plate	Any material, granules or powder.	....	0.01 to 35	40 to 1
Oscillating throat (universal)	Any material, any particle size.	....	0.02 to 100	40 to 1
Rotating disc	Most materials including NaF, granules or powder.	Use disc unloader for arching.	0.01 to 1.0	20 to 1
Rotating cylinder (star)	Any material, granules or powder.	....	8 to 2,000 or 7.2 to 300	10 to 1 or 100 to 1
Screw	Dry, free flowing material, powder or granular.	....	0.05 to 18	20 to 1
Ribbon	Dry, free flowing material, powder, granular, or lumps.	....	0.002 to 0.16	10 to 1
Belt	Dry, free flowing material up to 1½-inch size, powder or granular.	....	0.1 to 3,000	10 to 1 or 100 to 1
Gravimetric:				
Continuous–belt and scale	Dry, free flowing, granular material, or floodable material.	Use hopper agitator to maintain constant density.	0.02 to 2	100 to 1
Loss in weight	Most materials, powder, granular or lumps.	....	0.02 to 80	100 to 1
Solution feeder:				
Nonpositive displacement:				
Decanter (lowering pipe)	Most solutions or light slurries	....	0.01 to 10	100 to 1
Orifice	Most solutions	No slurries	0.16 to 5	10 to 1
Rotameter (calibrated valve)	Clear solutions	No slurries	0.005 to 0.16 or 0.01 to 20	10 to 1
Loss in weight (tank with control valve).	Most solutions	No slurries	0.002 to 0.20	30 to 1
Positive displacement:				
Rotating dipper	Most solutions or slurries	....	0.1 to 30	100 to 1
Proportioning pump:				
Diaphragm	Most solutions. Special unit for 5% slurries.[1]	....	0.004 to 0.15	100 to 1
Piston	Most solutions, light slurries.	....	0.01 to 170	20 to 1
Gas feeders:				
Solution feed	Chlorine	....	8000 lb/day max	20 to 1
	Ammonia	....	2000 lb/day max	20 to 1
	Sulfur dioxide	....	7600 lb/day max	20 to 1
	Carbon dioxide	....	6000 lb/day max	20 to 1
Direct feed	Chlorine	....	300 lb/day max	10 to 1
	Ammonia	....	120 lb/day max	7 to 1
	Carbon dioxide	....	10,000 lb/day max	20 to 1

[1] Use special heads and valves for slurries.

- the form of chemical being fed,
- properties of the chemical,
- maximum waste flows,
- reliability of the feeder.

In both storage and feeding, the capacity of a chemical feed system is important. Chemicals must not be allowed to deteriorate with time, and feeders must be able to work within the range of feeding rates required. Chemical feeder control can be manual, automatically proportioned to flow, dependent on some form of process feedback, or a combination of any two of these methods.

Most feeders use a small dissolving tank with a nozzle system and/or a mixer. It is essential that the surface of each chemical particle become completely wetted before entering the feed tank. This will avoid clumping, settling or floating and make sure the chemical is well mixed.

The dissolver should be designed for the right capacity, detention times, water requirements, and chemical properties.

Chemical Dosages and Performance Evaluation

Coagulants--

The amount of coagulant needed for good coagulation depends on the properties of the wastewater. Aluminum and iron salt dosages for good phosphorus removal are generally proportional to the phosphorus concentration, and lime dosages depend mostly on the alkalinity of the wastewater. Magnesium hydroxide, (formed when lime is added to hard waters containing the magnesium ion) also helps remove colloidal material. It may cause problems in sludge dewatering. Most coagulant doses are aluminum sulfate (alum), 75 to 250 mg/l; ferric chloride, 45 to 90 mg/l; and lime 200 to 400 mg/l. At these dosages, lime, alum, and ferric chloride can remove 85 to 95% phosphorus by sedimentation; and 98-99% when sedimentation is followed by filtration.

Sometimes extra lime may be needed to form a fast-settling floc. Lime also is used along with aluminum or ferric coagulants for pH control. Figure 70 shows how lime dosage affects alkalinity to get a pH of 11 (commonly used for ammonia stripping).

Lime coagulation can reduce heavy metal concentrations because many metals form insoluble hydroxides at pH 11. With the exception of mercury, cadmium, and selenium, 90 percent or more of most heavy metals may be removed by lime coagulation at pH 11. Also, at this pH, lime coagulation removes viruses, but disinfectants such as chlorine or ozone also must be used for complete disinfection.

Alum coagulation can remove 95 to 99% of viruses, and ferric chloride coagulation can remove 92 to 94%. With both alum and ferric chloride, good virus removal depends on good floc formation. With filtration, coagulation using alum or ferric chloride can remove 99% of viruses.

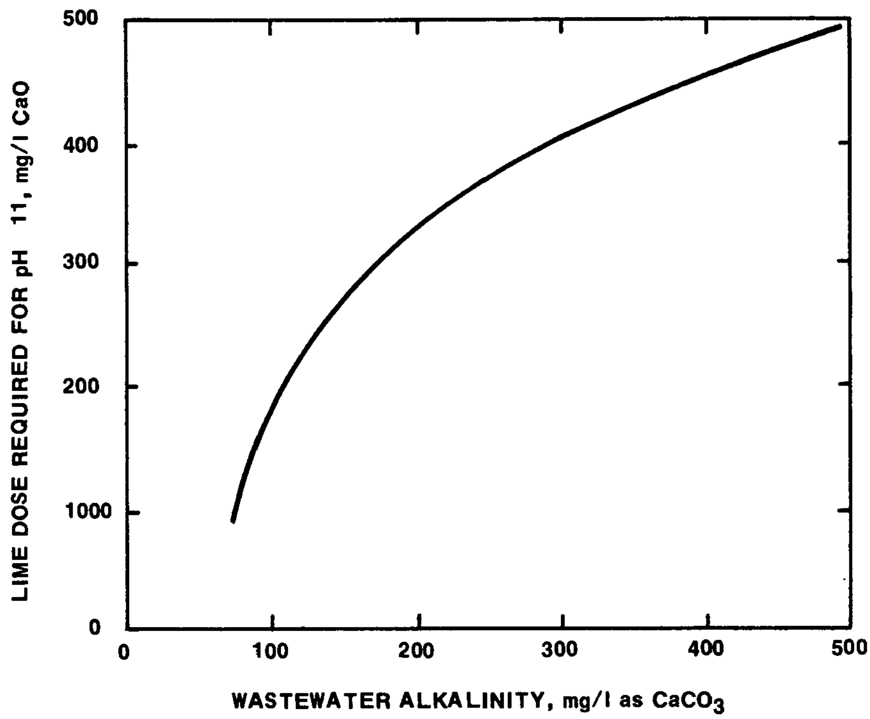


Figure 70. Lime dosage as related to wastewater alkalinity.

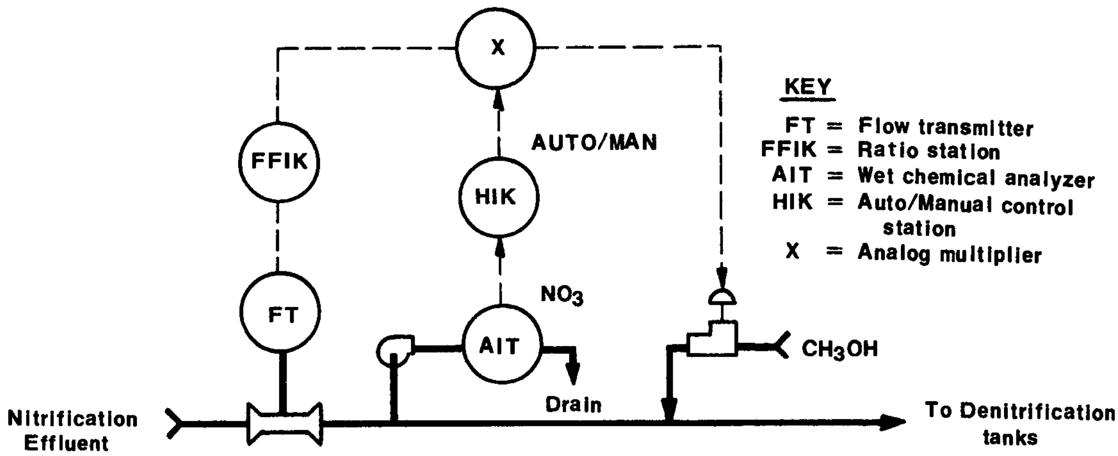


Figure 71. Feedforward control of methanol based on flow and nitrate nitrogen.

The following illustrates calculation of lime feed rates for a plant where lime recovery by recalcining of lime sludges is practiced:

Plant flow	=	15 mgd
Total CaO dosage	=	380 mg/l
$Ca(OH)_2$	=	1.32 x CaO; therefore
380 mg/l Cao	=	1.32 x 380 = 500 mg/l $Ca(OH)_2$
Makeup lime	=	92% CaO
Recalcined lime	=	70% CaO
Makeup lime dosage	=	25% of total
Recalcined dosage	=	75% of total

Makeup lime dosage	=	0.25 x 380 mg/l
	=	95 mg/l as Cao
95 x 8.34	=	791 lb of CaO/MG
$791 \times \frac{100}{92}$	=	860 lb makeup lime at 92% purity/MG
860 x 15	=	12,900 lbs for 15 MG, lb/day of makeup lime
$\frac{12,900}{24}$	=	536 lb/hr of makeup lime (makeup lime feeder setting)
Recalcined lime dosage	=	0.75 x 380 mg/l
	=	285 mg/l CaO
285 x 8.34	=	2,377 lb of CaO/MG
$2,377 \times \frac{100}{70}$	=	3,396 lb of recalcined lime at 70% purity/MG
3,396 x 15	=	50,940 lb for 15 MG (lb/day of recalcined lime)
$\frac{50,940}{24}$	=	2,123 lbs/hr of recalcined lime (recalcined lime feeder setting)

The following illustrates the calcuation of alum feed rates for a piston feed pump system:

Three alum feed pumps; two dual head and one single head.

Dual head pumps	0-50 gpm at 100% stroke/head
Single head pump	0-11.5 gph at 100% stroke

Plant flow	=	15 mgd
Liquid alum strength	=	5.4 lb dry alum/gal
Alum dosage	=	20 mg/l
Alum dosage	=	(20 mg/l) x (8.34 lb/gal)
	=	167 lb/MG
lb/15 mgd	=	(167 lb/MG) x (15 mgd)
	=	2,505 lb/day

$$lb/hr = \frac{2,505\ lb/day}{24\ hr/day} = 104\ lb/hr$$

$$gal/hr = \frac{104\ lb/hr}{5.4\ lb/gal} = 19\ gal/hr$$

$$\text{One pump (2 heads)} = \frac{(19\ gal/hr)}{(100\ gal/hr)} \times 100 = 19\ \text{(use 20\% stroke setting)}$$

Methanol--

For methanol in the nitrification-denitrification process, the methanol feed to nitrate-nitrogen ration often is about 3 to 1.

Powdered Carbon--

The design and performance of powdered activated carbon systems depends mostly on contact time and pretreatment of the wastewater. The effect of these items on carbon dosage is discussed in the Activated Carbon section of this manual.

Control Considerations

pH Adjustment--

Lime coagulation often raises the pH to 10 or 11. At this pH, the water is unstable and calcium carbonate floc will precipitate readily. This floc will cause problems by encrusting downstream pumps, piping, filters, and carbon particles. The pH must be lowered below 8.8 to stabilize the water. For good carbon adsorption and disinfection, it is also usually necessary to reduce the pH to less than 7.5. In large plants, pH usually is lowered by injecting carbon dioxide gas ("recarbonation process") into the wastewater. In small plants, acid is used to lower the pH.

Control of Coagulant Dosage--

Proper control of coagulant dosage is the jar test. A sample of wastewater is collected, taken to the laboratory, and divided into several beakers. Different coagulant dosages are then added to each beaker. After mixing, the floc is allowed to settle. The sample having the most clarity then is used to determine the best coagulant dose.

Methanol Feed Control--

Because methanol is expensive and too much can cause high effluent BOD_5, it is important to accurately pace methanol dosage with the nitrogen load. Pacing methanol dose with plant flow does not work well since it does not account for changes in the nitrate concentration. Feed forward control using plant flow and nitrification effluent nitrate-nitrogen is shown in Figure 71. Feed ratio is about three parts methanol to one part of nitrate-nitrogen (by weight). This method requires continuous nitrate measurement using an automatic wet chemistry analyzer. The wet chemistry analyzer (AIT) output is proportional to the nitrate concentration in the effluent. The dependability of this system depends on how reliable the automated wet chemical analyzer is. These analyzers require very careful regular maintenance and calibration.

Common Design Shortcomings and Ways to Compensate

	Shortcoming		Solution
1.	Use of iron or aluminum salts adds significant quantities of dissolved solids - such as sulfate and chloride to the treated water.	1.	If possible, use lime instead of alum or ferric chloride as coagulant.
2.	Inadequate equipment for monitoring coagulation process installed.	2.	Run frequent jar tests; install continuous turbidity monitoring equipment on effluent from clarifiers or filters.
3.	Lime added to hard waters containing magnesium may form MgOH which is a gelatinous precipitate that may adversely affect sludge dewatering.	3.	Reduce operating pH to 10.5 or less.
4.	Lack of flexibility in points at which chemicals can be added to wastewater processes.	4.	Run hoses from chemical feeders to desired points of chemical addition until suitable piping can be installed.
5.	Dry feed chemicals deposit in feeder.	5.	Provide mechanical mixers for dissolving solids and maintaining them in suspension prior to delivery to feeder.
6.	Corrosive properties of some chemicals.	6.	Use proper materials for transport and handling of chemicals.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. High turbidity in the settling tank effluent.	1a. Improper chemical dosage. 1b. Mechanical failure in feed system.	1a. Jar test. 1b. Visual inspection.	1a. Correct dosage according to results of jar test. 1b. Repair failure in feed system.
2. Air slaking occurring during storage of quicklime.	2a. Adsorption of moisture from atmosphere when humidity is high.	2a. Humidity, storage facility not airtight.	2a. Make storage facilities airtight, and do not convey pneumatically.
3. Feed pump discharge line clogged.	3a. Chemical deposits.	3a. Visual inspection.	3a. Provide sufficient dilution water.
4. Grit conveyor or slaker inoperable.	4a. Foreign material in the conveyor.	4a. Broken shear pin.	4a. Replace shear pin and remove foreign material from grit conveyor.
5. Paddle drive on slaker is overloaded.	5a. Lime paste too thick. 5b. Grit or foreign matter interferring with paddle action.	5a. Visual inspection. 5b. Visual inspection.	5a. Adjust compression on the spring between gear reducer and water control valve to alter the consistency of the paste. 5b. Remove grit or foreign materials or use a better grade of lime.
6. Lime deposits in lime slurry feeder.	6a. Velocity too low.		6a. Maintain continuously high velocity by use of a return line to the slurry holding tank.
7. "Downing" or incomplete slaking of quicklime.	7a. Too much water is being added.	7a. Hydrated particles coarse due to rapid formation of a coating.	7a. Reduce quantity of water added to quicklime (detention slakers water to lime ratio = 3-1/2:1 paste slaker ratio = 2:1)

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
8. "Burning" during quicklime slaking.	8a. Insufficient water being added, resulting in excessive reaction temperatures.	8a. Some particles left unhydrated after slaking.	8a. Add sufficient water for slaking (See Solution 7).
9. Chemical feed lines ruptures.	9a. Positive displacement pump has been started against a closed valve.	9a. Valve positions.	9a. Open valves in feed lines before pump is started.

RAPID MIXING AND FLOCCULATION

Process Description

When coagulants are added to wastewater, good mixing is necessary for effective treatment. Rapid mixing basins are used to completely mix the coagulant particles with the wastewater. Figure 72 shows a rapid mix basin with a mechanical mixer.

After the rapid mix process, the coagulated wastewater flows to a flocculation basin where slow-mixing can occur. The flocculation process stirs the water slowly to allow large particles to form which can then be removed by gravity settling. Mechanically driven paddles (Figure 73) or air mixing may be used for stirring. When flocculation is carried out in separate multiple basins, two or three basins usually are placed in series, each one providing more gentle stirring as the water moves down the line.

Figure 74 shows a schematic of the coagulation and flocculation processes and how they are related to one another.

Typical Design Criteria and Performance Evaluation

Rapid Mixing--

Rapid mixing basins for dissolving the coagulants usually have high-speed mixers that can operate at 300 fps/ft with detention times of 15-60 sec. Power requirements for mechanical mixers are 0.25 to 1 hp/mgd. The following shows design data for a rapid mixer that can handle a flow of 10 mgd:

Detention time at maximum flow, in minutes	1.1
Width, in feet	11.0
Water depth, in feet	8.5
Volume, in cubic feet	1,030
Propeller diameter, in inches	38
Propeller capacity, in cubic feet per minute	2,060
Shaft speed, in revolutions per minute	100
Motor horsepower	5

Flocculation--

Flocculators usually are operated at 0.6 fpm, with velocity gradients of 30-100 fps/ft. Flocculator detention times of 15-60 minutes are commonly used.

When flocculation is carried out in a separate basin from the clarifier, the flow from the floc basin to the clarifier should be kept between

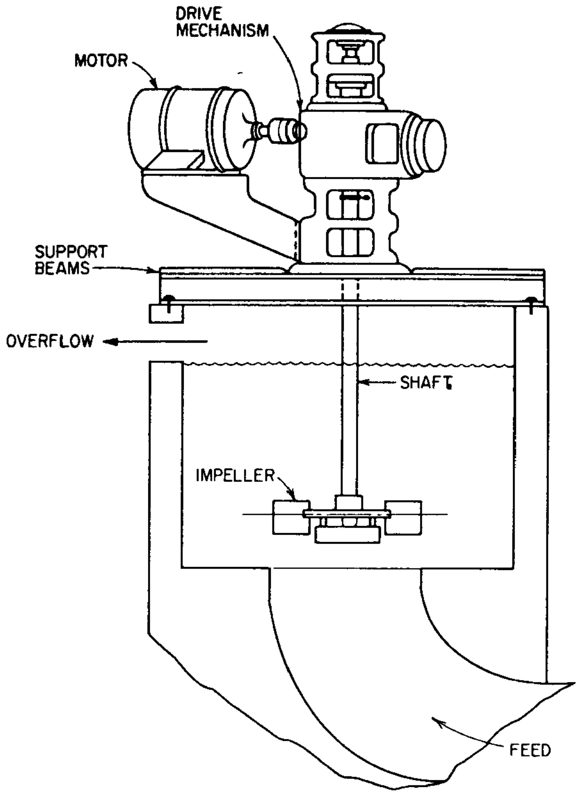


Figure 72. Mechanical rapid-mixing device.

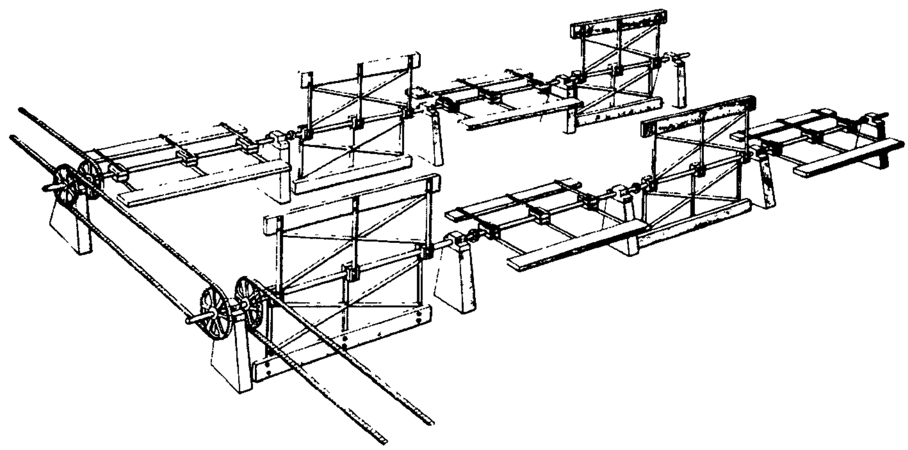


Figure 73. Typical paddle-type flocculator.

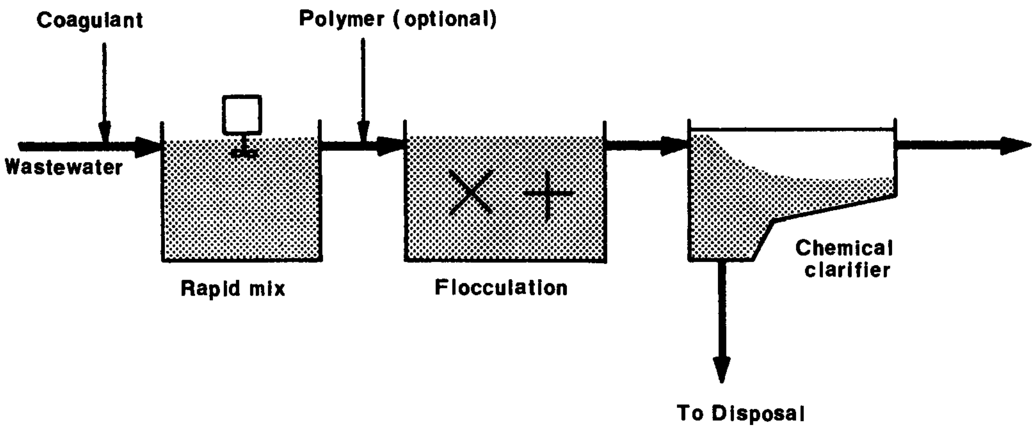


Figure 74. Schematic of rapid mix, flocculation and sedimentation system using separate basins.

0.5 and 1.0 fps to keep the floc from breaking up.

For a flow of 10 mgd, the following dimensions are typical:

Width, in feet	30
Depth, in feet	10
Length, in feet	140
Volume of tank, in cubic feet	41,778
Detention period, in minutes	45

Performance Evaluation

The flocculation and rapid mix processes can only be considered efficient operations if the downstream clarifier produces a good quality effluent. If the flocculation basin produces a good floc that does not break up and which settles quickly in the clarifier, the process can be considered to operate effectively. If it does not produce a good floc, the troubleshooting guide should be read for possible solutions to the problem.

Control Considerations

Rapid Mixing--

Good mixing of the coagulant and wastewater is important to ensure efficient use of the coagulant. An overfeeding of chemicals usually is needed if the system is poorly mixed.

The mixing must be rapid enough to obtain uniformly dissolved chemicals throughout the wastewater before the floc begins to form. Too much rapid mixing will cause floc break-up into fine particles that settle at a very slow rate.

Flocculation--

The velocity of flocculator mixers must be carefully controlled. Very high velocity gradients will prevent a settleable floc from forming. To produce compact floc particles, the highest velocity gradient should be used which still produces a strong floc.

Since flocculated particles are quite fragile, velocities in and after the flocculating unit generally should not be greater than 1.2 fps.

In wastewater treatment, a blanket should not be allowed to form in the clarifier, because the sludge contains organics that may quickly turn anaerobic. This will lower phosphorus removal and clarifier efficiency.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Mechanical flocculators fouled with rags and debris.	1. Remove rags and screened debris from wastewater stream and dispose separately. Do not run debris through a comminutor and return debris to the treatment process.
2. Poor floc formation.	2. Increase solids concentration by recirculation of chemical solids from clarifier sludge removal line to rapid mix or flocculator influent line.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Poor floc formation and settling characteristics.	1a. Chemicals not sufficiently dispersed during rapid mixing.	1a. Chemicals not uniformly distributed in rapid mix basin.	1a. Increase speed of rapid mixing device.
	1b. Prolonged rapid mixing.	1b. Floc formation breakup in rapid mix basin, rapid mix detention time.	1b. Reduce rapid mixing time (usually 15-60 seconds is sufficient).
	1c. Improper coagulant dosage.	1c. Jar test.	1c. Correct coagulant dosage as per jar test results.
	1d. Flocculator agitators operating at excessive speeds.	1d. Agitator speed.	1d. Reduce flocculator agitator speed.
2. Good floc formation in flocculation basin but poor settleability in clarifier tank.	2a. Excessive velocity between flocculation unit and clarifier unit.	2a. Velocity between flocculation and clarifier units.	2a. Reduce velocity (usually velocity should not exceed 1.2 fps).
3. Clarifier sludge turning anaerobic.	3a. Sludge blanket present in clarifier.	3a. Visual inspection.	3a. Increase sludge removal rate to remove sludge blanket and prevent its formation.
	3b. Excessive carryover of organic solids from secondary process to chemical clarifier.	3b. Secondary effluent quality.	3b. Correct problems in secondary process (see appropriate section of this manual).

RECARBONATION

Process Description

The main purpose of recarbonation is to inject carbon dioxide gas into the wastewater to lower the high pH resulting from lime treatment. When carbon dioxide is added, the pH is lowered and the hydroxides are converted to carbonates and bicarbonates. Recarbonation prevents calcium scale formation.

Recarbonation can be carried out in either one or two stages of treatment. In single-stage recarbonation, the pH of the water is usually reduced from 9-11 down to 7-8 by applying all of the carbon dioxide at one point. This results in the calcium (which is added with the lime) being dissolved and being present in the plant effluent. In two-stage recarbonation, the pH is lowered to about 9.3 in the first stage. At this pH, calcium carbonate floc readily forms, and allows the calcium to be removed easily from the wastewater making it available for recovery of lime. The floc often needs a coagulant or settling aid, and enough CO_2 is then added to further reduce the pH to the desired value. The second stage of recarbonation to pH 7 does several things:

- It prepares the water for filtration
- It lowers the pH to a value which aids carbon adsorption of organics; provides effective disinfection by chlorine; and a pH value good for dischage
- It keeps scale from forming in pipelines

The usual source of carbon dioxide for recarbonation is stack gas either from sludge incineration or lime recalcining furnaces. When stack gas is not available, special CO_2 generators, underwater burners, or liquid CO_2 may be used.

Typical Design Criteria and Performance Evaluation

Stack Gas as a Source of CO_2--
If stack gas is used as a source of CO_2, the gas should be passed through a wet scrubber to cool the gas and to remove solids from the gas. Scrubbers remove air pollutants from the exhaust gas, and help to protect the CO_2 compression equipment against plugging or scaling.

With 8 percent CO_2 in the stack gas about 270 CFM of compressor capacity is needed per mgd of water for recarbonation. A water-sealed compressor should be used when dirty stack gas from sludge or lime furnaces is used.

A typical recarbonation system using stack gas at atmospheric pressure is shown in Figure 75. As shown in the figure, automatic pH control of the recarbonated effluent can be provided by the system.

Pressure Generators--

Pressure or forced-draft generators produce CO_2 by burning natural gas, oil, or other fuels in a pressure chamber. The fuel and excess air first are compressed, and then burned at a high enough pressure to feed directly into the water to be recarbonated. The compressors can use only dry gas or dry air at ambient temperatures, so there are no corrosion problems resulting from hot, moist stack gases. Because of limited capacity range (usually 3-1), two or more units may be needed for flexibility and process control.

Submerged Underwater Burners--

In this system, air and natural gas are compressed and then burned underwater in the recarbonation basin. Automatic underwater ignition equipment is used to start the burning process. Like pressure generators, underwater burners have a limited capacity range (about 2-1) so that it is necessary to have enough burners to get the desired range of CO_2 dosages.

Liquid Carbon Dioxide--

Liquid carbon dioxide is available in tank trucks ranging in size from 10-20 tons. For smaller plants, 20-50 lb cylinders are more common.

Liquid CO_2 may be fed using either liquid or gas feed systems. When CO_2 is removed from the storage tank, the pressure usually is reduced in two stages before feeding at 20 psi. This reduces the chances for dry ice formation which could occur if the expansion takes place too quickly. Vapor heaters also may be used just ahead of the pressure reducing valves.

For CO_2 gas feed, flow may be measured using a manometer in the feed line. A manual valve may be placed downstream to control the amount of CO_2 applied. The CO_2 feed also can be made fully automatic using pH control. In this case, an electrode is used to measure the pH of the recarbonated water. The signal is sent through a control valve on the feed line which closes at low pH and opens it at high pH.

Except for materials of construction, equipment for solution feed of CO_2 is much like solution feed chlorinators. When used to feed CO_2, chlorinator capacity is reduced about 25 percent. About 60 gal of water are needed to dissolve 1 lb of CO_2 at room temperature and atmospheric pressure. With solution feed of CO_2 almost 100 percent absorption is possible.

Design of Diffusion Systems and Reaction Basins--

Carbon dioxide distribution grids usually are pipes with holes and

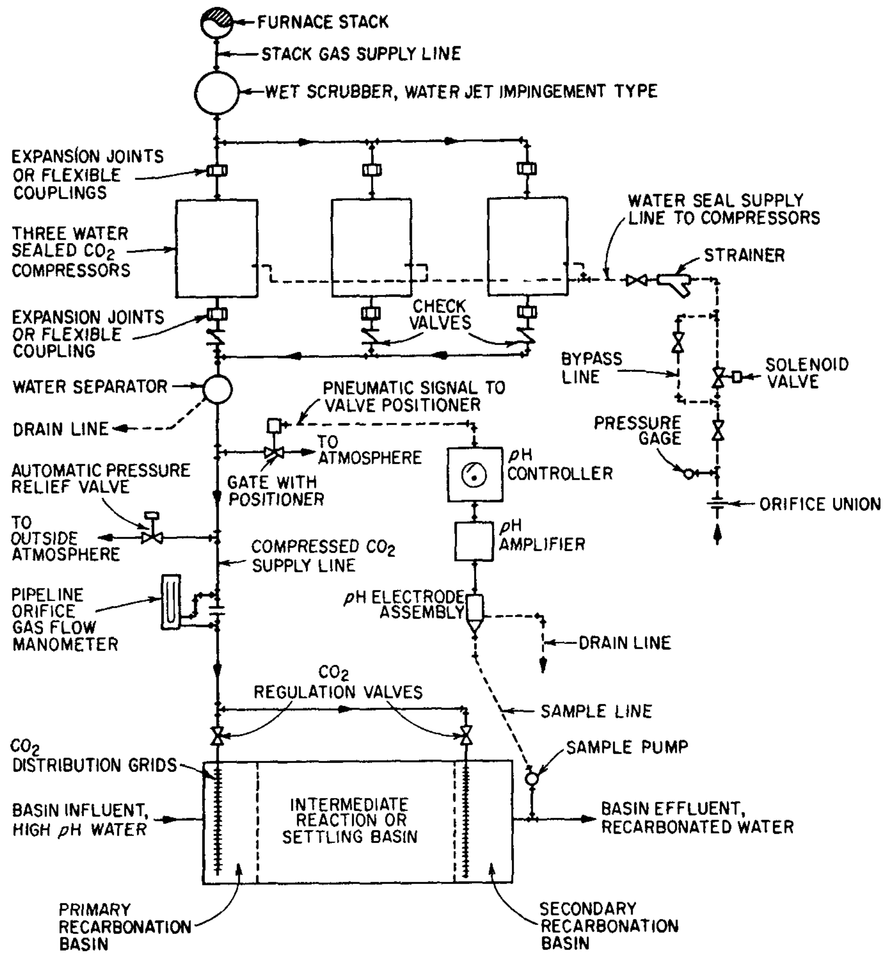


Figure 75. Typical recarbonation system using stack gas.

submerged in the wastewater at least 8 feet. This will make sure that the CO_2 bubbles dissolve before they reach the surface. Well designed systems put 85-100 percent of the CO_2 into solution.

Figure 76 shows the two-stage recarbonation basins being used at the Orange County Water District Facility. Table 22 describes the design data for the system.

Control Considerations

Using pH measurements, control of CO_2 dosages may be determined by trial and error. In two-stage systems, the CO_2 flow first should be set to reduce the pH in the second-stage recarbonation basin. Then, this flow should be split between the two stages to get a pH of 10 in the center of the intermediate settling basin. Once the CO_2 valves are set for a proper split, they should need very little other adjustment for changes in total CO_2 flow. At average wastewater temperatures, about 15 min are needed for all CO_2 bubbles to react completely to form calcium carbonate. This is why pH is measured at the middle of the settling basin rather than at the entrance.

Common Design Shortcomings and Ways to Compensate

Shortcomings	Solution
1. No backup or auxiliary system to supplement stack gas as CO_2 source.	1. Install liquid CO_2 feed system for use when stack gas is not available.
2. CO_2 compressor equipment becomes plugged or scaled by particulates from stack gas.	2. Improve operation of wet scrubber to remove particulates before gas enters compressor.
3. Pressure generators and underwater burners have a limited capacity range.	3. Install 2 or more units in order to provide more flexibility.

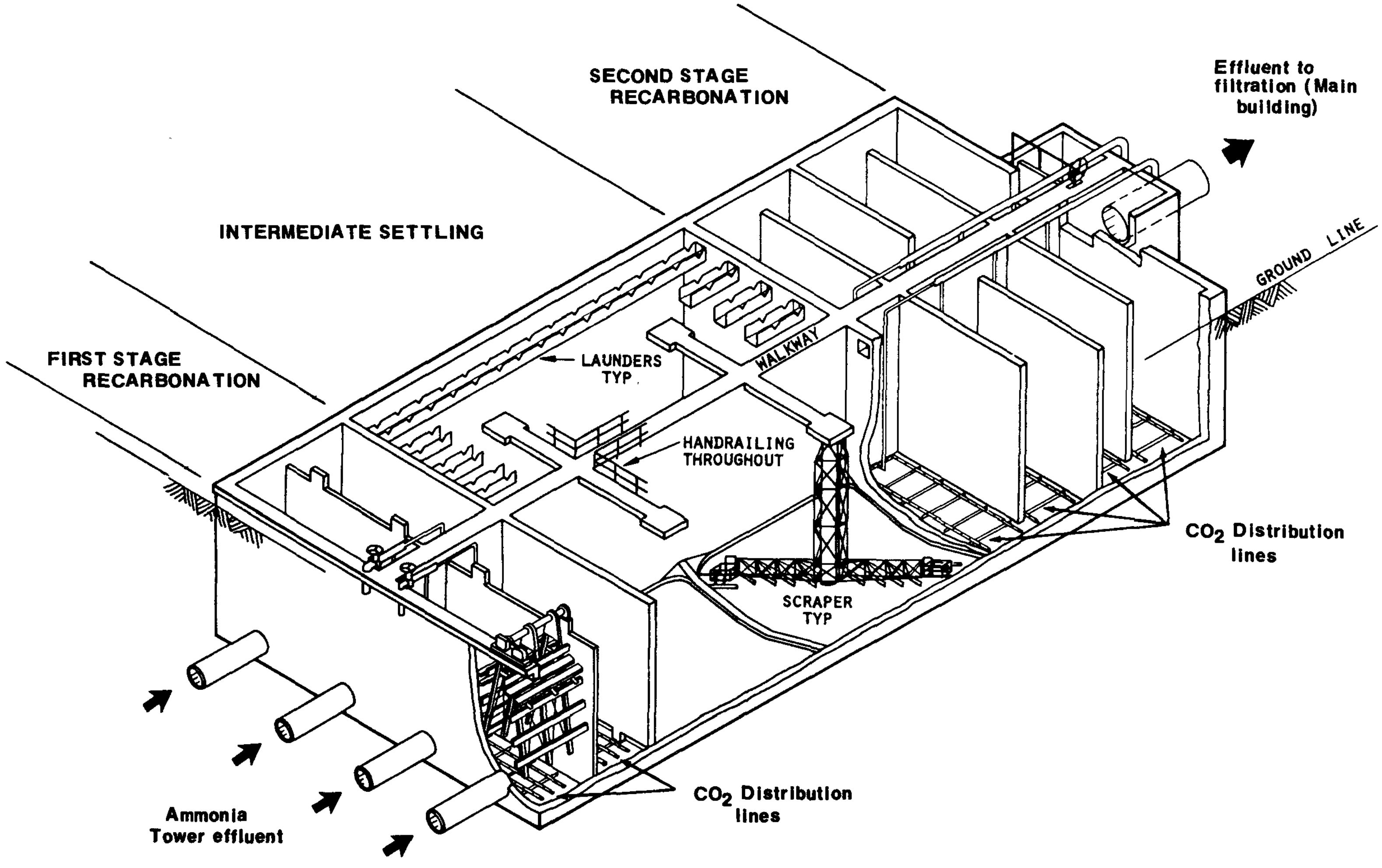


Figure 76. Recarbonation basins at Orange County Water District Facility.

TABLE 22. DESIGN CRITERIA FOR ORANGE COUNTY WATER DISTRICT RECARBONATION PROCESS

Basins	
Number	2 (parallel)
1st Stage Recarbonation Basin (each basin divided into two compartments, equipped with oscillating flocculators and CO_2 distributors)	
Length, ft	16
Width, ft	36.75
Depth, ft	10
Water depth, ft	9
Detention time, min @ 15 mgd	15
Intermediate Settling	
Length, ft	70.75
Width, ft	73.5
Sidewall depth, ft	12.17
Sidewater depth, ft	10.5
Overflow rate, gpd/ft^2 @ 15 mgd	3000
Weir loading, gpm/ft @ 15 mgd	18.3
Detention time, min @ 15 mgd	40
2nd Stage Recarbonation Basin (three of four compartments equipped with CO_2 distributors)	
Length, ft	7.17
Width, ft	36.75
Depth, ft	12
Water depth, ft	10
Detention time, min @ 15 mgd	15

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Inadequate CO_2 supply to recarbonation basins.	1a. CO_2 compressor malfunction.	1a. Visual inspection.	1a. Connect auxiliary liquid CO_2 source and inspect compressor for damage.
	1b. Plugging of CO_2 diffusers.	1b. Visual inspection.	1b. Clean or replace diffusers.
	1c. Improper valving.	1c. Valve position.	1c. Open valves.
2. Sludge scraper in intermediate settling basin stops.	2a. Object jammed under scraper arm.	2a. Visual inspection.	2a. Remove object jamming system.
3. White scale is depositing in pipes or other treatment units downstream of recarbonation.	3a. Calcium carbonate deposits.	3a. pH of recarbonation effluent should be less than 8.8 to prevent scale deposition.	3a. Increase CO_2 additions to recarbonation basin to lower effluent pH to less than 8.8(see Item 1).
4. In two stage system, calcium carbonate floc is being formed in first stage but does not settle well in intermediate basin.	4a. Floc size too small.	4a. Milky appearance in intermediate settling basin.	4a. 1. Add coagulants such as $FeCl_3$ or settling aids such as polymers. 2. Recirculate settled calcium carbonate sludge to first stage basin to provide nuclei for floc formation.

LAND TREATMENT

Process Description

In land treatment, effluent usually is pretreated and applied to land by conventional irrigation methods. With this process, wastewater and its nutrients are used as a resource rather than considered as a disposal problem. Treatment is provided by natural processes as the effluent flows through the soil and plants. Part of the wastewater is lost by evapotranspiration, and the rest goes back to the hydrologic cycle through overland flow or the groundwater system. Most of the groundwater finally returns, directly or indirectly, to the surface water system. Land treatment of wastewater may be done by one of the following methods (Figure 77):

- Irrigation
- Overland flow
- Infiltration-percolation

In the irrigation method, the wastewater is applied to the land by sprinkling or by surface spreading (Figure 78). Sprinkling systems may be either fixed or moving. Fixed sprinkling systems, often called solid set systems, may be either on the ground surface or buried. Both types usually have sprinklers set on risers that are spaced along pipelines. These systems can be used on many kinds of terrain and may be used for irrigation of either cultivated land or woodlands. There are several kinds of moving sprinkling systems, but the center pivot system is the most widely used for wastewater irrigation.

The two main types of surface application systems are ridge-and-furrow and flooding techniques. In ridge-and-furrow irrigation, the effluent flows by gravity through furrows where it seeps into the ground.

Typical removals of pollutants from secondary effluent by irrigation are:

BOD	98%
COD	80%
Suspended solids	98%
Nitrogen	85%
Phosphorus	95%
Metals	95%
Micro-organisms	98%

In an overland flow system, the wastewater is sprayed over sloping terraces where it flows slowly down the hill and through the vegetation.

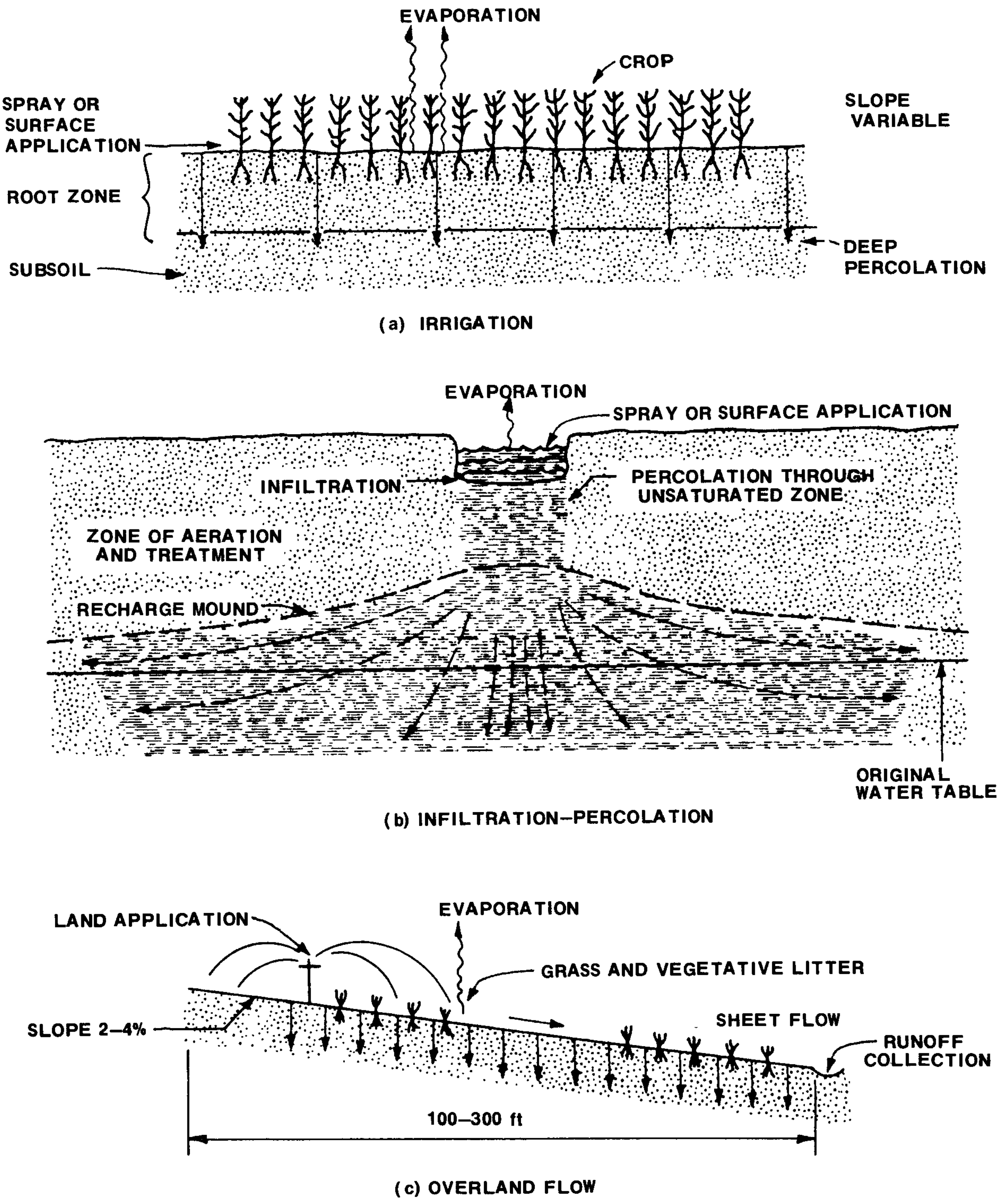


Figure 77. Methods of land application.

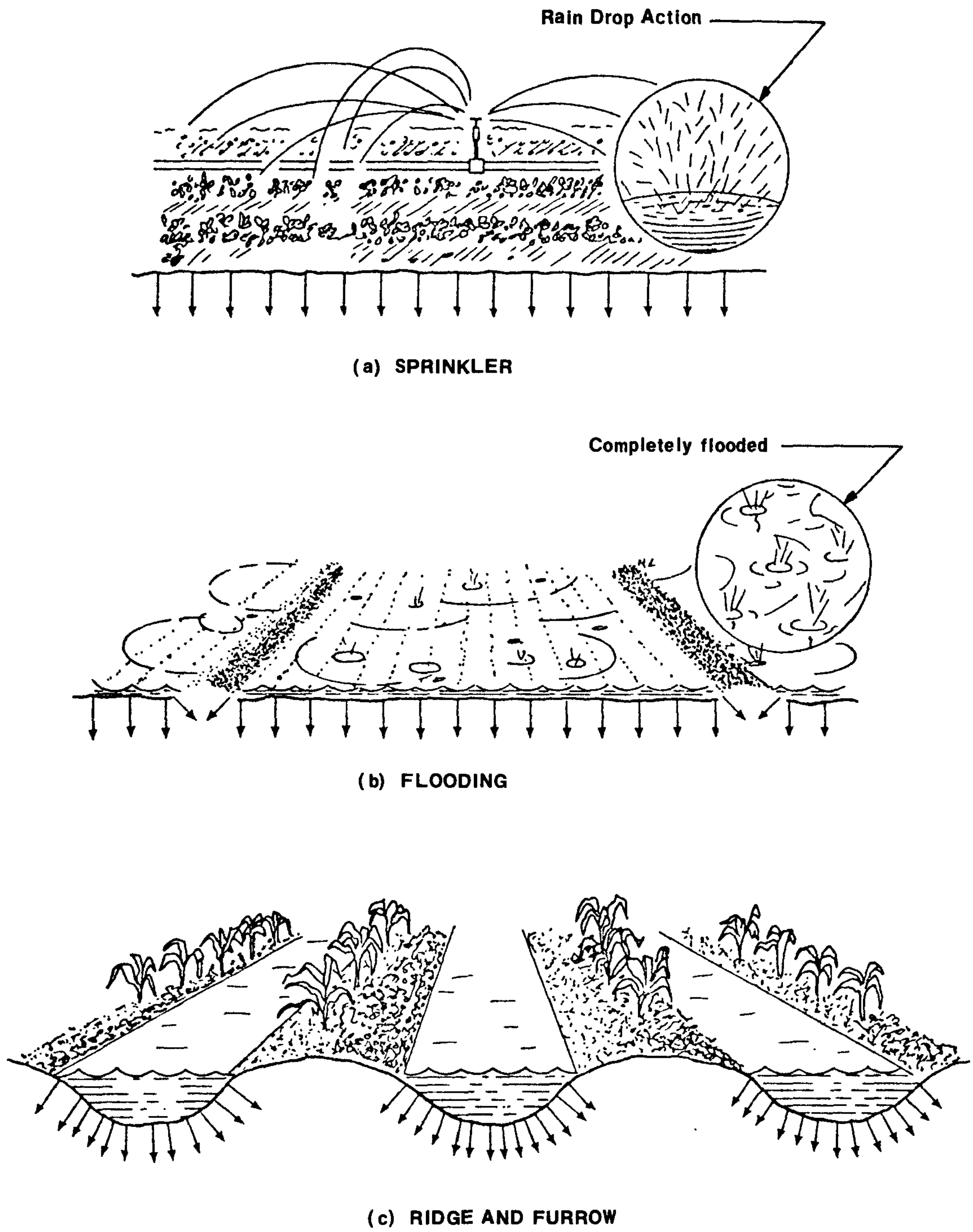


Figure 78. Irrigation techniques.

Although the soil is not the primary filter, treatment efficiencies are high in a well-run system. Typical removals are:

BOD	92%
Suspended solids	92%
Nitrogen	70-90%
Phosphorus	40-80%
Metals	50%

Soils best suited for this approach are clays and clay loams with even, moderate slopes (2-6%). Grass usually is planted to provide a habitat for biota and to prevent erosion. As the effluent flows down the slope, some flows into the soil, a small amount evaporates, and the rest flows to collection channels. As the effluent flows through the grass, the suspended solids are filtered out and the organic matter is oxidized by the bacteria living in the vegetative litter.

In infiltration-percolation systems, the groundwater is recharged by percolation of wastewater (after secondary treatment) using spreading basins. There is not much difference between treatment and disposal in this process. Wastewater applied to the land for the purpose of disposal is also being treated by infiltration and percolation. Removals by this system for secondary effluent are:

BOD	85-99%
Suspended solids	98%
Nitrogen	0-50%
Phosphorus	60-95%
Metals	50-95%

Infiltration-percolation is mostly a groundwater recharge system, and does not recycle nutrients through crops.

Land application systems usually include the following parts:

- Preapplication treatment
- Transmission to the land treatment site
- Storage for the wastewater during the non-irrigation season
- Distribution over the irrigated area
- A system to recover the renovated water
- The crop system

Typical Design Criteria and Performance Evaluation

There are no two land application systems exactly alike, and design depends on many factors, especially the site and project objectives. Table 23 briefly lists some of the major design differences. This table can be used as a guide for performance evaluation of actual land treatment systems. If a system does not perform as shown in the table, the troubleshooting guide should be checked. Each of the major parts of a land treatment system that must be carefully designed and operated are discussed below.

TABLE 23. TYPICAL DESIGN CRITERIA FOR IRRIGATION, INFILTRATION-PERCOLATION, AND OVERLAND FLOW SYSTEMS FOR MUNICIPAL WASTEWATER

	Irritation			
	Low rate	High rate	Infiltration-percolation	Overland flow
Liquid loading rate, in/wk	0.5 to 1.5	1.5 to 4.0	4 to 20	2 to 9
Annual application, ft/yr	2 to 4	4 to 18	18 to 500	8 to 40
Land required for 1 mgd flow-rate, acres[a]	280 to 560	62 to 280	2 to 62	28 to 140
Application techniques	Spray or surface		Usually surface	Usually spray
Vegetation required	Yes	Yes	No	Yes
Crop production	Excellent	Good/Fair	Poor/none	Fair/Poor
Soils	Moderately permeable soils with good productivity when irrigated		Rapidly permeable soils, such as sands, loamy sands, and sandy loams	Slowly permeable soils, such as clay loams and clays
Climatic constraints	Storage often needed		Reduce loadings in freezing weather	Storage often needed
Wastewater lost to:	Evaporation and percolation		Percolation	Surface runoff and evaporation with some percolation
Expected treatment performance				
BOD and SS removal	98+1		85 to 99%	92+1
Nitrogen removal	85+1[a]		0 to 50%	70 to 90%
Phosphorus removal	80 to 99%		60 to 95%	40 to 80%

[a]Dependent on crop uptake.

Preapplication Treatment--

The type and level of treatment will have an effect on:

- The loading rate of different contaminants
- The methods of application to be used
- The type of crop or vegetative cover to be grown

Before wastewater is applied to the land, it is usually treated by oxidation ponds, aerated lagoons, or secondary treatment processes, followed by disinfection.

Transmission--

The three main ways of transferring the wastewater to the point of application are:

- Gravity pipe
- Open channels
- Force mains

The method of transmission depends mostly on terrain. When open channels are used, however, the chances of public contact with the wastewater must be carefully considered.

Storage--

Requirements for storage may range from 1 day to 6 months of flow. Storage capacity should be based on the local climate and the time period of operation for the system. System backup and flow equalization also should be considered.

To prevent percolation to the groundwater, some storage reservoirs must be lined.

Distribution--

Solid set spraying--Solid set spraying using buried pipe is used mostly for spray irrigation systems. It may also be used for infiltration-percolation and overland flow systems. Designs may differ in sprinkler spacing, application rate, nozzle size and pressure, depth of buried pipe, pipe materials, and type of control system.

- Sprinkler spacing - May range from 40 to 60 ft to 100 by 100 ft. Spacing may be rectangular, square, or triangular.

- Application rate - May range from 0.10 to 1 in/hr or more, with 0.16 to 0.25 in/hr being most common. Annual rates depend on climate, soil type, and crop requirements and may range from 1 to 15 ft/yr.

- Nozzles - Openings range in size from 0.25 in to 1 in. The discharge per nozzle often is 8 to 25 gpm, with discharge pressures ranging from 50 to 60 psi.

- Depth of buried laterals and mainlines - Where freezing is not a problem, a depth of 18 in for laterals and 36 in for mainlines is common. Aluminum surface piping may be 40 to 50% less costly than buried piping, but it is also less reliable.

- Pipe materials - May be any type used for standard pressure pipe; however, asbestos-cement and plastic (PVC) pipes are most common.

Center pivot spraying--For moving sprinkling systems, center pivot systems are most often used.

- Sizes - System laterals may be 600 to 1,400 ft long. The lateral is supported by wheels which are free to rotate. Each unit can irrigate areas of 35 to 135 acres.

- Propulsion - May be by means of either hydraulic or electric drive. One rotation may take from 8 hrs to as much as 1 wk.

- Pressures - Usually 50 to 60 psi at the nozzle, which may require 80 to 90 psi at the pivot. Standard sprinkler nozzles or spray heads are used.

Surface flooding--For surface flooding using border strips, there are several different designs:

- Strip dimensions - Depend on type of crop, type of soil, and slope. Border widths are usually 40 to 60 ft, and slopes may range from 0 to 0.4%. The steeper slopes are used with relatively permeable soils. Strip length may range from 600 to 1,400 ft.

- Method of distribution - Generally by a concrete-lined ditch with slide gates at the head of each strip, or underground pipe with risers and valves.

- Application rates - At the head of each strip, rates depend mostly on soil type. Rates may range from 10 to 20 gpm/ft width of strip for clay, and 50 to 70 gpm/ft width of strip for sand. The period of application for each strip depends on strip length and slope.

The major design variables are:

- Application - Usually by gated aluminum pipe. Short runs of pipe (80 to 100 ft) are used to minimize pipe diameter and headloss and to provide maximum flexibility. Surface standpipes are used to provide the 3 to 4 ft of head necessary for even distribution.

- Topography - Relatively flat land (less than 1% slope) with furrows running down the slope, or on moderately sloped land with furrows running along the contour.

- Dimensions - Furrow lengths usually range from 600 to 1,400 ft. Furrows are usually spaced between 20 and 40 in apart, depending on the crop.

Overland flow distribution--General practice is as follows:

- Sprinkler application - May be by either fixed sprinklers or rotating boom-type sprays. Sprinklers are spaced from 60 to 80 ft apart on the laterals.

- Surface application - May be by flooding or by gated pipe. Works best with wastewater low in organic solids.

- Slopes - Slopes may range from 2 to 8%, but a 2 to 4% slope is best for adequate detention time. Lengths of slope may range from 150 to 300 ft.

- Application cycles - Commonly 6 to 8 hrs of wetting and 16 to 18 hrs of drying to keep the microorganisms active on the soil.

Infiltration basins--

- Application rates - Rates range from 4 to 120 in/wk, with the most common rate being 12 to 24 in/wk. Loading cycles may be from 9 hrs to 2 weeks of wetting, followed by 1 day to 3 weeks of drying.

- Basin size - Usually depends on flow, and the wetting and drying periods. Basins may range in size from less than 1 acre to more than 10 acres. Usually at least two separate basins are provided.

- Height of dikes - Depends on the depths of water applied. For depths of 1 to 2 ft, about 4 ft dikes are common.

Recovery of Renovated Water--

Systems that may be used to recover renovated water include underdrains, runoff collection followed by chlorination and discharge, and recovery wells.

Underdrains--An underdrain system normally has a number of drainage pipes (4 to 8 inches in diameter) and buried 4 to 10 ft. These pipes empty at one end of the field into a ditch. The distance between pipes can range from 100 ft for clayey soils to 400 ft for sandy soils.

Tailwater return--A tailwater return system is used with surface irrigation to collect and return excess applied water from the bottom of the strip or furrow. The system usually has collection ditches, a small reservoir, a pump, and piping to the nearest distribution line.

Recovery wells--Recovery well systems are used for reducing groundwater levels to make sure that treatment is effective or to collect and reuse renovated water. Design variables include well location and spacing, depth, type of packing, and flowrate. Each of these variables depends on the geology, soil, and groundwater conditions at the site, application rates, and the amount of renovated water to be recovered.

Crops--

Except for infiltration-percolation systems, crops or vegetative cover are an important part of all land application systems. In selecting the type of crop to be grown, the following should be considered:

- Water requirement and tolerance
- Nutrient requirements, tolerances, and removal capabilities
- Sensitivity to inorganic ions
- Public health considerations relating to the use of the crop
- Ease of cultivation and harvesting
- Length of growing season
- Value of crop (marketability)

Control Considerations

The best operation of irrigation systems requires good crop management and proper wastewater pretreatment. Personnel must have a working knowledge of farming practices, and principles of wastewater treatment. Seasonal (often weekly) changes in operation must respond to changing crop requirements for nutrients and water; monitoring must be done to determine removal efficiencies and to forecast buildups of toxic compounds; and the system must be continuously watched to avoid problems of ponding, runoff, or mechanical breakdowns.

There are several different ways land treatment systems can be managed:

- Managed and operated by the wastewater agency
- Managed by the wastewater agency and operated by a private party through contract or crop sharing
- Managed and operated by agreement with one private party
- Managed by agreement with a private party and operated by a subcontract agreement with another private party.

Close cooperation between the treatment system management and the farm operation is always needed. Irrigation must be scheduled with farm operations such as planting, tilling, spraying and harvesting, for successful operation. Farm specialists can be helpful in setting up the management of the crops, soil, and irrigation portions of the operation.

Proper cropping is also important for good nitrogen removal to prevent pollution of groundwater. Nitrate-nitrogen can be removed by growing and removing from the area a crop which takes up nitrogen. Nitrogen removal by crops is dependent on the length of growing season, crop type, and the availability of nitrogen.

Crop requirements for nitrogen during the growing season are about the same as evapotranspiration demand. Thus, applications based on seasonal changes in evapotranspiration may be better than constant application.

Crops normally used with land application can be divided into three broad groups and removal rates. A forage crop, such as grasses, will remove 150-160 lbs/acre or more of nitrogen, field crops, such as corn, will remove 75-150 lbs/acre, and forests will remove 20-100 lbs/acre. Some crops do not fit under these general removal groups because of differences in the length of the growing season.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Water ponding during project start-up because of poor site choice.	1. Improve drainage by installing drainage wells or drain tiles or decrease application rate to level compatible with soils while expanding total site area.
2. Plastic laterals installed above ground are breaking because of cold weather or deterioration from sunlight.	2. Bury plastic laterals.
3. Spray nozzles plugged because of no screens on inlet side of irrigation pumps.	3. Install screens.
4. Aerosols are drifting onto neighbors property because of inadequate buffer area.	4. Do not operate sprays on windy days; enlarge buffer area.
5. Excessive wear on irrigation pumps due to sand in wastewater.	5. Improve pretreatment or install sand trap ahead of pumps.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Water ponding in irrigated area where ponding normally has not been used.	1a. Application rate is excessive.	1a. Application rate.	1a. Reduce rate to normal value.
	1b. If application rate is normal, drainage may be inadequate.	1b(1) Seasonal variation in groundwater level.	1b(1) Irrigate portions of the site where groundwater is not a problem or store wastewater until level has dropped.
		1b(2) Operability of any drainage wells.	1b(2) Repair drainage wells or increase pumping rate.
		1b(3) Condition of drain tiles.	1b(3) Repair drain tiles.
	1c. Broken pipe in distribution system.	1c. Leaks in system.	1c. Repair pipe.
2. Lateral aluminum distribution piping deteriorating.	2a. Effluent permitted to remain in aluminum pipe too long causing electrochemical corrosion.	2a. Operating techniques.	2a. Drain aluminum lateral lines except when in use.
	2b. Dissimilar metals (steel valves and aluminum pipe).	2b. Pipe and valve specifications.	2b. Coat steel valves or install cathodic or anodic protection.
3. No flow from some sprinkler nozzles.	3. Nozzle clogged with particles from wastewater due to lack of screening at inlet side of irrigation pumps.	3. Screen may have developed hole due to partial plugging of screen.	3. Repair or replace screen.
4. Wastewater is running off of irrigated area.	4a. Sodium adsorption ratio of wastewater is too high and has caused clay soil to become impermeable.	4a. Sodium adsorption ratio (SAR) should be less than 9.	4a. Feed calcium and magnesium to adjust SAR.
	4b. Soil surface sealed by solids.	4b. Soil surface.	4b. Strip crop area.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	4c. Application rate exceeds infiltration rate of soil.	4c. Application rate.	4c. Reduce application rate until compatible with infiltration rate.
	4d. Break in distribution piping.	4d. Leaks in distribution piping.	4d. Repair breaks.
	4e. Soil permeability has decreased due to continuous application of wastewater.	4e. Duration of continuous operation on the given area.	4e. Each area should be allowed to rest (2-3 days) between applications of wastewater to allow soil to drain.
	4f. Rain has saturated soil.	4f. Rainfall records	4f. Store wastewater until soil has drained.
5. Irrigated crop is dead.	5a. Too much (or not enough) water has been applied.	5a. Water needs of specific crop versus application rate.	5a. Reduce (or increase) application rate.
	5b. Wastewater contains excessive amount of toxic elements.	5b. Analyze wastewater and consult with county agricultural agent.	5b. Eliminate industrial discharges of toxic materials.
	5c. Too much insecticide or weed killer applied.	5c. Application of insecticide or weed killer.	5c. Proper control of application of insecticide or weed killer.
	5d. Inadequate drainage has flooded root zone of crop.	5d. Water ponding.	5d. (See Item 1)
6. Growth of irrigated crop is poor.	6a. Too little nitrogen (N) or phosphorus (P) applied.	6a. N and P quantities applied - check with county agricultural agent.	6a. If increased wastewater application rates are not practical, supplement wastewater N or P with commercial fertilizer.
	6b. Timing of nutrient application not consistent with crop need. (Also, see 5a - 5c)	6b. Consult with county agricultural agent.	6b. Adjust application schedule to meet crop needs.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
7. Irrigation pumping station shows normal pressure but above normal flow.	7a. Broken main, lateral, riser, or gasket.	7a. Inspect distribution system for leaks.	7a. Repair leak.
	7b. Missing sprinkler head or end plug.	7b. Inspect distribution system for leaks.	7b. Repair leak.
	7c. Too many laterals on at one time.	7c. Number of laterals in service.	7c. Make appropriate valving changes.
8. Irrigation pumping station shows above average pressure but below average flow.	8. Blockage in distribution system due to plugged sprinklers, valves, screens, or frozen water.		8. Locate blockage and eliminate.
9. Irrigation pumping station shows below normal flow and pressure.	9a. Pump impeller is worn.	9a. Pump impeller.	9a. Replace impeller (See Design Shortcoming No. 5 also).
	9b. Partially clogged inlet screen.	9b. Screen.	9b. Clean screen.
10. Excessive erosion occuring.	10a. Excessive application rates.	10a. Application rate.	10a. Reduce application rate.
	10b. Inadequate crop cover.	10b. Condition of crop cover.	10b. (See Items 5 and 6)
11. Odor complaints.	11a. Sewage turning septic during transmission to irrigated site and odors being released as it is discharged to pretreatment.	11a. Sample sewage as it leaves transmission system.	11a. Contain and treat off-gases from discharge point of transmission system by covering inlet with building and passing off-gases through deodorizing system.
	11b. Odors from storage reservoirs.	11b. DO in storage reservoirs.	11b. Improve pretreatment or aerate reservoirs.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
12. Center pivot irrigation rigs stuck in mud.	12a. Excessive application rates.		12a. Reduce application rates.
	12b. Improper tires or rigs.		12b. Install tires with higher flotation capabilities.
	12c. Poor drainage.		12c. Improve drainage (See Item 1b).
13. Nitrate concentration of groundwater in vicinity of irrigation site is increasing.	13a. Application of nitrogen is not in balance with crop needs.	13a. Check lbs/acre/yr of nitrogen being applied with needs of crops.	13a. Change crop to one with higher nitrogen needs.
	13b. Nitrogen being applied during periods when crops are dormant.	13b. Application schedules.	13b. Apply wastewater only during periods of active crop growth.
	13c. Crop is not being harvested and removed.	13c. Farming management.	13c. Harvest and remove crop.

FLOW MEASUREMENT

Process Description

Flow measurement is necessary for good operation and control of a wastewater treatment plant. Reasons for measuring flow of wastewater include:

1. To provide operating and performance data concerning the treatment plant.

2. To compute costs of treatment, where such costs are based on wastewater volume.

3. To obtain data for long term planning of treatment plant capacity versus actual capacity used.

There are many methods of measuring flow; some for open channel flows, and others to measure flow in pipelines. The most commonly used flow measurement devices will be described in the following paragraphs.

Propeller Meter--

The propeller meter (Figure 79) operates on the principle that liquid hitting the propeller will cause the propeller to rotate at a speed that is proportional to flow rate. The meter is self-contained and requires no other energy or equipment other than a mechanical totalizer to obtain a reading of cumulative flow. Equipment may be added to the meter to produce a flow rate reading, pace chemical feed equipment, and control telemetering equipment for remote readout.

Magnetic Flow Meter--

If a liquid conductor (such as wastewater or sludge) moves through a magnetic field, a voltage is induced. This voltage in turn, is directly proportional to the velocity of the liquid moving through the field. This is the basis for the operation of a magnetic flow meter (Figure 80). The magnetic flow meter does not restrict flow and normally does not need any flushing or cleaning to maintain good operation. The meter may be provided with recorders, and totalizers using electric or pneumatic transmission systems.

This type of flow meter is useful at sewage lift stations, to measure total raw wastewater flow, or to measure raw or recirculated sludge.

Venturi Tube--

This meter only can be used in pipes where the wastewater flow is under pressure. With the Venturi Tube (Figure 81), the wastewater flows

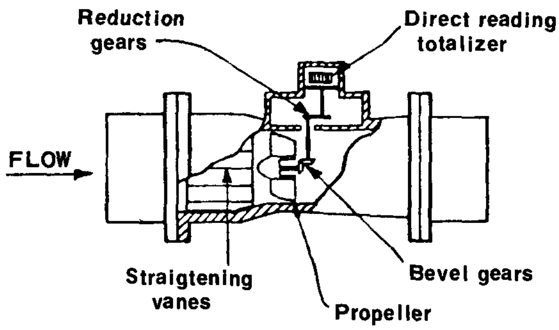


Figure 79. Propeller meter.

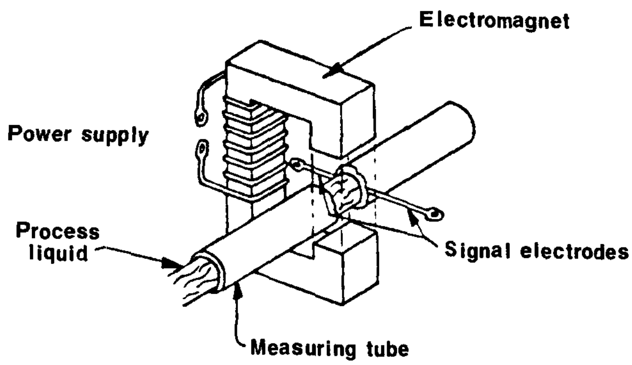


Figure 80. Magnetic flow meter.

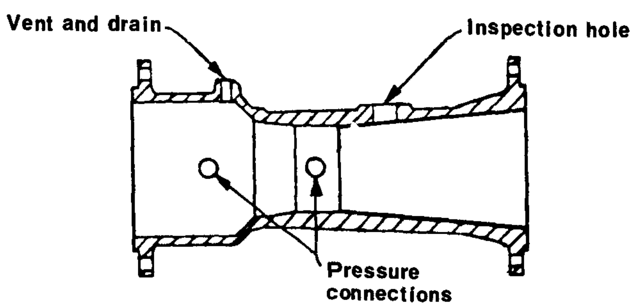


Figure 81. Venturi tube meter.

through a constriction of known dimensions that will cause a pressure drop at the constricted area. The difference between the inlet and exit pressures is proportional to the flow rate. Venturi meters may be used for nearly all pipe flows including raw wastewater, settled wastewater, plant effluent, raw sludge, digested sludge, mixed liquors, and air.

Positive Displacement Diaphragm Meter--

This meter (Figure 82) operates on the principle of alternately filling and discharging a definite volume of gas from either side of a stroking diaphragm. The motion turns a direct reading register. It is a low pressure, wide range device and is used to meter digester gas.

Weirs--

Weirs (Figure 83) consist of a vertical plate with a sharp crest, placed in a stream, channel or partly filled pipe. The top of the plate may be straight, v-notched, or trapazoidal in shape, suitable for the quantity of flow passing over it. To determine the flow rate, it is necessary only to measure the head (height) of water above the crest of the weir. In order for this device to be accurate, the crest of the weir must be kept clean, sharp, and close to original dimensions and elevation, and particles clinging to it must be removed.

When a continuous flow record is needed, permanent or "bubbler" meters may be used with a weir. Mechanical float and cable gauges also may be used for water height measurements.

In wastewater treatment plants, weirs often are used to measure flow recirculation, return sludge, and mixed liquor flow.

Parshall Flume--

The Parshall Flume (Figure 84) operates on the principle that open channel flow, when passing a constriction in the channel, will pass through a minimum (critical) depth. This will produce a hydraulic head at a certain point upstream of the constriction that is proportional to the flow.

The Parshall flume is good for measuring open channel waste flow because there is no difficulty with sand or suspended solids since the flume cleans itself; is simple; and is accurate.

Kennison or Parabolic Nozzle--

This nozzle (Figure 85) is much like a Parshall flume. The wastewater flows through a partially filled pipe with a known constriction, and produces a certain hydraulic head at a point upstream of the constriction. By choosing a particular shape for the constriction, the flow can be calculated from the head, as long as the nozzle has free discharge. These nozzles, like the flume, are self-cleaning and can handle liquids high in solids quite well.

Rotameter--

The rotameter (Figure 86) or variable area meter operates as a flow tube, with float position dependent on <u>viscous</u> differential head or

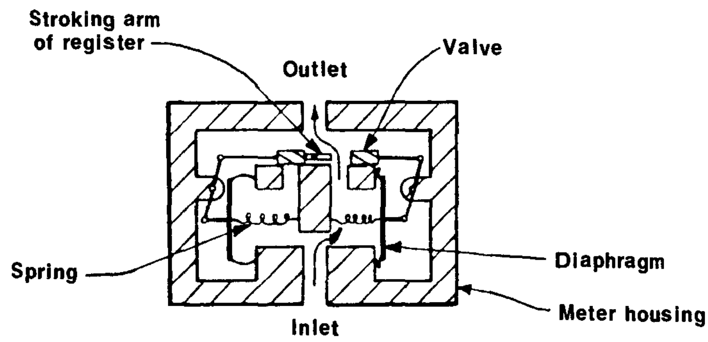


Figure 82. Positive displacement diaphragm meter

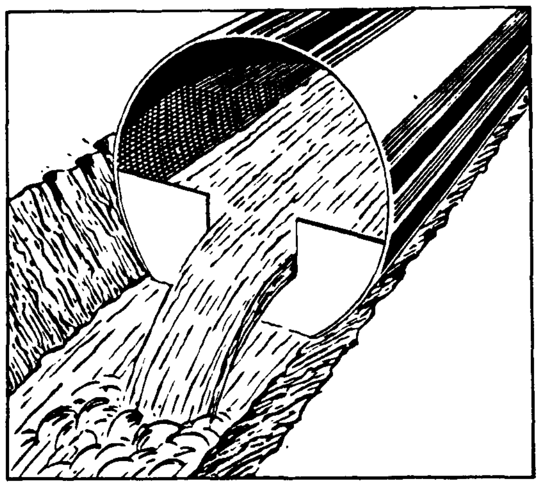


Figure 83. Typical pipe and weir installation.

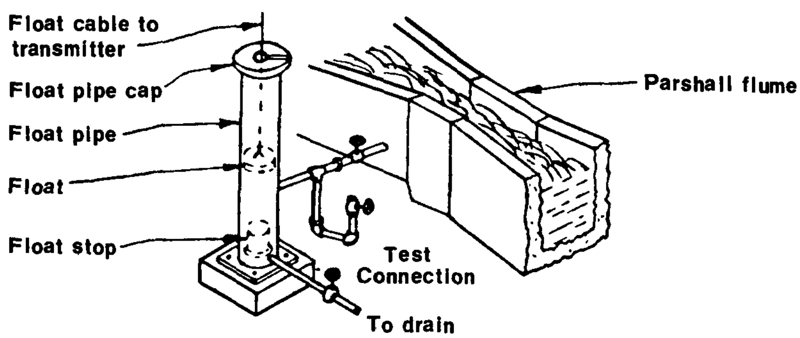


Figure 84. Parshall flume.

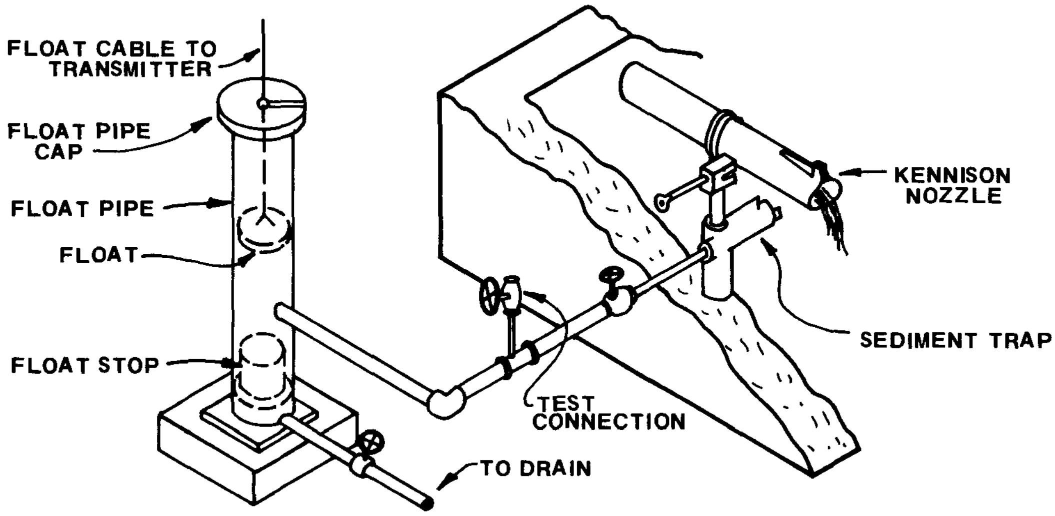


Figure 85. Kennison or parabolic nozzle.

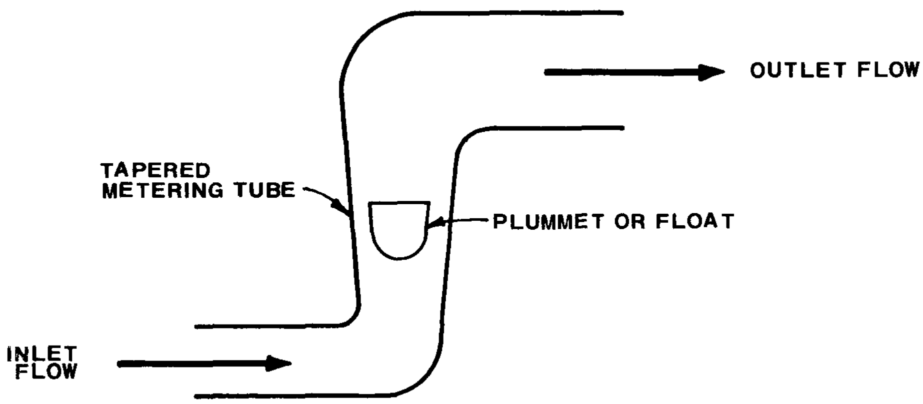


Figure 86. Rotameter.

pressure. The rotameter is most often used for measuring chemical flows, but cannot be used for measuring wastewater or other plant flows which may clog the system.

Typical Design Criteria and Performance Evaluation

Not all flow measurement devices can be used for all purposes at a wastewater treatment plant. Some designs, such as the propeller meter, are affected by high solids concentrations and cannot be used for measuring wastewater flows with excessive solids. Some units require frequent or continuous backflushing when the meters are used to handle raw wastewater or sludge. The range of flows, accuracy, space available, particular application and maintenance, are important design considerations which must be evaluated for each type of flow measuring device. Table 24 shows the normal accuracy for each type of meter already described.

Control Considerations

Because most wastewater treatment processes require accurate flow measurement for effective operation, measuring devices must be checked at regular intervals to make sure that the flow is unobstructed and that the meter is discharging freely. When weirs are used, careful attention should be paid to level setting, low approach velocity, and depth of flow above and below the weir.

Common Design Shortcomings and Ways to Compensate

	Shortcomings		Solution
1.	Weirs must be kept clean and particles clinging to it must be removed periodically for proper operation.	1.	Replace weir with a Parshall flume which scours itself clean or place a screen before the weir.
2.	Most flow measuring devices in pipelines involve some constriction in flow.	2.	Replace with a magnetic flow meter where no flow constriction is necessary for operation.
3.	Magnetic flow meters require an auxiliary power source.	3.	If possible, replace with a Venturi meter which requires no power and can be used for nearly all pipeline flows.
4.	Magnetic flow meters cannot be used for measuring flows in partially filled pipelines.	4.	Install a weir or Parshall flume which would be more practical for open channel flow or flow in partially filled pipelines.
5.	Vent holes in Venturi tube pressure chambers are subject to clogging.	5.	Provide hand-operated vent cleaners (special rods with handles) which can be pushed into the vent to remove accumulations.

TABLE 24. ACCURACY OF VARIOUS FLOW MEASURING DEVICES

Type of flow meter	% Accuracy
Propeller meter	±2% of actual flow rate over a range of 7:1 for small meters and up to 12:1 for large meters
Magnetic meter	
Below 3 fps	±1% of maximum scale reading
3 - 30 fps	±2% of maximum scale reading
Venturi tube	±3 to 4% of flow rate
Flow tube	±1% of flow rate
Positive displacement and diaphragm meter	±1% of flow rate
Weirs	±5% of flow rate
Parshall flume	±5% of flow rate
Kennison or parabolic nozzle	±2% of flow rate over flow range of 10:1
Rotameter	±2% of maximum scale

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Drop or sharp increase in indicated flow.	1a. Obstruction on float (if float operated).	1a. Visual inspection.	1a. Remove obstruction. Keep float clean and free from grease.
	1b. Improper air flow, or bubbler tube damaged (if operated on bubbler).	1b. Check air pressure gauge.	1b. Clean bubbler and keep free from grease.
	1c. Grease build-up on magnetic flow meter coils.	1c. Visual inspection.	1c. Remove grease build-up.
	1d. Weir plates clogged with foreign material.	1d. Visual inspection.	1d. Clean foreign matter off weir.
2. Inconsistent or inaccurate weir flow measurement readings.	2a. Weir not level.	2a. Visual inspection using a leveling device.	2a. Level the weir.
3. Propeller meter shows inaccurate reading.	3a. Improper calibration.		3a. Recalibrate meter.
	3b. Meter clogged with debris.	3b. Visual inspection.	3b. Remove debris and consider replacing meter with a self-scouring type.

SLUDGE PUMPING

Process Description

Sludge pumps have many uses in a municipal wastewater treatment plant. Settled primary sludge must be moved regularly; activated sludge must be returned continuously to aeration tanks, with the extra sludge wasted; scum must be pumped to digestion tanks; and sludge must be recirculated and transferred within the plant in processes such as digestion, trickling filter operation, and final disposal. The type of pumping station used at the plant depends on the characteristics of the sludge itself.

Pumps used for handling sludges may be centrifugal, air lift and ejectors, grinding, Archimedes screw lift, and positive displacement types.

Typical Design Criteria and Performance Evaluation

Centrifugal and Screw Lift Pumps--

Centrifugal and screw lift pumps are used to handle large volumes of flow that have a low solids content, and when precise control of the flow rate is not required. Centrifugal pumps often are used to return activated sludge and waste unthickened solids from primary and secondary treatment processes. This pump also is used for recirculation of digester contents (with less than 4 or 5 percent TS), and for scum and skimmings removal.

Positive Displacement Pumps--

The most common types of positive displacement pumps used for sludge include the plunger, rotary pump and diaphragm pump.

The plunger pump is the most popular pump for handling high viscosity sludges containing large and abrasive solids.

Of the rotary positive displacement pumps, only the progressing cavity pump has widespread use in pumping sludges. This pump is self-priming and delivers a smooth flow in contrast to the plunger-type pump. Not only is the rotary displacement pump able to handle very thick sludges, but it also may be used to transport sludge cake; it can pump centrifuge and filter cakes having 15 to 40 percent TS. When the progressing cavity pump is made of the right materials, it also may be used for handling chemical slurries. The diaphragm-type pump may be used for the same applications as a plunger pump, except that it has no problems with abrasion. This pump also may be used for handling strong or toxic chemicals when leakage of the chemicals is a major concern.

Sludge Grinding Pumps--

There are two main types of sludge grinding pumps. The first type is a comminuting device which produces only enough head to pass solids through the grinder itself. This unit is mostly used for comminuting thickened sludges, scum, and screenings that may cause clogging in dewatering systems.

The second type of pump combines both grinding and pumping of the liquid and comminuted solids. The unit may be used to grind scum and screenings, handle sludge flows, and break up relatively large trash particles.

Table 25 lists various types of sludge pumps, their capacities, and delivered pressure. This table may be used as a general guide to evaluating the performance of sludge pumps at a treatment plant. For a very precise evaluation, the actual operating characteristics of the pump should be checked against manufacturers design data for the pump. Pumps cannot be expected to operate beyond their designed capacity and intended use.

Control Considerations

To be effective, sludge pumping systems must be flexible under different plant operating conditions. The overall piping, valves, and pumping system must be set up to allow bypassing and provide standby pumping capacity when problems occur.

The most important control considerations which must be understood by the operator are 1) the total quantity of sludge per day to be handled, and 2) the rate at which solids build up and must be removed. Unless the system and the operator are prepared to handle grit and other solids during times of heavy solids inflow, the operator may find all the sludge lines plugged and overloaded. The operator also must be aware of the effects of overpumping and underpumping from different unit operations. For example, solids removed at too high of a rate will result in thin sludge and overpumping of the thickener.

Sludge removal rates may depend on downstream operations such as dewatering and combustion. For these processes, a uniform rate of solids delivery is necessary. On the other hand, sludge flow is not so critical in downstream units like aerobic or anaerobic digestion.

If a sludge concentrator is used, time is needed to accumulate the solids (known as a "solids inventory"). If the removal rate is higher than the stocking rate of the inventory, then the solids concentration will be lowered. Whenever possible, the concentration of the withdrawn sludge should be used to determine the sludge pumping rate.

When multiple units are used, it is best to withdraw thickened sludge from two or more units at the same time using a multiple pump arrangement. This practice will result in a much more uniform and highly

TABLE 25. TYPES OF SLUDGE PUMPS

Type of pump	Capacity (gpm)	Delivered pressure (psi)
Plunger pump	up to 500	100 - 150
Rotary positive displacement (progressing cavity pump)	up to 400	up to 500
Diaphragm	up to 100	up to 100
Sludge grinding pumps (comminuting and pumping type)	25 - 300	--
Screw lift pump	up to 80,000	--

concentrated sludge than doubling the pumping rate of a single unit. Another way is to pump at a higher rate, but for a much shorter time.

Sludge removal from an aerobic or anaerobic digester is more efficient when the pumping schedule is based on solids accumulation. The pumping program should tend to underpump the thickener or secondary settling tank so that a daily manual check on the sludge inventory can be made, and the pumping schedule adjusted to remove any accumulated inventory. Sludge removal considerations also are discussed in each unit process section of this manual.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Overpumping.	1a. Long suction line with high head loss on suction side of pump.	1a. Sludge dilutes as it breaks through sludge blanket if pump is operating at too high a rate.	1a. (1) Pump sludge more frequently. (2) Reduce speed of pump.
2. Unwanted (dilute) flow of sludge through pump.	2a. Improper location of pump.		2a. Relocate pump.
	2b. Ball valve too light or ball hung up on trash accumulations.	2b. Visual inspection.	2b. Change the weight of the ball check to prevent it from lifting and allowing dilute sludge to flow through the pump.
3. Water hammer.	3a. High suction head and high discharge pressure.	3a. Check pressures.	3a. (1) Be sure suction and discharge air chambers are filled with air. (2) Change ball checks and seating arrangement. (3) Modify pumping rate.
4. Pump inefficiency at high suction.	4a. Air leakage through pump seals or valve stem seals.	4a. Pour water around seal and visibly inspect sealing check. You may also hear the leak.	4a. Check seating and seals on valves, valve covers, valve stems, and piston on plunger pump (repair or replace damaged and worn parts.)
5. Grease build-up in raw sludge line.	5a. Sludge characteristics.		5a. (1) Fill raw sludge line with digested sludge and let sit overnite. (2) Recirculate warm sludge through raw sludge line to "melt" grease.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
6. Excessive wear on pumps.	6a. Plunger pump operating on a short stroke for long periods of time.		6a. Run pump on a longer stroke at slower speed.
	6b. Improper clearance adjustment on grinder pump.	6b. Cutter clearance.	6b. Properly adjust clearance of cutters.
7. Excessive leakage around seals on shafts and plungers.	7a. Excessive wear on shaft or cylinder.	7a. Packing rapidly destroyed.	7a. Replace shaft or plunger, replace mechanical seals with water-lubricated seals.
8. Progressive cavity pump unable to transport sludge.	8a. Slippage occurring in pump due to wear on stators and rotors.	8a. Stator and rotor condition.	8a. Replace stator and/or rotor.
	8b. Pump operating at excessive speeds.	8b. Excessive wear.	8b. Reduce operation to 200 to 300 rpm.

THERMAL TREATMENT OF SLUDGES

Process Description

There are two basic types of high temperature, high pressure treatment of sludges. One - "wet air oxidation" - involves the flameless oxidation of sludges at 450-550°F at pressures of about 1200 psig. The other type - "heat treatment" - is more common and is carried out at lower temperatures and pressures (350-400°F at 150-300 psig) to improve sludge dewatering. Because the equipment for both processes is almost the same, this section reviews both approaches.

Water escapes from the sludge as the sludge is heated. Heat treatment systems release bound water from the sewage sludge to improve dewatering and thickening.

A typical heat treatment process is shown in Figure 87. Sludge is ground and pumped to a pressure of about 300 psi. Compressed air is fed into the system and the mixture is brought to an operating temperature of about 350°F. The heated, conditioned sludge is cooled by heat exchange with the incoming sludge. The treated sludge is separated by settling before the dewatering step. Gases released at the separation step are passed through a catalytic afterburner at 650-750°F.

The same basic system can be used for sludge reduction by wet air oxidation, except that higher temperatures (450-650°F) and higher pressures (1200-1600 psig) are used. The wet air oxidation (WAO) process is based on the fact that any material that can be burned can also be oxidized in the presence of liquid water at temperatures between 250°F and 700°F. Wet air oxidation does not require preliminary dewatering or drying, like other burning processes. However, the oxidized ash must be separated from the water by vacuum filtration, centrifugation, or some other solids separation process.

Unfortunately, heat treatment converts suspended solids to dissolved or dispersed solids. These dissolved solids cause a highly polluted liquid from the dewatering process which must be recycled to the wastewater treatment plant for reprocessing.

Typical Design Criteria and Performance Evaluation

The size of heat treatment units depends on the expected sludge flow rate (gpm). The detention time in the heat exchanger is usually 30-60 minutes.

The degree of wet oxidation - low, intermediate, or high - refers

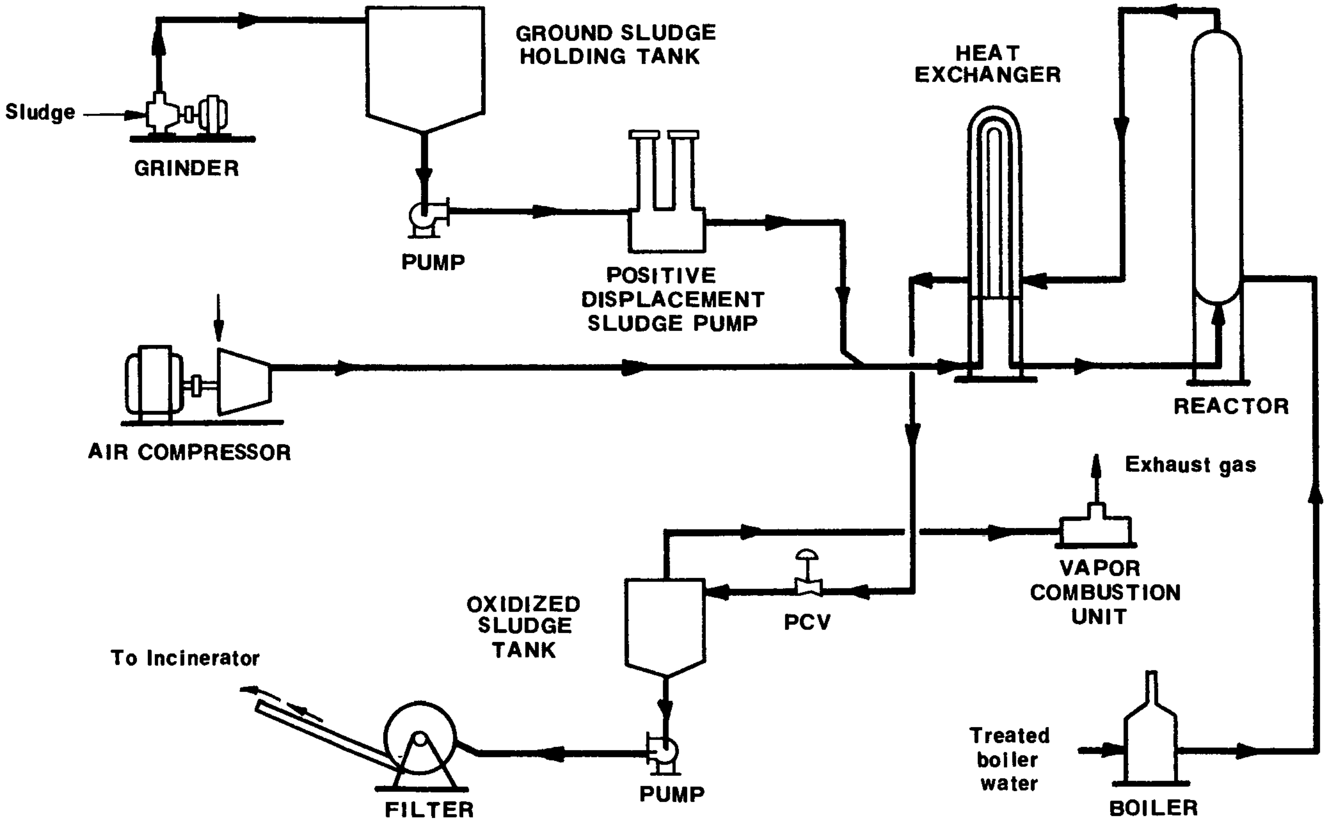


Figure 87. Heat treatment system schematic.

to how much the COD of the sludge is reduced. Higher temperatures are needed to obtain higher degrees of oxidation. The higher temperatures, in turn, require higher pressures in order to prevent flashing to steam or burning.

The operating temperature and pressure ranges for the three degrees of oxidation are given below:

Oxidation	Reduction in sludge COD, percent	Temp., ^{o}F	Pressure, psi
Low	5	350-400	300-500
Intermediate	40	450	750
High	92-98	675	1,650

With high oxidation, the amount of sludge ash is about the same as with incineration.

If the detention time in the thermal reactor is increased, COD and color of the liquor increase. For example, in low oxidation at 350 to 400^{o}F, the color of the liquor increases from 2,150 units for a reaction time of 3 minutes, to 3,800 units at 15 minutes, to 5,500 units at 30 minutes.

It is much easier to dewater a sludge that has been heat treated than one which has been chemically conditioned (sludge solids of 30-40% as opposed to 15-20% with chemical conditioning). The dewatering also can handle relatively high loading rates for heat treated sludges (2-3 times the rates with chemical conditioning). The process also provides effective disinfection of the sludge.

Control Considerations

Four important factors control the performance of wet oxidation units: temperature, air supply, pressure, and feed solids concentration. The degree and rate of sludge solids oxidation are greatly influenced by the reactor temperature. Much higher degrees of oxidation and shorter reaction times are possible with increased temperatures. Like conventional incinerators, an external supply of oxygen (air) is needed for almost complete oxidation. The amount of air needed for the process depends on the heat value of the sludge and the degree of oxidation. Thermal efficiency and process economy depend on air input, so it is important that the right amount be used. Because the input air becomes saturated with steam in the reactor, it is important to control the air also to prevent too much water from evaporating.

The reactor temperature and pressure affect the amount of recycle BOD and how easily the sludge can be dewatered. Temperatures usually should be kept as low as possible, consistent with adequate conditioning of the sludge. Higher temperatures breakdown the sludge particles, produce more BOD in the liquor and breakdown the fibrous material in the sludge which is needed for high filtration rates and thick cakes.

The following lists some of the substances found in thermal treatment liquor.

Substances in strong liquor	Concentration range, mg/l (except as shown)
SS	100 - 20,000
COD	100 - 17,000
BOD	3,000 - 15,000
NH_3-N	400 - 1,700
Phosphorus	20 - 150
Color	1,000 - 6,000 units

These high concentrations show the potential impact that liquor recycle can have on the wastewater treatment processes. It is important that the operator know and understand the importance of the recycle load in overall plant operation.

"Over-cooking" can breakdown fibrous material which would otherwise aid filtration. Filterability also is affected by the pH of the sludge. Low pH values are much more effective, but corrosion problems are increased. Odor can be reduced if the conditioned sludges are cooled before being exposed to the atmosphere. Increases in the solids content of heat treatment process feed lowers operating costs, but makes dewatering of the conditioned sludge more difficult. This results in increasing the dissolved COD, nitrogen, and phosphorus in the liquor. If the heat treatment temperature is increased, soluble nitrogen increases, and suspended solids decrease in the recycle liquor.

Thermal treatment units should always have an operator in attendance when the units are running. The lead operator should be able to do routine preventive maintenance on the thermal conditioning equipment.

Each hour, the operator should:

1. Record all instrument readings on log sheet. Compare with previous readings and check any unusual changes. Rapid changes in temperature or pressure may be the first indication of trouble.

2. Adjust pumping system to maintain proper sludge flow rate.

3. Adjust oxidation system to maintain proper temperatures.

4. Examine each operating piece of equipment. Check lubrication, cooling water, operating temperatures, leakage, sound, and vibration. Any unit which may not be operating properly should be closely watched, and the cause of the problem discovered and corrected quickly. The operator should shut down the system if operating problems continue without obvious cause, or become worse.

5. Take samples as required.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Effects of recycled liquors on wastewater process were not adequately considered and plant is upset.	1a. Store liquors and recycle during low flow night-time conditions. 1b. Install separate treatment system for liquors before they are recycled (review with consultant).
2. Off-gases from decant tanks, thickeners, or dewatering system subject to odors.	2a. Temporary solutions may include addition of hydrogen peroxide to open tanks or use of masking chemicals. 2b. Install adequate deodorization equipment (review with consultant).
3. Backup support systems (boiler, feed pumps, grinders, air compressors, etc) not provided.	3. Install backup components.
4. High temperatures and presence of calcium, sulfates, or chlorides in the sludge can create scaling and corrosion in heat exchangers & reaction vessels, and piping.	4. Use SS 316L or Titanium for materials of construction.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Odors.	1a. Odors being released in decant tanks, thickeners, vacuum pump exhaust or in dewatering.		1a.(1) Cover units, collect air and deodorize it before release by use of incineration, adsorption, or scrubbing. 1a.(2) Cover open tank surface with small floating plastic balls to reduce evaporation and odor loss.
	1b. Odors being released when recycle liquors enter wastewater treatment tanks.		1b. Pre-aerate liquors in covered tank and deodorize off gases.
2. Raw sludge grinder requires very frequent maintenance.	2. Excessive grit in raw sludge.	2. Operation of raw sludge degritting system and raw sewage grit removal.	2. Maintain and properly operate the raw sludge and raw sewage degritting systems.
3. Scaling of heat exchangers.	3a. Calcium sulfate deposits.	3a. Efficiency of heat transfer - difficult to maintain reactor temperatures.	3a. Provide acid wash in accordance with manufacturers instructions.
	3b. Operating temperatures too high - causing baking of solids.		3b. Operate reactor at temperatures below 390°F for heat conditioning of sludge. 3c. Use hydraulically driven cleaning bullet to clean inner tubes.
4. Heat treatment system down time is substantial.	4. Inadequate operation and maintenance skills.		4. Contract for maintenance of system and institute training program for operators.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Grinder has shut down.	5a. Loss of seal water. 5b. Grinder has jammed.	5a. Seal water supply - are valves open. 5b. Is grinder motor reversing automatically when overloaded.	5a. Establish flow of seal water. 5b. Remove obstruction.
6. Feed pumps are overheating.	6a. Inadequate lubrication. 6b. Cooling water supply inadequate.	6a. Oil levels. 6b. Cooling water.	6a. Lubricate pumps. 6b. Establish adequate flow of cooling water.
7. Steam use is high.	7. Sludge concentration to heat treatment unit is low.	7. Sludge concentration.	7. Operate thickener to maintain 6% solids if possible; 3% minimum.
8. Solids dewater poorly.	8a. Anaerobic digestion prior to heat treatment. 8b. Temperatures not maintained high enough.	 8b. Reactor temperatures.	8a. Discontinue anaerobic digestion of sludge to be heat treated. 8b. Temperature should be at least 350°F.
9. High system pressure.	9a. Blockage in reactor. 9b. Pressure controller set too high. 9c. Block valve closed.	9a.(1) If relief valves are blowing, shut down unit. 9a.(2) If relief valves are not blowing, blockage was temporary. 9b. Pressure controller setting. 9c. Block valve.	9a.(1) Remove blockage. 9a.(2) Check pressures and temperatures to note any discrepancies from normal. 9b. Reduce set point on pressure controller. 9c. Check system for proper valving.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
10. Feed pumps not pumping adequate flow.	10a. Improper control setting.	10a. Control setting.	10a. Adjust control setting.
	10b. Leakage or plugging in product check valves.		10b. Repair or replace check valves.
	10c. Air trapped in pump cylinders.		10c. Bleed off air.
11. System pressure is dropping.	11a. Pressure contoller set too low.	11a. Setting on pressure controller.	11a. Set pressure controller at proper valve.
	11b. Pressure control valve trim is eroded.	11b. Inspect valve.	11b. Replace valve.
12. Oxidation temperature is rising.	12a. Inlet temperature too high.	12a. Should not exceed 310°F for sludge conditioning.	12a. Reduce temperature by diluting incoming sludge with water.
	12b. Sludge feed rate is too slow.	12b. Operation of sludge feed pumps and feed rate.	12b. Increase sludge feed rate.
	12c. Improper control setting.	12c. Temperature control.	12c. Appropriately adjust control setting.
	12d. Pump stopped or slowed.	12d. Pump operation.	12d. Start pump and/or increase rate.
	12e. Volatile matter such as gas or oil being pumped through the system.		12e. Switch from sludge to water and stop the process air compressor.
	12f. Pneumatic steam valve not functioning properly.	12f. Valve operation.	12f. Repair malfunctioning valve.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
13. Oxidation temperature is falling.	13a. Heat exchanger fouled.	(see item 3)	
	13b. Reactor inlet temperature is too low, because of low density sludge.	13b. Should be at least 280°F.	13b. Reduce dilution of incoming sludge.
	13c. High flow rate being pumped through system.	13c. System flow rate.	13c. Reduce flow rate at high pressure pump(s).
	13d. Improper temperature control setting.	13d. Temperature control setting.	13d. Appropriately adjust.
	13e. Pneumatic steam valve not functioning properly.	13e. Steam valve.	13e. Repair malfunctioning valve.
	13f. No signal air to the temperature control valve.		13f. Check instrument air supply.
	13g. Boiler not functioning properly.	13g. Boiler operation.	13g. Consult boiler manufacturer's instruction manual for corrective action.
14. Scoring of air compressor cylinder walls and pistons.	14a. Carbon or other foreign material in compression cylinder.	14a. Visual inspection.	14a. Maintain compressor system to avoid material from entering system.
15. Filter cake difficult to feed into incinerator.	15a. Filter cake too dry.		15a. Reduce temperature (and pressure) of the treatment system.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
16. Low system pressure.	16a. High pressure pump and/or process air compressor and/or boiler stopped.		
	16b. Intake filter clogged.	16b. Inspect filter for clogging.	16b. Clean or replace filter.
	16c. Pressure controller set too low.	16c. Pressure controller setting.	16c. Increase set point on pressure controller.
	16d. Any of the blowdown valves may be partially opened.	16d. Valves.	16d. Check compressor valving.
	16e. Leaking interstage trap.		16e. Check trap for proper operation.
	16f. Slipping drive belts.	16f. Drive belt slippage.	16f. Adjust belt tension.
17. High temperature.	17a. Inadequate water flow.	17a. Water flow.	17a. Adjust water flow.
	17b. Leaking cylinder valves.	17b. Cylinder valves.	17b. Repair and/or clean or replace.
	17c. Intercooler and/or jackets plugged.	17c. Visual inspection.	17c. Clean intercooler and/or replace.
	17d. Poor lubrication.	17d. (1) Low oil level.	17d. (1) Add oil.
		17d. (2) Malfunctioning lubricator.	17d. (2) Repair lubricator.
		17d. (3) Loose or worn belt	17d. (3) Tighten loose belt, or replace if worn.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
18. Air compressor safety valve relieving.	18a. Pressure controller set too high.	18a. All system pressures appear high.	18a. Reduce set point on controller.
	18b. No signal air pressure to PCVs.		18b. Check instrument air supply.
	18c. One or more block valves in the system are closed.	18c. Valves closed.	18c. Check system for proper valving.
	18d. Plugged pressure control valve (PCV).	18d. Visual inspection.	18d. Switch to standby PCV and clean plugged valve.

GRAVITY THICKENING

Process Description

Gravity thickening is a type of sedimentation process for sludge which usually is operated continuously, with flow dependent on plant flow.

A conventional gravity thickener is shown in Figure 88. The thickener looks like a circular clarifier, but the bottom has more slope. Sludge enters at the middle of the thickener and the solids settle into a sludge blanket at the bottom. The thickened sludge is very gently mixed by the moving rake which releases gas bubbles. This prevents bridging of the sludge solids, and keeps the sludge moving to the center where it is removed. Supernatant liquor passes over an effluent weir around the outside of the thickener.

Supernatant flow from the thickener is usually returned to either the primary settling tank or the secondary process. Thickened sludge usually is pumped either to a blending, holding, or surge tank or directly to a sludge dewatering process.

Typical Design Criteria and Performance Evaluation

Gravity thickeners are designed on the basis of hydraulic and solids surface loadings. Most thickeners are designed for hydraulic overflow rates of 400-800 gpd/sq ft. Table 26 shows common design data and expected performance. In evaluating the performance of a gravity thickener the following steps should be taken:

1. Identify the type of sludge being thickened.

2. Determine the percent solids in the feed, the loading rate, and the thickened sludge concentration.

   The loading rate may be calculated as follows:

   Primary sludge solids concentration to thickener = 4.7%
   1% solids = 10,000 mg/l = 83,400 lbs/MG
   4.7% solids = 47,000 mg/l = 392,000 lbs/MG

   Flow to thickener = 115,000 gpd = 0.115 mgd
   Solids to thickener = 0.115 mgd x 392,000 lbs/MG =
   45,080 lbs/day
   Thickener Diameter = 50 ft
   Thickener Area = 1963 sq ft

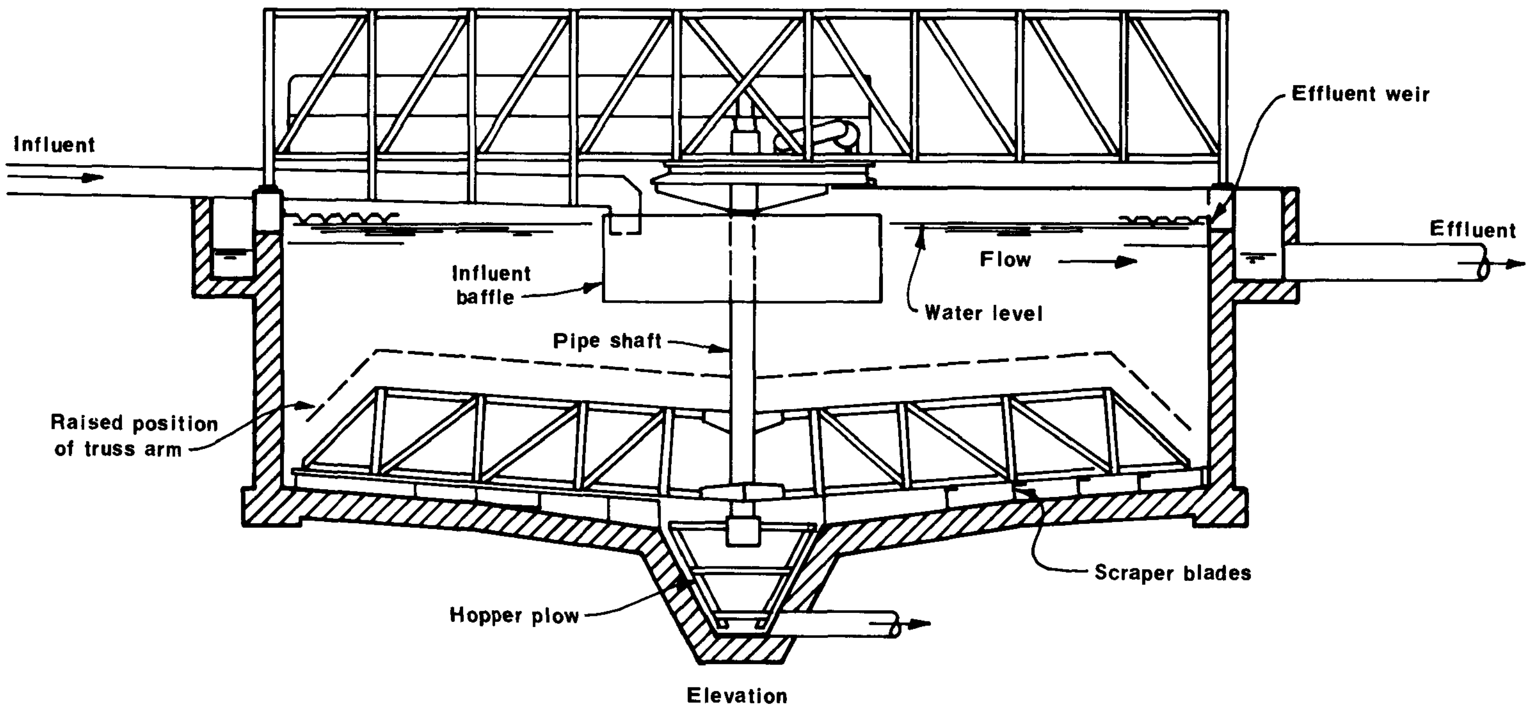


Figure 88. Gravity thickener.

TABLE 26. TYPICAL DESIGN CRITERIA AND PERFORMANCE DATA FOR GRAVITY THICKENING

Sludge type	Feed solids concentration (percent)	Typical loading rate (lb/sq ft/day)	Thickened sludge concentration (percent)
Primary	5.0	20-30	8.0-10
Trickling filter	1.0	8-10	7-9
Primary + $FeCl_3$	2.0	6	4.0
Primary + low lime	5.0	20	7.0
Primary + high lime	7.5	25	12.0
Primary + WAS*	2.0	6-10	4.0
WAS	1.0	5-6	2-3
Primary + (WAS + $FeCl_3$)	1.5	6	3.0
(Primary + $FeCl_3$) + WAS	1.8	6	3.6
Digested primary	8.0	25	12.0
Digested primary + WAS	4.0	15	8.0
Digested primary + (WAS + $FeCl_3$)	4.0	15	6.0
Tertiary, 2 stage high lime	4.5	60	15.0
Tertiary, low lime	3.0	60	12.0

*WAS = Waste Activated Sludge

$$\text{Loading} = \frac{45{,}080 \text{ lbs/day}}{1963 \text{ sq ft}} = 23 \text{ lbs/day/sq ft}$$

3. Check the values obtained in Step 2 against the performance data shown in Table 26.

4. If the system does not operate within or near the values shown in the Table, the troubleshooting guide should be checked for possible solutions to the problem.

CONTROL CONSIDERATIONS

Fresh liquid should be kept from entering the thickener so that septic conditions and odors do not develop. This can be done with overflow rates of 600 to 800 gpd/sq ft. To get hydraulic loadings in this range, secondary effluent is sometimes blended with the sludge feed to the thickener. Another control is the sludge volume ratio (SVR) which is the volume of the sludge blanket divided by the daily volume of sludge pumped from the thickener. This ratio has the units of days and is used to measure the average retention time of solids in the thickener. A long SVR gives a very thick sludge, but may cause too much biological decomposition. Values for SVR usually are kept between 0.5 and 2 days, with the lower values being used during warmer weather. The sludge blanket depth may be changed with differences in solids production to achieve good compaction. During peak conditions, the detention time may have to be shortened to keep the sludge blanket from flowing over the weirs.

The quality of supernatant from a well operated thickener is usually about the same as the quality of raw municipal wastewater, and does not cause problems when recycled to the plant. However, if the thickener operates poorly, large amounts of solids can be lost over the thickener weir and create problems when returned to the plant.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Scum overflow.	1. Move scum collection system away from outlet weir.
2. Sludge hard to remove because of too much grit.	2. Improve grit removal operation or eliminate sources of grit entering system.
3. Short circuiting of flow through tank causing poor solids removal.	3. Modify hydraulic design and install baffles.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Septic odor, rising sludge.	1a. Rate of thickened sludge pumping is too low. 1b. Thickener overflow rate is too low.	1a. Depth of sludge blanket too high (>4 ft). 1b. Maintain minimum overflow rate at 600 gpd/sf.	1a. Increase pumping of thickened sludge. 1b. Increase influent flow to thickener - a portion of the secondary effluent may be pumped to thickener. 1c. Chlorinate influent to thickener to maintain 1 mg/l residual in thickener effluent. 1d. Add air 1-2 ft below surface or in wet well.
2. Thickened sludge too thin.	2a. Overflow rate is too high. 2b. Underflow rate is too high. 2c. Short circuiting of flow through tank.	2a. If overflow rate exceeds 800 gpd/sf, may be the cause. 2b. Maintain a minimum sludge depth of 3 feet. 2c. Visual observation of tank surface; uneven discharge of solids over effluent weir.	2a. Decrease influent raw sludge pumping rate. 2b. Decrease pumping of thickened sludge. 2c. Change weir settings: repair or replace baffles.
3. Torque overload of sludge collecting equipment.	3a. Heavy accumulation of sludge following a period of equipment shut down. 3b. Heavy foreign object jamming the scraper.	3a. Probe along front of collector arms.	3a. Agitation of sludge blanket in front of collector arms with rods or water jets. 3b. Remove foreign object with grappling device if possible; if not, drain basin and remove object.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
4. Excessive growth on weirs.	4. Accumulations of wastewater solids and resultant growth.	4. Inspect surfaces.	4. Frequent and thorough cleaning of surfaces.
5. Sludge lines and pump plugging.	5. Attempting to pump sludge at too high a concentration.		5. Flush line with water; make sure all valves are fully open. (See sludge pumping section also).

FLOTATION THICKENING

Process Description

The flotation thickening process feeds air into the sludge under pressure (40-80 psi), so that a large amount of air can be dissolved. The sludge then flows into an open tank (Figure 89) where, at atmospheric pressure, much of the air comes out of solution as small air bubbles which attach themselves to sludge solids particles and float them to the surface. Flotation works very well on activated sludge, which is difficult to thicken by gravity. The sludge forms a layer at the top of the tank; this layer is removed by a skimmer for further processing.

Figure 90 shows a typical air flotation system. Part of the effluent from the flotation unit is pumped to a retention tank at 60-70 psig. Air is fed into the pump discharge line at a controlled rate and mixed by the reaeration pump. The flow through the recycle system is controlled by a valve. Effluent recycle ratios can range from 30-150 percent of the influent flow. The recycle flow and sludge feed are mixed in a chamber at the entrance to the unit. If flotation aids are used, they usually are fed into this mixing chamber. The sludge particles are floated to the sludge blanket and the clarified effluent flows over a weir. The thickened sludge is removed by a skimmer. Bottom sludge collectors are used to remove any settled sludge or grit.

The sludge is thickened in the sludge blanket, which usually is 8-24 inches thick. The floating sludge and air bubbles force the blanket to settle above the water level so that the water from the sludge particles drains out. Detention time in the flotation basin is not too important, as long as the particles rise quickly and the sludge blanket is not broken.

Typical Design Criteria and Performance Evaluation

1. Check the solids loading.

Solids loading often is designed at 2 lb/hr/sq ft. This rate is possible using flotation aids, with or without auxiliary recycle. Many flotation thickeners are operated at 3.0 lb/hr/sq ft, although built-in capacities of 4.0-5.0 lb/hr/sq ft are common (Table 27) and provide flexibility in operation. There are times when flotation can be done without flotation aids, and auxiliary recycle is used instead. Without flotation aids, loading rates are about 50 percent and solids removal may be less.

2. Check the float solids concentration.

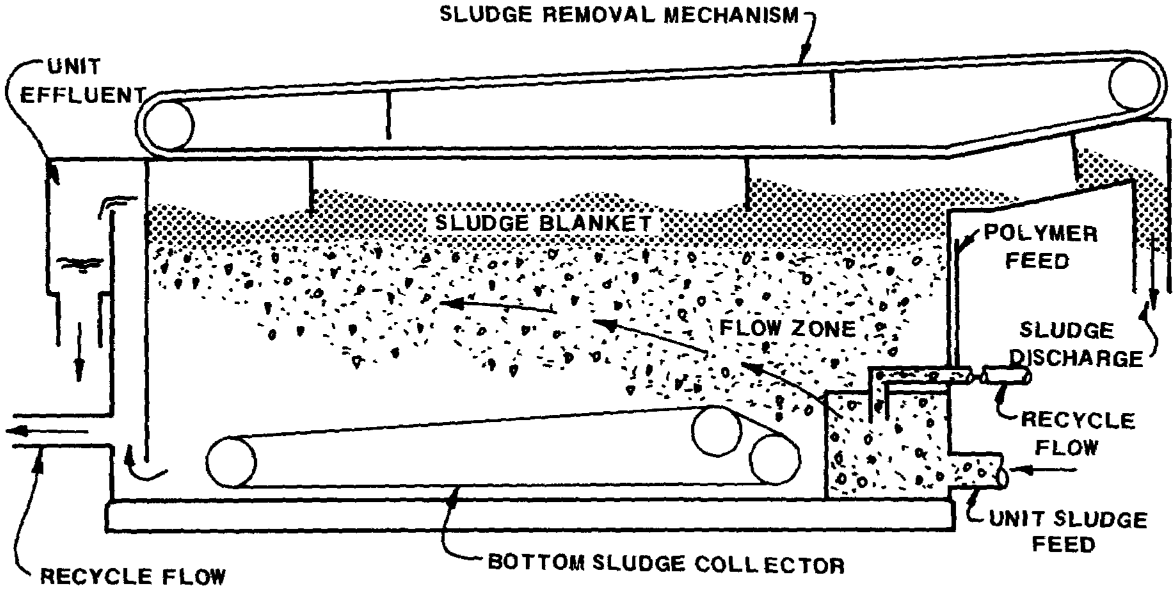


Figure 89. Dissolved air flotation unit.

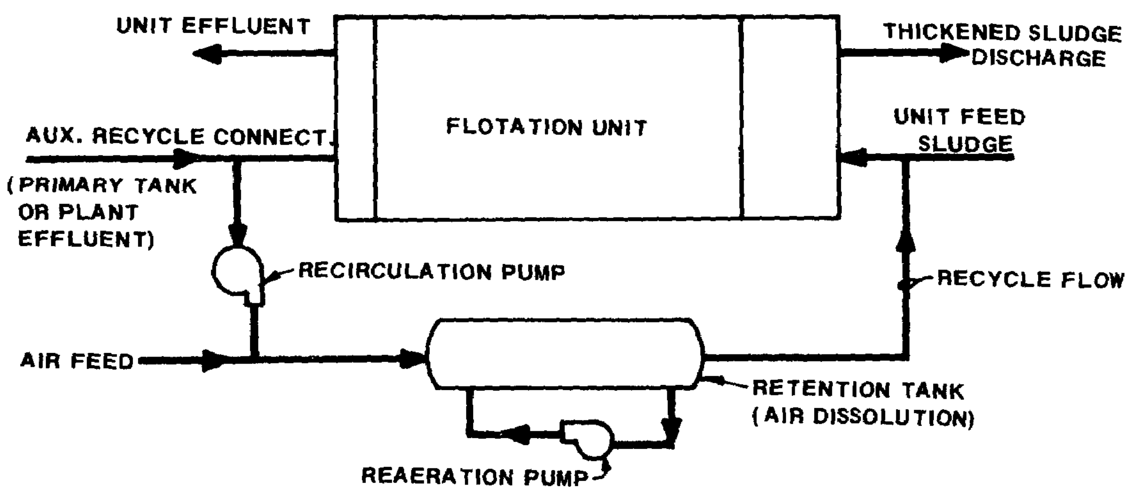


Figure 90. Dissolved air flotation system.

TABLE 27

OPERATING DATA FOR PLANT SCALE DAF UNITS

Location	Feed	Influent ss mg/l	Subnatant ss mg/l	% Removal ss	Float % Solids	Loading lb/hr/ft²	Flow gpm/ft²	Remarks
Bernardsville, N.J.	M.L.[a]	3,600	200	94.5	3.8	2.16	1.2	Standard[c]
Bernardsville, N.J.	R.S.[b]	17,000	196	98.8	4.3	4.25	0.5	Standard
Abington, Pa.	R.S.	5,000	188	96.2	2.8	3.0	1.2	Flotation Aid[d]
					6.0			After 12 hours holding
Hatboro, Pa.	R.S.	7,300	300	96.0	4.0	2.95	0.8	Flotation Aid
Morristown, N.J.	R.S.	6,800	200	97.0	3.5	1.70	0.5	Standard
Omaha, Nebr.	R.S.	19,660	118	99.8	5.9	7.66	0.8	Flotation Aid
					8.8			After 24 hours holding
Omaha, Nebr.	M.L.	7,910	50	99.4	6.8	3.1	0.8	Flotation Aid
Belleville, Ill.	R.S.	18,372	233	98.7	5.7	3.83	0.4	Flotation Aid
Indianapolis, Ind.	R.S.	2,960	144	95.0	5.0	2.1	1.47	Flotation Aid
					7.8			After 12 hours holding
Warren, Mich.	R.S. M.L.	6,000	350	95.0	6-9	5.2	1.75	Flotation Aid
Frankenmuth, Mich.	M.L.	9,000	80	99.1	6-8	6.5	1.3	Flotation Aid
Oakmont, Pa.	R.S.	6,250	80	98.7	8.0	3.0	1.0	Flotation Aid
Columbus, Ohio	R.S.	6,800	40	99.5	5.0	3.3	1.0	Flotation Aid
Levittown, Pa.	R.S.	5,700	31	99.4	5.5	2.9	1.0	Flotation Aid
Nassau Co., N.Y. Bay Park S.T.P.	R.S.	8,100	36	99.6	4.4	4.9	1.2	Flotation Aid
Nassau Co., N.Y. Bay Park S.T.P.	R.S.	7,600	460	94.0	3.3	1.3	0.33	Standard
Nashville, Tenn.	R.S.	15,400	44	99.6	12.4	5.1	0.66	Flotation Aid

[a]M.L. - Mixed liquor from aeration tanks.

[b]R.S. - Return sludge.

[c]Standard - Indicates no flotation aid and no holding before sampling.

[d]Flotation Aid - Indicates use of coagulant-flotation aid.

A 4 percent minimum float solids concentration by weight is normally used for design purposes. However, a 5-6 percent float solids concentration can be expected. Flotation without chemical aids usually results in a solids concentration that is about 1 percent less than with flotation aids.

Typical maximum hydraulic loading or overflow rate is 0.80 gpm/sq ft at minimum solids concentration of 5,000 mg/l. Lower solids levels or higher hydraulic loadings result in lower efficiencies and/or float solids concentrations. Using flotation, at least 95 percent of suspended solids can be removed with flotation aids, and 50-80 percent without flotation aids. Tables 27 and 28 can be used as a guide in evaluating the performance of flotation thickening systems. The gravity thickening section shows how to calculate solids loadings.

Control Considerations

The primary operating variables for flotation thickening are:

- Pressure
- Recycle ratio
- Feed solids concentration
- Detention period
- Air-to-solids ratio
- Type and quality of sludge
- Solids and hydraulic loading rates
- Use of chemical aids

Air pressure used in flotation is important because it determines the size of the air bubbles, and can affect the solids concentration and the subnatant (separated water) quality. Either increased pressure or air flow produces greater float (solids) concentrations and a lower effluent suspended solids concentration. There is an upper limit, however, because too much air breaks up floc.

Recycle ratio and feed solids concentration are related. Additional recycle of clarified effluent does two things:

1. It allows more air to be dissolved because there is more liquid.

2. It dilutes the feed sludge.

Dilution reduces the effect of particle interference on the rate of separation. Concentration of sludge increases and the effluent suspended solids decrease as the sludge blanket detention time increases.

The air-to-solids ratio is also important because it affects the sludge rise rate. The air-to-solids ratio needed, depends mostly on sludge characteristics such as SVI. The most common air-to-solids ratio used for an activated sludge thickener is 0.02.

TABLE 28. AIR FLOTATION THICKENING PERFORMANCE DATA

Type of sludge	Sludge loading psf/day	Feed solids percent	Float solids percent	Solids recovery percent
Waste activated	12-18	0.5-1.5	4.0-6.0	85-95
Waste activated[1]	24-48	0.5-1.5	4.0-5.0	95-99
Waste activated	13.9	0.81	4.9	85
Waste activated	7.1	0.77	3.7	99
Waste activated	19.8	0.45	4.6	83
Waste activated	26.2	0.80	6.5	93
Waste activated	28.8	0.46	4.0	88
Combined primary and waste activated	24-30	1.5-3.0	6.0-8.0	85-95
Combined primary and waste activated	21	0.64	8.6	91
Combined primary and waste activated	46.6 40.7	2.30 1.77	7.1 5.3	94 88

[1]3-6 lb polyelectrolyte/ton dry solids.

Chemical flotation aids (polymers) improve thickening and solids capture. The dosage must be determined for each specific sludge, but dosages of 5-15 lbs/ton of sludge are common. To determine the right polymer dosage, take a 1,000 ml sample of sludge, and using a pipette, measure the ml of polymer solution (from mix tank) needed to produce a firm, well defined floc. Set the polymer feed pump at about 1.5-2.0 times this ratio when the system is started. With experience, reduce the chemical feed to a minimum that will produce good results.

Experience will allow most operators to judge the performance of their flotation thickeners. The rise test performed as follows, is useful to compare test results with those conditions that have produced good operating results in the past. On most units, a valve is provided to sample from the inlet mixing chamber. When the unit is in operation, a quart jar sample is taken and the time for the sludge to rise to a clear surface is measured. Normal rise times are 10-25 seconds, and an optimum time can be found for each particular plant. The relative depth of the blanket, subnatent clarity and general appearance of flocculated sludge particles are also good visual indicators.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Feed pumps run on an on-off cycle causing uneven feed to dissolved air flotation unit.	1. Install a flow indicator and flow control system to provide even, controllable inflow rate.
2. Only primary effluent available for auxiliary recycle.	2. Install line so that secondary effluent can be used for recycle during times when primary effluent has more than 200 mg/l solids or contains unusual amounts of stringy materials.
3. Wide variations in feed solids concentrations occur due to direct feed of DAF from final clarifier.	3. Move feed point to sludge reaeration tank if available or install a mixing-storage tank to minimize fluctuations.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Floated sludge too thin.	1a. Skimmer speed too high.	1a. Visual inspection.	1a. Adjust as required.
	1b. Unit overloaded.	1b. Rise rate.	1b. Turn off feed sludge and allow unit to clear or purge the unit with auxiliary recycle.
	1c. Polymer dosages too low.	1c. Proper operation and calibration of polymer pumps.	1c. Adjust as required.
	1d. Excessive air/solids ratio.	1d. Float appears very frothy.	1d. Reduce air flow to pressurization system.
	1e. Low dissolved air.	1e. (see Item 2)	
2. Low dissolved air.	2a. Reaeration pump off, clogged, or malfunctioning.	2a. Pump condition.	2a. Clean as required.
	2b. Eductor clogged.	2b. Visual inspection.	2b. Clean eductor.
	2c. Air supply malfunctioning.	2c. Compressor, lines, and control panel.	2c. Repair as required.
3. Effluent solids too high.	3a. Unit overloaded.	3a. (see Item 1b)	
	3b. Polymer dosages too low.	3b. (see Item 1c)	
	3c. Skimmer off or too slow.	3c. Skimmer operation.	3c. Adjust speed.
	3d. Low air/solids ratio.	3d. Poor float formation with solids settling.	3d. Increase air flow to pressurization system.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
4. Skimmer blade leaking on beaching plate.	4a. Skimmer wiper not adjusted properly.	4a. Visual inspection.	4a. Adjust as required.
	4b. Hold-down tracks too high.	4b. Visual inspection.	4b. Adjust as required.
5. Skimmer blade binding on beaching plate.	5. Skimmer wiper not properly adjusted.	5. Visual inspection.	5. Adjust as required.
6. High water level in retention tank.	6a. Air supply pressure low.	6a. Compressor and air lines.	6a. Repair as required.
	6b. Level control system not operat-ing.	6b. Level control system.	6b. Repair as required.
	6c. Insufficient air injection.	6c. Compressor and air lines.	6c. Repair as required.
7. Low water level in retention tank.	7a. Recirculation pump not operating or clogged.	7a. Pump operation.	7a. Inspect and clean as required.
	7b. Level control system not operating.	7b. Level control.	7b. Repair as required.
8. Low recirculation pump capacity.	8. High tank pressure.	8. Back pressure.	8. Adjust back pressure valve.
9. Rise rate too slow.	9a. Unit overloaded.	(see Item 1b)	
	9b. Low dissolved air.	(see Item 1e)	
	9c. Polymer dosages too low.	(see Item 1c)	

ANAEROBIC DIGESTION

Process Description

EPA has published "Operations Manual - Anaerobic Sludge Digestion" (EPA 430/9-76-001) which provides very detailed information on the process and troubleshooting. This manual should be read for more complete information than given here. In this process, the organic matter in the sludge is broken down without oxygen. Anaerobic digesters may be "low rate" or "high rate". In the low rate, one-stage digestion process (Figure 91) fresh sludge is fed into the system two or three times daily. As decomposition occurs, three separate layers form. A scum layer is formed at the top of the digester, and below it are supernatant and sludge layers. The sludge zone has an actively decomposing upper layer and a relatively stablized bottom layer. The stabilized sludge settles at the base of the digester and supernatant is usually returned to the plant influent. Most modern systems are "high rate" systems utilizing one or two stages. A typical two-stage process is shown in Figure 92. The sludge stabilizes in the first stage, while the second stage provides settling and thickening. In a single-stage system, the secondary digester is replaced by some other thickening process. The digester is headed to 85-95°F and usually provides 10-20 days detention of the sludge.

The process has been successful when fed primary sludge or combinations of the primary sludge and small amounts of secondary sludge. With more efficient systems than simple sedimentation, large amounts of activated sludges are produced at many plants. This additional sludge, when placed in a two-stage anaerobic digestion process, does not settle well or dewater well after digestion.

The process converts about 50 percent of the organic solids to liquid and gas, greatly reducing the amount of sludge to be disposed. About two-thirds of the gas produced in the process is methane, with a heat value of 600 BTU/standard cubic foot (scf). About 15 scf of gas is formed per pound of volatile solids destroyed. Anaerobic digester gas has been used in wastewater treatment plants for many years to heat digesters and buildings and as fuel for engines that drive pumps, air blowers and electrical generators.

Typical Design Criteria and Performance Evaluation

Table 29 summarizes design criteria for low and high rate digestion systems. Digesters have either fixed or floating covers, as shown in Figure 93.

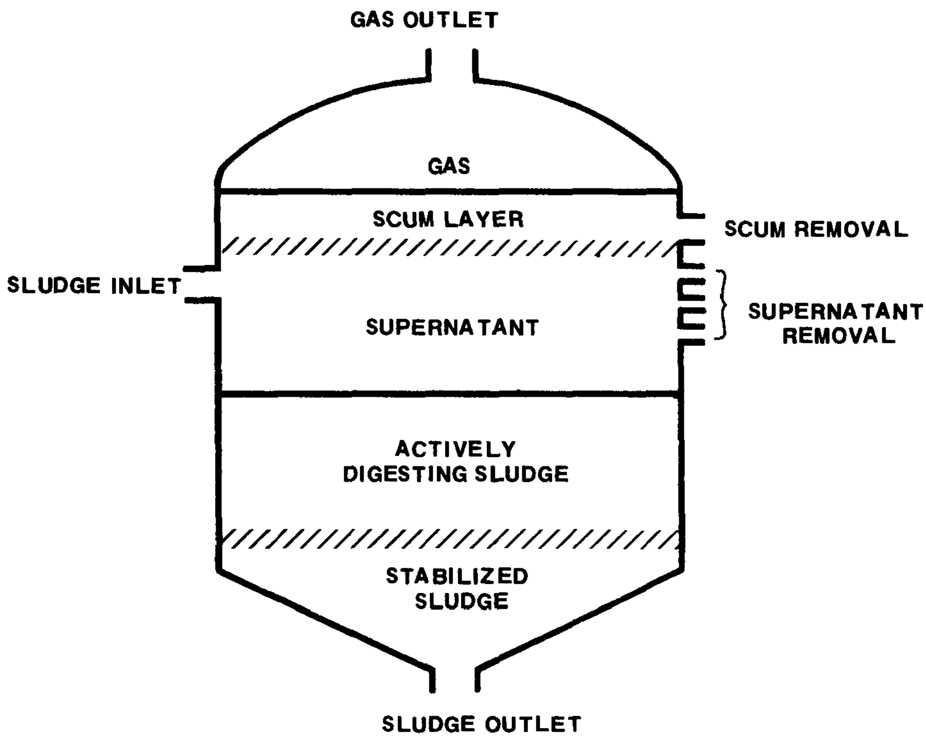


Figure 91. Low rate digester.

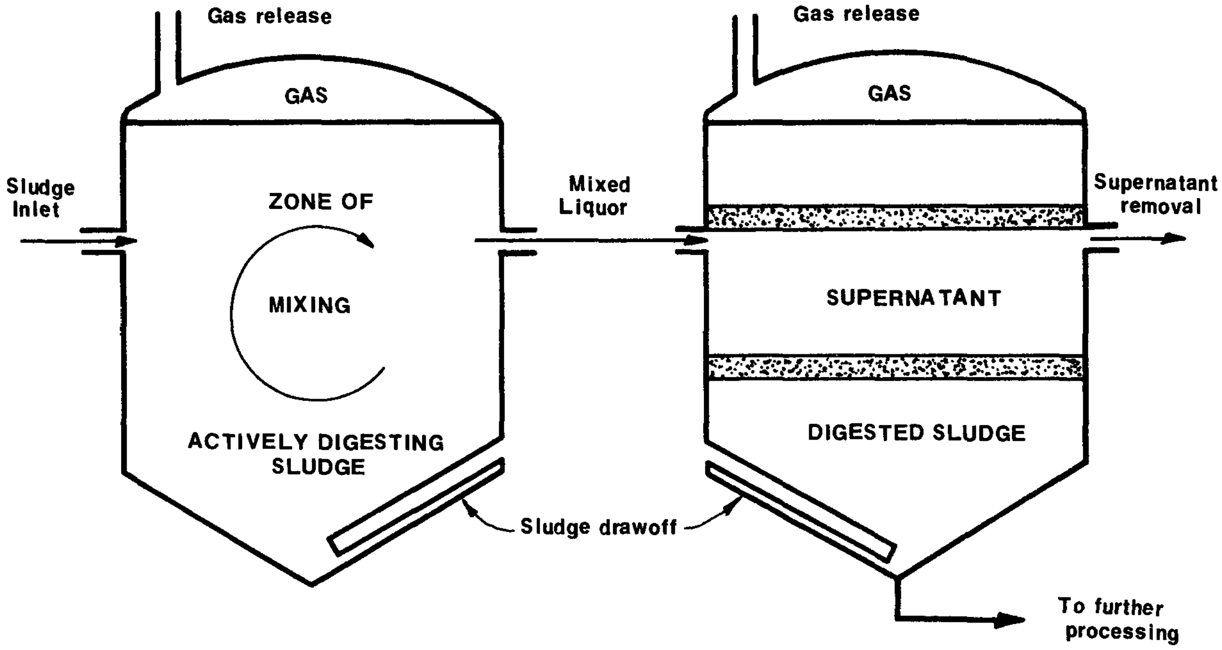


Figure 92. Two-stage anaerobic digestion.

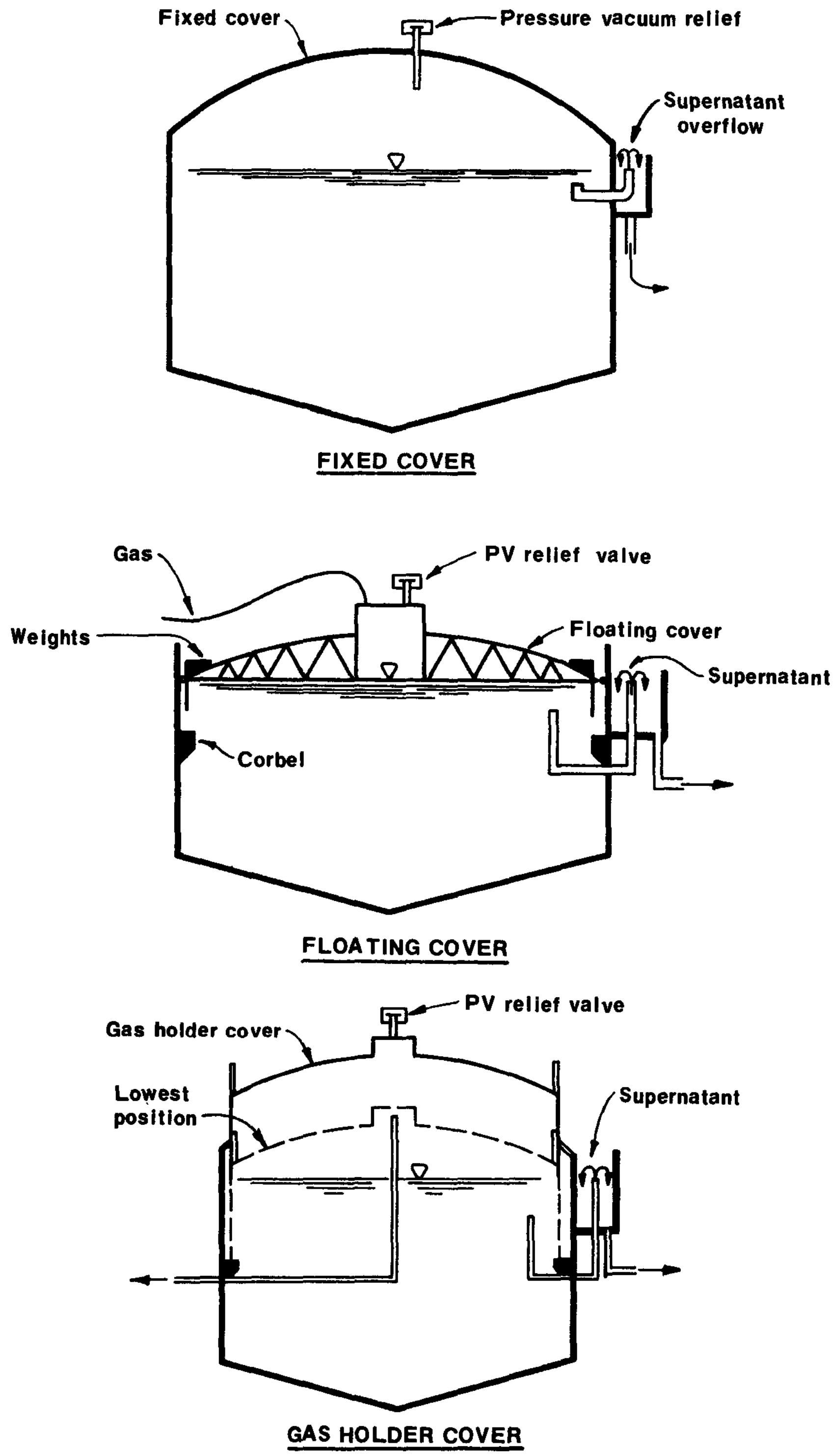


Figure 93. Fixed and floating digestion covers.

TABLE 29. TYPICAL DESIGN CRITERIA FOR LOW RATE AND HIGH RATE DIGESTERS

Parameter	Low rate	High rate
Solids retention time (SRT), days	30-60	10-20
Solids loading, lb VSS/cu ft/day	0.04-0.1	0.15-0.40
Volume criteria, cu ft/capita		
Primary sludge	2-3	1.33 - 2.0
Primary sludge + trickling filter sludge	4-5	2.66 - 3.33
Primary activated + waste activated sludge	4-6	2.66 - 4.0

Fixed-covers are made of concrete or steel and may be flat, conical, or domed. It is difficult to make concrete covers gas-tight because concrete tends to develop cracks. Sludge must be removed from fixed-cover units without letting air into the system and possibly forming an explosive mixture. For this reason, fixed-cover digesters have water-level controls to make the overflow equal to inflow.

Floating covers may be either: (a) the floating cover type resting directly on the liquid with limited gas storage; or (b) the gas-holder type provided with side skirts and resting on a cushion of gas. Floating covers are the safest digesters to operate since there is little chance of creating an explosive mixture under the cover.

The gas-holder type is used to store gas as it is produced. The pressure developed inside the tank causes the cover to lift as much as six feet or more above the minimum height.

Digesters can be heated by:

1. Hot-water coils within the digester,
2. Recirculating sludge through an external heat exchanger,
3. Direct contact of hot gas with sludge, and
4. Steam injection.

Hot water coils inside the digester have been used widely in the past. Their main disadvantage is that they corrode and cake with sludge.

The external heat exchanger with recirculation of the sludge is the most often used method of heating. This method provides good scum control with no pipes inside the digester.

Direct flame heating has been used where gas is mixed into the sludge in small heating tanks. Steam injection has been used in only a few cases.

Mixing can be provided by:

1. Recirculating sludge through an exterior heat exchanger,

2. Mechanically mixing or pumping the sludge within the digester, and

3. Releasing compressed wastewater gas through diffusers near the bottom of the digester, through several pipes discharging above the top of the cone.

In evaluating the performance of an anaerobic digester, the following steps are useful:

1. Check the digester temperature. It should be 90-95°F and should be held constant.

2. Check the digester pH and alkalinity. The pH should be 6.5-7.5 and preferably 6.8-7.2. The bicarbonate alkalinity should be 1,000 mg/l. If the alkalinity has been dropping but the pH is still good, it is an indication of future trouble.

3. Check the digester gas production. The digester should produce 13 to 18 cu ft of gas per pound of volatile solids destroyed and the gas should be at least 50% methane.

If any of these values are outside these ranges, the Control Considerations and Troubleshooting sections should be read. The EPA publication, "Operations Manual - Anaerobic Sludge Digestion" (EPA 430/9-76-001) also is useful.

Control Considerations

Anaerobic primary sludge digestion works in two steps. In the first step, facultative and anaerobic bacteria, (called acid-forming bacteria) convert the organic material in the sludge to organic acids. In the first step, some carbon dioxide is formed, and some stabilization occurs. In the second step, the organic acids are converted to carbon dioxide and methane by anaerobic bacteria called methane-forming bacteria. Most of the stabilization occurs in this step as the organics are converted into gas, water, and a small amount of biological mass.

The anaerobic process is mostly controlled by the methane-forming bacteria. These bacteria grow slowly and have generation times which range from just less than 2 days to about 22 days. Methane formers are very sensitive to pH, sludge composition, and temperature. If the pH drops below 6.0, methane does not form and the organics in the sludge do not decrease. The methane bacteria are very active in the mesophilic range between 80°F and 110°F, and in the thermophilic range between 113°F and 149°F. Almost all digesters in the United States operate within the mesophilic temperature range.

Proper control of anaerobic sludge digestion is based on:

- Food supply
- Time and temperature
- Mixing
- pH and alkalinity
- Gas production

Food Supply--

Digester organisms are most effective when food (raw sludge feed) is provided in small amounts at frequent intervals or on a continuous basis. If too much sludge is added too quickly to the primary digesters, the first (acid-forming) step may produce acid faster than the organisms needed for the second (gas-forming) step can break them down. This results in incomplete digestion, along with causing bad odors.

The sludge fed to the digester should be as thick as possible without clogging pumps and piping. Thin sludge takes up too much digester space and adds excess water which must be heated.

Time and Temperature--

Less detention time usually is needed for complete digestion as temperature increases. Most digesters are designed to operate in the 90-95°F temperature range. If the temperature falls much below this range, more time is needed for digestion. Complete digestion usually occurs in about 15 days in a well mixed, properly heated digester. A temperature change of 2 or 3 degrees can be enough to disturb the balance between the acid and methane formers.

Mixing--

Raw sludge feed should be well mixed with the contents of the primary digester. This helps to assure that the organisms have their food supply, and that the digester temperature is even. The mixing system operation should be closely monitored.

pH and Alkalinity--

Anaerobic digestion is relatively effective within the pH range of 6.5-7.5; however, the optimum range is 6.8-7.2. Outside these ranges, digestion efficiency drops rapidly. Bicarbonate alkalinity should be kept at a minimum level of 1,000 mg/l as calcium carbonate ($CaCO_3$) for good pH control. To determine the bicarbonate alkalinity, both the volatile acid concentration and the total alkalinity must be measured. The bicarbonate alkalinity is then calculated as shown:

Bicarbonate Alkalinity = (Total Alkalinity - 0.8 Volatile Acids)

The 0.8 factor in the above equation is needed to convert the volatile acid units from mg/l as acetic acid to mg/l as $CaCO_3$, the equivalent alkalinity unit. The volatile acid to total alkalinity ratio should be kept below 0.5 for good digester operation.

If digester volatile acid concentration increases, pH is lowered unless bicarbonate alkalinity is added. If alkalinity drops, pH problems can be expected. Alkalinity can be added in many chemical forms. Two of the most popular are lime and sodium bicarbonate. Lime additions beyond a bicarbonate alkalinity of 500-1,000 mg/l will react with carbon dioxide, form a precipitate, and have little effect on digester pH. Sodium bicarbonate does not react with carbon dioxide, and although it is more expensive than lime, smaller amounts are needed because it does not precipitate out of solution.

Chemicals can be added to the digestion system as several points. It is best to feed the chemicals with metering pumps for good control. Chemicals can be added directly to the digester to make big changes in bicarbonate alkalinity. The EPA operations manual on anaerobic digestion contains detailed guidance on chemical addition.

Gas Production--

Gas production is one of the most important measurable digestion parameters. Overall digester performance is reflected by the total volume, rate, and composition of gas produced. Generally, the gas production should be between 13-18 cu ft of digester gas/lb VS destroyed.

Differences in average gas production at a plant usually mean a change in the degree of digestion or a change in the character of the sludge being fed.

Gas from a properly operating digester contains about 65 percent methane and 30 percent carbon dioxide. If more than 35 percent of the gas is carbon dioxide, there is probably something wrong with the digestion process.

As noted in Figures 91 and 92, supernatant (the liquid above the sludge zone) is displaced as sludge is added to the digester. Usually, supernatant is returned to the head of the plant; however, this recycle stream may greatly increase the BOD, SS, and ammonia nitrogen loading on the plant. Table 30 presents typical digester supernatant quality data.

When operations permit, it is good to return supernatant to other plant units where it will have the least bad effect. Usually, it is best to do this when the raw wastewater flow to the plant is at its daily low. It is not good to add the supernatant load during peak flows. Inadequate digestion can result in poor quality supernatant which can lower overall plant performance when recycled.

TABLE 30. SUPERNATANT CHARACTERISTICS FROM ANAEROBIC DIGESTERS

	Primary plants (mg/l)	Trickling filters* (mg/l)	Activated sludge plants* (mg/l)
Suspended solids	200-1,000	500- 5,000	5,000-15,000
BOD_5	500-3,000	500- 5,000	1,000-10,000
COD	1,000-5,000	2,000-10,000	3,000-30,000
Ammonia as NH_3	300- 400	400- 600	500- 1,000
Total phosphorus as P	50- 200	100- 300	300- 1,000

*Includes primary sludge.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Gas recirculation system for mixing undersized with only 5-10 cfm/1,000 cu ft of digester volume.	1. Increase capacity of compressors to provide 20 cfm/1,000 cu ft.
2. No provisions for controlled addition of chemicals for alkalinity control.	2. Install chemical storage tank and metering pump.
3. Pressure relief valves exposed to cold weather are freezing.	3. Place a barrel over the valve with an explosion-proof light bulb inside it.
4. Sludge metering system inaccurate or unreliable.	4. Measure the distance that floating cover travels when pumping in and not removing supernatant. Calculate volume of sludge by this method.
5. High air temperatures cause mechanical mixers to kick out.	5. Protect motor by covering with ventilator housing.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. A rise in the volatile acid/alkalinity (VA/Alk.) ratio.	1a. Hydraulic overload caused by storm infiltration, accidental overpumping, withdrawing too much sludge.	1a. Monitor the following twice daily until problem is corrected: - volatile acids - alkalinity - temperature	1a. If ratio increases to 0.3: (1) add seed sludge from secondary digester (or) (2) decrease sludge withdrawal rate to keep seed sludge in digester (and/or) (3) extend mixing time. (4) check sludge temperatures closely and control heating if needed.
	1b. Organic overload.	1b. Monitor sludge pumping volume, amount of volatile solids in feed sludge; check for increase in septic tank sludge discharged to plant or industrial wastes.	1b. See 1a.
	1c. Discharge of toxic materials to digesters such as heavy metals, sulfides, ammonia.	1c. Volatile acids, pH, gas production; check industrial wastes at source; check for inadequate sludge pumping generating sulfides.	1c. Use any or combination of the following: (1) solids recycle. (2) liquid dilution. (3) decrease feed concentration (4) precipitate heavy metals with sulfur compound. Be sure pH in digester is greater than 7.0. (5) Use iron salts to precipitate sulfides. (6) institute source control program for industrial wastes.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
2. CO_2 in gas starts to increase.	2. VA/Alk. ratio has increased to 0.5.	2a. Waste gas burner.	2. See Item 1 and start adding alkalinity using the volatile acids to calculate the amount.
		2b. Gas analyzer.	
3. pH starts to drop and CO_2 increases to the point (42-45%) that no burnable gas is obtained.	3a. VA/Alk. ratio has increased to 0.8.	3a. Monitor as indicated above.	3a. Add alkalinity.
		3b. Hydrogen sulfide (rotten egg) odor.	3b. Decrease loading to less than 0.01 lb vol. solids/cu ft/day until ratio drops to 0.5 or below.
		3c. Rancid butter odor.	
4. The supernatant quality returning to process is poor, causing plant upsets.	4a. Excessive mixing and not enough settling time.	4a. Withdraw sample and observe separation pattern.	4a. Allow longer periods for settling before withdrawing supernatant.
	4b. Supernatant draw-off point not at same level as supernatant layer.	4b. Locate depth of supernatant by sampling at different depths.	4b. Adjust tank operating level or draw-off pipe.
	4c. Raw sludge feed point too close to supernatant draw-off line.	4c. Determine volatile solids content. Should be close to value found in well mixed sludge and much lower than raw sludge.	4c. Schedule pipe revision for soonest possible time when digester can be dewatered.
	4d. Not withdrawing enough digested sludge.	4d. Compare feed and withdrawal rates - check volatile solids to see if sludge is well-digested.	4d. Increase digested sludge withdrawal rates. Withdrawal should not exceed 5% of digester volume per day.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
			4e. Review feasibility of adding powdered carbon to digesters with consultant or regulatory agency.
5. Supernatant has a sour odor from either primary or secondary digester.	5a. The pH of digester is too low.	5a. See Item 3.	5a. See Item 3.
	5b. Overloaded digester ("rotten egg odor").	5b. See Item 3.	5b. See Item 3.
	5c. Toxic load (rancid butter odor).	5c. See Item 1c.	5c. See Item 1c.
6. Foam observed in supernatant from single stage or primary tank.	6a. Scum blanket breaking up.	6a. Check condition of scum blanket.	6a. Normal condition but should stop withdrawing supernatant if possible.
	6b. Excessive gas recirculation.	6b. 20 CFM/1,000 cu ft is adequate.	6b. Throttle compressor output.
	6c. Organic overload.	6c. Volatile solids loading ratio.	6c. Reduce feeding rate.
7. Bottom sludge too watery or disposal point too thin.	7a. Short-circuiting.	7a. Draw-off line open to Supernatant Zone.	7a. Change to bottom draw-off line.
	7b. Excessive mixing.	7b. Take sample and check how it concentrates in setting vessel.	7b. Shut off mixing for 24-48 hours before drawing sludge.
	7c. Sludge coning, allowing lighter solids to be pulled into pump suction.	7c. Total solids test or visual observation.	7c. (1) "Bump" the pump 2 or 3 times by starting and stopping. (2) Use whatever means available to pump digester contents back through the withdrawal line.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
			7c. (continued) (3) If available, attach a water hose to the pump suction line and force water through it. (Water source must be nonpotable.) Run for no more than 2 or 3 min to avoid diluting the digester
8. Sludge temperature is falling and can not be maintained at normal level.	8a. Sludge is plugging external heat exchanger.	8a. Check inlet and outlet pressure or exchanger.	8a. Open heat exchanger and clean.
	8b. Sludge recirculation line is partially or completely plugged.	8b. Check pump inlet and outlet pressure.	8b. (1) Backflush the line with heated digester sludge. (2) Use mechanical cleaner. (3) Apply water pressure. Do not exceed working line pressure. (4) Add approx. 3 lb/100 gal water of trisodium phosphate (TSP) or commerical degreasers. (Most convenient method is to fill scum pit to a volume equal to the line, add TSP or other chemical, then admit to the line and let stand for an hour.)
	8c. Inadequate mixing.	8c. Check temperature profile in digester.	8c. Increase mixing.
	8d. Hydraulic overload.	8d. Incoming sludge concentration.	8d. See Item 1a.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	8e. Low water feed rate in internal coils used for heat exchange.	8e. (1) Air lock in line. (2) Valve partially closed.	8e. (1) Bleed air relief valve. (2) Upstream valve may be partially closed.
	8f. Boiler burner not firing on digester gas.	8f. (1) Low gas pressure. (2) Unburnable gas due to process upset.	8f. (1) Locate and repair leak. (2) See Item 3.
	8g. Heating coils inside digester have coating.	8g. Temperature of inlet and outlet water is about the same.	8g. (1) Remove coating, may require draining tank. (2) Control water temperature to 130°F maximum.
9. Sludge temperature is rising.	9. Temperature controller is not working properly.	9. Check water temperature and controller setting.	9. If over 120°F, reduce temperature. Repair or replace controller.
10. Recirculation pump not running; power circuits O.K.	10. Temperature override in circuit to prevent pumping too hot water through tubes.	10. Visual check, no pressure on sludge line.	10a. Allow system to cool off. 10b. Check temperature control circuits.
11. Gas mixer feed lines plugging.	11a. Lack of flow through gas line. 11b. Debris in gas lines.	11. Identify low temperature of gas feed pipes or low pressure in the manometer.	11a. Flush out with water. 11b. Clean feed lines and/or valves. 11c. Give thorough service when tank is drained for inspection.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
12. Gear reducer wear on mechanical mixers.	12a. Lack of proper lubrication.	12a. Excessive motor amperage, excessive noise and vibration, evidence of shaft wear.	12a. Verify correct type and amount of lubrication from manufacturer's literature.
	12b. Poor alignment of equipment.	12b. See Item 15	12b. Correct imbalances caused by accumulation of material on the internal moving parts.
13. Shaft seal leaking on mechanical mixer.	13. Packing dried out or worn.	13. Evidence of gas leakage (evident odor of gas).	13a. Follow manufacturer's instructions for repacking. 13b. Replace packing any time the tank is empty if it is not possible when unit is operating.
14. Wear on internal parts of mechanical mixer.	14. Grit or misalignment.	14. Visual observation when tank is empty, compare with manufacturer's drawings for original size. Motor amperage will also go down as moving parts are worn away and get smaller.	14. Replace or rebuild - experience will determine the frequency of this operation.
15. Imbalance of internal parts because of accumulation of debris on the moving parts of mechanical mixers (large-diameter impellers or turbines would be affected most).	15. Poor comminution and/or screening.	15. Vibration, heating of motor, excessive amperage, noise.	15a. Reverse direction of mixer if it has this feature. 15b. Stop and start alternately. 15c. Open inspection hole and visually inspect. 15d. Draw down tank and clean moving parts.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
16. Rolling movement of scum blanket is slight or absent.	16a. Mixer is off.	16a. Mixer switch or timer.	16a. May be normal if mixers are set on a timer. If not and mixers should be operating, check for malfunction.
	16b. Inadequate mixing.		16b. Increase mixing.
	16c. Scum blanket is too thick.	16c. Measure blanket thickness.	16c. See Items 18 and 19.
17. Scum blanket is too high.	17. Supernatant overflow is plugged.	17. Check gas pressure, it may be above normal or relief valve may be venting to atmosphere.	17. Lower contents through bottom drawoff then rod supernatant line to clear plugging.
18. Scum blanket is too thick.	18. Lack of mixing, high grease content.	18. Probe blanket for thickness through thief hole or in gap beside floating cover.	18a. Break up blanket by using mixers.
			18b. Use sludge recirculation pumps and discharge above the blanket.
			18c. Use chemicals to soften blanket.
			18d. Break up blanket physically with pole.
			18e. Tank modification.
19. Draft tube mixers not moving surface adequately.	19. Scum blanket too high and allowing thin sludge to travel under it.	19. Rolling movement on sludge surface.	19a. Lower sludge level to 3-4" above top of tube allowing thick material to be pulled into tube - continue for 24-48 hours.
			19b. Reverse direction (if possible)

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
20. Gas is leaking through pressure relief valve (PRV) on roof.	20. Valve not seating properly or is stuck open.	20. Check the manometer to see if digester gas pressure is normal.	20. Remove PRV cover and move weight holder until it seats properly. Install new ring if needed. Rotate a few times for good seating.
21. Manometer shows digester gas pressure is above normal.	21a. Obstruction or water in main burner gas line.	21a. If all use points are operating and normal, then check for a waste gas line restriction or a plugged or stuck safety device.	21a. Purge with air, drain condensate traps, check for low spots. Care must be taken not to force air into digester.
	21b. Digester PRV is stuck shut.	21b. Gas is not escaping as it should.	21b. Remove PRV cover and manually open valve, clean valve seat.
	21c. Waste gas burner line pressure control valve is closed	21c. Gas meters show excess gas is being produced, but not going to waste gas burner.	21c. Relevel floating cover if gas escapes around dome due to tilting.
22. Manometer shows digester gas pressure below normal.	22a. Too fast withdrawal causing a vacuum inside digester.	22a. Check vacuum breaker to be sure it is operating properly.	22a. Stop supernatant discharge and close off all gas outlets from digester until pressure returns to normal.
	22b. Adding too much lime.	22b. Sudden increase in CO_2 in digester gas.	22b. Stop addition of lime and increase mixing.
23. Pressure regulating valve not opening as pressure increases.	23a. Inflexible diaphragm.	23a. Isolate valve and open cover.	23a. If no leaks are found (using soap solution) diaphragm may be lubricated and softened using neats-foot oil.
	23b. Ruptured diaphragm.	23b. Visual inspection.	23b. Ruptured diaphragm would require replacement.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
24. Yellow gas flame from waste gas burner.	24. Poor quality gas with a high CO_2 content.	24. Check CO_2, content will be higher than normal.	24. Check concentration of sludge feed - may be too dilute. If so, increase sludge concentration. See Items 2 and 3.
25. Gas meter failure (propeller or lobe type).	25a. Debris in line.	25a. Condition of gas line.	25a. Flush with water, isolating digester and working from digester toward points of usage.
	25b. Mechanical failure.	25b. Fouled or worn parts.	25b. Wash with kerosene or replace worn parts.
26. Gas meter failure (bellows type).	26a. Inflexible diaphragm.	26a. Isolate valve and open cover.	26a. If no leaks are found (using soap solution) diaphragm may be lubricated and softened using neats-foot oil.
	26b. Ruptured diaphragm.	26b. Visual inspection.	26b. Replace diaphragm.
			26c. Metal guides may need to be replaced if corroded.
27. Gas pressure higher than normal during freezing weather.	27a. Supernatant line plugged.	27a. Supernatant overflow lines.	27a. Check every two hours during freezing conditions, inject steam, protect line from weather by covering and insulating overflow box.
	27b. Pressure relief stuck or closed.	27b. Weights on pressure relief valves.	27b. If freezing is a problem, apply light grease layer impregnated with rock salt.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
28. Gas pressure lower than normal.	28a. Pressure relief valve or other pressure control devices stuck open.	28a. Pressure relief valve and devices.	28a. Manually operate vacuum relief and remove corrosion if present and interferring with operation.
	28b. Gas line or hose leaking.	28b. Gas line and/or hose.	28b. Repair as needed.
29. Leaks around metal covers.	29. Anchor bolts pulled loose and/or sealing material moved or cracking.	29. Concrete broken around anchors, tie-downs bent, sealing materials displaced.	29. Repair concrete with fast sealing concrete repair material. New tie-downs may have to be welded onto old ones and redrilled. Tanks should be drained and well ventilated for this procedure. New sealant material should be applied to leaking area.
30. Suspected gas leaking through concrete cover.	30. Freezing and thawing causing widening of construction cracks.	30. Apply soap solutions to suspected area and check for bubbles.	30. If this is a serious problem, drain tank, clean cracks and repair with concrete sealers. Tanks should be drained and well ventilated for this procedure.
31. Floating cover tilting, little or no scum around the edges.	31a. Weight distributed unevenly.	31a. Location of weights.	31a. If moveable ballast or weights are provided, move them around until the cover is level. If no weights are provided, use a minimal number of sand bags to cause cover to level up. (Note: pressure relief valves may need to be reset if significant amounts of weight are added.)

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	31b. Water from condensation or rain water collecting on top of metal cover in one location.	31b. Check around the edges of the metal cover. (Some covers with insulating wooden roofs have inspection holes for this purpose.)	31b. Use siphon or other means to remove the water. Repair roof if leaks in the roof are contributing to the water problem.
32. Floating cover tilting, heavy thick scum accumulating around edges.	32a. Excess scum in one area, causing excess drag.	32a. Probe with a stick or some other method to determine the condition of the scum.	32a. Use chemicals or degreasing agents such as Digest-aide or Sanfax to soften the scum, then hose down with water. Continue on regular basis every two to three months or more frequently if needed.
	32b. Guides or rollers out of adjustment.	32b. Distance between guides or rollers and the wall.	32b. Soften up the scum (as in 32a) and readjust rollers for guides so that skirt doesn't rub on the walls.
	32c. Rollers or guides broken.	32c. Determine the normal position if the suspected broken part is covered by sludge. Verify correct location using manufacturer's information and/or prints if necessary.	32c. Drain tank if necessary taking care as cover lowers to corbels not to allow it to bind or come down unevenly. It may be necessary to use a crane or jacks in order to prevent structural damage with this case.
33. Cover binding even through rollers and guides are free.	33. Internal guide or guy wires are binding or damaged (some covers are built like umbrellas with guides attached to the center column).	33. Lower down to corbels. Open hatch and using breathing apparatus & explosionproof light, if possible, inspect from the top. If cover will not go all	33. Drain and repair, holding the cover in a fixed position if necessary.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
		33. (continued) the way down, it may be necessary to secure in one position with a crane or by other means to prevent skirt damage to sidewalls.	

AEROBIC DIGESTION

Process Description

Aerobic digestion is separate aeration of waste primary sludge, waste biological sludge, or a combination of these in an open or closed tank. It is usually used to stabilize excess activated sludges, but has also been used to stabilize both primary and activated sludge solids. Figure 94 is a schematic of an aerobic digestion system.

Some plants use a separate sedimentation tank (Figure 94) and others use a one-tank, batch-type system, where the sludge is aerated and mixed for a long time, then settled and decanted in the same tank. Aerobic digesters are often designed as rectangular aeration tanks and use conventional aeration systems. In the past, aerobic digestion has been used mostly at small plants on either contact stabilization sludge or on mixtures of primary and activated sludge. Aerobic digesters in small package plants often are segments of the circular package plant.

Recently, pure oxygen aeration has been used in aerobic digester design. In conventional digesters, influent sludge VSS concentrations must be no more than 3 percent for retention times of 15 to 20 days. Above this percentage, oxygen from atmospheric air cannot be dissolved into the digesting sludge fast enough to keep the biological reaction going. However, pure oxygen can dissolve in sludge nearly five times as fast as can oxygen from the air. As a result, pure oxygen aeration allows a more concentrated sludge feed. By feeding a more concentrated sludge, either the sludge retention time (SRT) can be longer or the total pounds of sludge digested per day can be increased. Pure oxygen digesters usually are closed so that oxygen is not lost to the atmosphere.

Typical Design Criteria and Performance Evaluation

Table 31 summarizes typical design criteria, and Table 32 shows operating data for batch-type digestion of mixtures of primary and waste activated sludge.

Usually, about 15 days of detention time is provided for excess biological sludge, and more time when primary sludge is included. Loadings normally are from 0.1 to 0.2 lb VSS/ft^3/day, with volatile suspended solids being reduced by 40-50 percent. The supernatant may contain as little as 10-30 mg/l BOD, 10 mg/l ammonia nitrogen, and from 50-100 mg/l nitrate-nitrogen. When nitrification occurs, both pH and alkalinity are reduced.

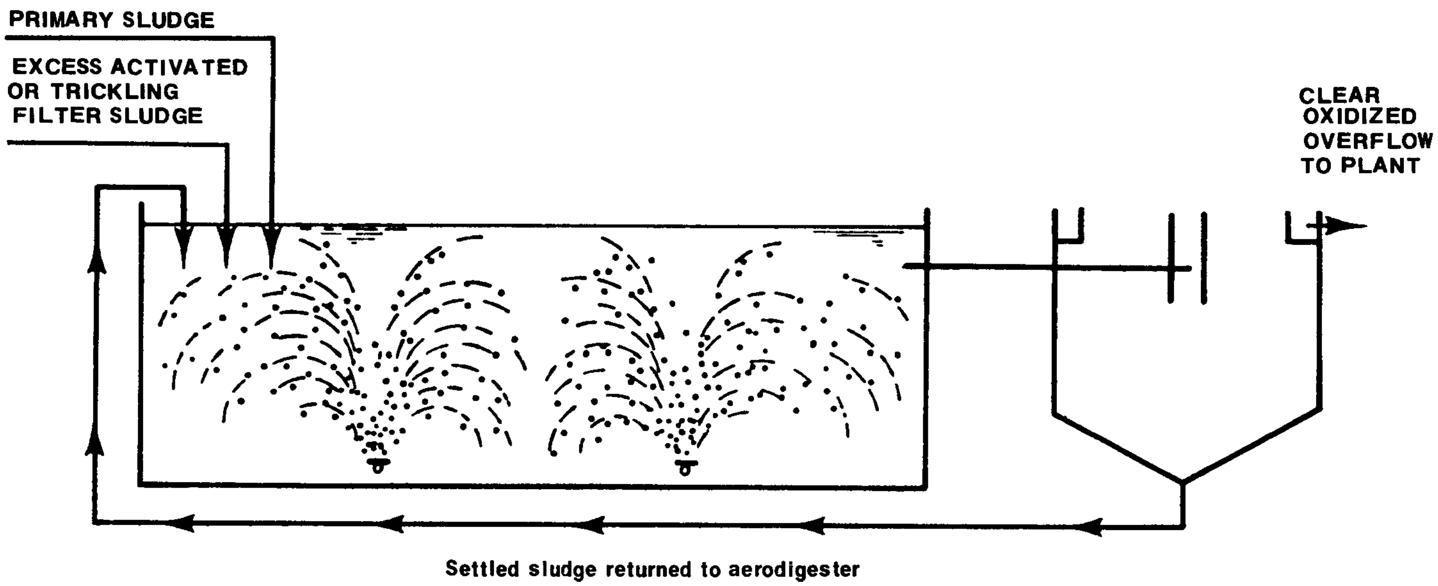


Figure 94. Schematic of aerobic digestion system.

TABLE 31. AEROBIC DIGESTION DESIGN PARAMETERS

Parameter	Value	Remarks
Solids retention time, days	10-15[a]	Depending on temperature, type of sludge, etc.
Solids retention time, days	15-20[b]	
Volume allowance, cu ft/capita	3-4	
VSS loading, pcf/day	0.024-0.14	Depending on temperature, type of sludge, etc.
Air requirements		
Diffuser system, cfm/1,000 cu ft	20-35[a]	Enough to keep the solids in suspension and maintain a DO between 1-2 mg/l.
Diffuser system, cfm/1,000 cu ft	>60[b]	
Mechanical system, hp/1,000 cu ft	1.0-1.25	This level is governed by mixing requirements. Most mechanical aerators in aerobic digesters require bottom mixers for solids concentration greater than 8,000 mg/l, especially if deep tanks (>12 feet) are used.
Minimum DO, mg/l	1.0-2.0	
Temperature, °C	>15	If sludge temperatures are lower than 15°C, additional detention time should be provided so that digestion will occur at the lower biological reaction rates.
VSS reduction, percent	35-50	
Tank design		Aerobic digestion tanks are open and generally require no special heat transfer equipment or insulation. For small treatment systems (0.1 mgd), the tank design should be flexible enough so that the digester tank can also act as a sludge thickening unit. If thickening is to be utilized in the aeration tank, sock type diffusers should be used to minimize clogging.
Power requirement, BHP/10,000 Population Equivalent	8-10	

[a]Excess activated sludge alone.

[b]Primary and excess activated sludge, or primary sludge alone.

TABLE 32. BATCH-TYPE AEROBIC SLUDGE DIGESTION OPERATING DATA FOR MIXTURES OF PRIMARY AND WASTE ACTIVATED SLUDGE

Detention Time	Temperature	VSS Reduction	pH	Alkalinity	NH_3-N	NO_2-N	NO_3-N
days	deg C	percent		mg/l	mg/l	mg/l	mg/l
5	15	21	7.6	510	54	Trace	None
10	15	32	7.6	380	3.2	1.28	64
30	15	40.5	6.6	81	4.0	0.36	170
60	15	46	4.6	23	38	0.23	835
5	20	24	7.6	590	54	Trace	None
10	20	41	7.6	390	4.9	0.59	60
15	20	43	7.8	560	7.0	2.27	29
30	20	44	5.4	31	28	0.19	275
60	20	46	5.1	35	7.0	0.51	700
5	35	26	7.9	630	14	0.18	None
10	35	45	8.0	540	10.0	0.08	None

To evaluate the performance of the aerobic digester:

1. Check the dissolved oxygen. It should be at least 1 mg/l.

2. Check the sludge retention time (see Activated Sludge Chapter for example). It should be 10-15 days for waste activated sludge and 15-20 days for primary and waste activated sludge.

3. Check data on VSS reduction. It should be in the range of 40-50 percent. If temperatures are low ($<15^{o}C$), reductions may fall to 35-40 percent unless very long detention times are provided.

4. Check digester pH, it should be above 6.5.

If the above checks show unusual values, refer to the Troubleshooting Guide.

Control Considerations

The rate of aerobic digestion is affected by temperature and SRT. The rate of a biological reaction will increase as the temperature increases. A rule of thumb is that the reaction rate doubles for each $10^{o}C$ rise in temperature. Unfortunately, actual aerobic digestion plant experience does not support fully this rule of thumb. Because of long detention times and tank sizes, aerobic digestion usually occurs at ambient temperatures. However, the energy released by the process can cause temperatures to rise if the digester is covered. The effects of SRT on the digestion process are shown in Figure 95.

The normal operating procedures for a batch-feed digester are as follows:

1. Turn off aeration equipment and allow the solids to settle. This solid-liquid separation should not be longer than several hours or else air diffusers may become clogged.

2. Decant as much supernatant as possible. Sample a portion of the supernatant for quality control.

3. Remove the thickened, digested sludge. The removed sludge should be sampled for quality control.

4. Add the sludge feed volume. Sludge feed should be added over a period of time, if possible. The volume and concentration of sludge added each day should be as uniform as possible. Sludge settling and removal may be performed once a week, while sludge addition or feed is practiced daily. The sludge volume in the digester therefore will increase each day until the next decanting and removal period.

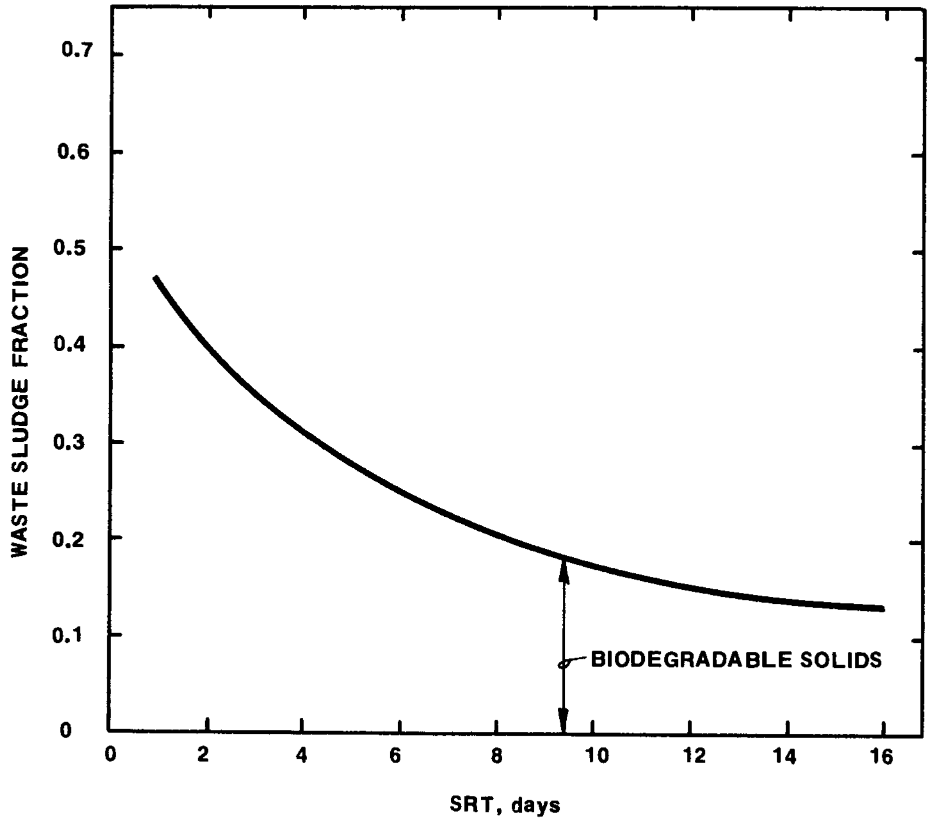


Figure 95. Effect of SRT on reduction of biodegradable solids by aerobic digestion.

For continuous feed digesters, the operator should adjust the rate of settled sludge return to get the best return sludge concentration and supernatant quality. He should watch carefully the settling tank inlet and outlet flow to prevent short-circuiting and turbulence.

Aerobic digestion is a self-regulating process, except when the process is overloaded or the equipment does not operate. Routine checks should include periodic looks at electrical and mechanical equipment such as seals, packings, timers, and relays.

Common Design Shortcomings and Ways to Compensate

	Shortcoming		Solution
1.	No provisions made for pH control resulting in undesirably low pH in aerobic digester.	1.	Install system to feed sodium bicarbonate to digester influent or alkaline materials such as sodium hydroxide or lime to digester.
2.	Air diffusers plug frequently.	2.	Replace diffusers with sock-type devices or course bubble diffusers.
3.	Solids depositing and accumulating in digester due to poor mixing.	3.	Improve operation of grit chamber, install grit separator on sludge feed stream, or increase mixing in digester by adding mechanical mixers to supplement aerators.
4.	No provision for solids separation.	4.	Add clarifier downstream or use batch operation as described in Control Consideration Section.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Excessive foaming.	1a. Organic overload.	1a. Organic load.	1a. (1) Reduce feed rate. (2) Increase solids in digester by decanting and recycling solids.
	1b. Excessive aeration.	1b. Dissolved oxygen.	1b. (1) Use surface sprays. (2) Reduce aeration rate. (3) Use a defoaming agent.
2. Low dissolved oxygen.	2a. Diffusers clogging.	2a. Decant digester, withdraw sludge and inspect diffusers.	2a. Clean diffusers or replace with coarse bubble diffusers or sock-type devices.
	2b. Liquid level not proper for mechanical aeration.	2b. Check equipment specifications.	2b. Establish proper liquid level.
	2c. Blower malfunction.	2c. Air delivery rate, pipeline pressure, valving.	2c. Repair pipe leaks, set valves in proper position, repair blower.
	2d. Organic overload.	2d. See 1a.	
3. Sludge has objectionable odor.	3a. Inadequate SRT.	3a. SRT.	3a. See 1a.
	3b. Inadequate aeration.	3b. D.O. should exceed 1 mg/l.	3b. Increase aeration or reduce feed rate.
4. Ice formation damaging mechanical aerators.	4. Extended freezing weather.	4. Check digester surface for ice block formation.	4. Break and remove ice before it causes damage.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. pH in digester has dropped to undesirable level.	5a. Nitrification is occurring and waste-water alkalinity is low. 5b. In covered digester CO_2 is accumulating in air space and is dissolving into sludge	5a. Alkalinity and nitrates in digester supernatant.	5a. Add sodium bicarbonate to feed sludge or lime or sodium hydroxide to digester. 5b. Vent and scrub CO_2.

CENTRIFUGATION

Description

Solids-liquid separation occurs in a centrifuge by rotating the liquid at high speeds to cause separation by gravitational forces.

There are many types of centrifugal equipment, for different uses in industry. However, the solid bowl centrifuge is the most often used type for dewatering of sewage sludge. The solid bowl-conveyor sludge dewatering centrifuge assembly (Figure 96) has a rotating unit with a bowl and conveyor. The bowl, or shell, is supported between two sets of bearings. The unit has a conical section at one end that acts as a drainage deck. The conveyor screw pushes the sludge solids to outlet ports and then to a sludge cake discharge hopper. Sludge slurry enters the rotating bowl through a feed pipe leading into the hollow shaft of the rotating screw conveyor. The sludge is distributed through ports into a pool inside the rotating bowl.

As the liquid sludge flows through the hollow shaft toward the overflow devices, finer solids settle to the rotating bowl wall. The screw conveyor pushes the solids to the conical section where the solids are forced out of the water, and free water drains from the solids back into the pool.

Most solid bowl centrifuges use countercurrent flow as pictured in Figure 96 and are called "countercurrent" centrifuges. Recently, a "concurrent" centrifuge design has also been introduced in which the solids and liquid flow in the same direction. These units are much like the countercurrent design except there are no effluent ports in the bowl head. Instead, the clarified effluent is removed by a skimmer near the bowl and drainage deck.

In addition to dewatering sludges, centrifuges have been used to separate impurities from the lime sludges resulting from some phosphorus removal processes. Centrifuges allow efficient recovery and reuse of the lime.

Typical Design Criteria and Performance Evaluation

Loading Rates - The sizing of centrifuge equipment depends on sludge feed rate, solids characteristics, temperature and condition processes. Sludge feed rate is the parameter most often used for sizing centrifuges. Single centrifuge capacities range from 4 gpm to about 250 gpm. Typical quantities of sludge are shown in Table 33.

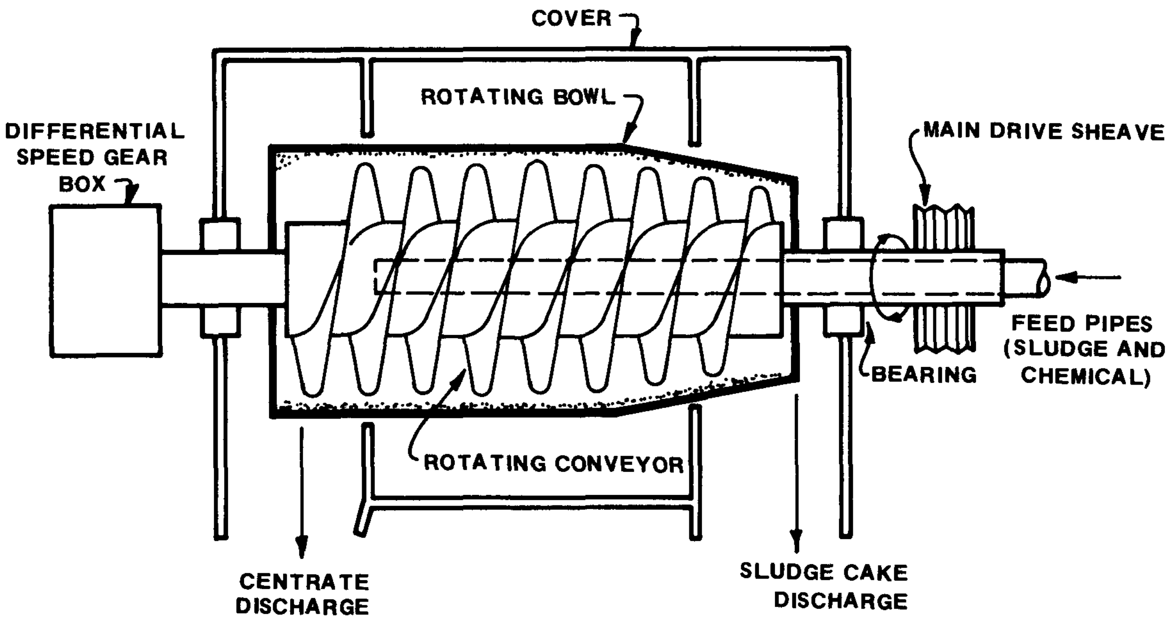


Figure 96. Continuous countercurrent solid bowl-conveyor discharge centrifuge.

TABLE 33. TYPICAL SLUDGE QUANTITIES

Sludge type	Total solids (wt percent of sludge)	Sludge solids (lb/mil gal) total solids	Sludge volume (gpm/mgd)
Primary	5	1151	1.9
Primary + $FeCl_3$	2	2510	11.5
Primary + low lime	5	4979	8.3
Primary + high lime	7.5	9807	10.9
Primary + WAS	2	2096	8.7
Primary + (WAS + $FeCl_3$)	1.5	2685	14.9
(Primary + $FeCl_3$) + WAS	1.8	3144	14.6
WAS	1.0	945	7.9
WAS + $FeCl_3$	1.0	1535	12.8
Digested primary	8.0	806	0.8
Digested primary + WAS	4.0	1226	2.6
Digested primary + WAS + $FeCl_3$	4.0	1817	3.8
Tertiary alum	1.0	700	5.8
Tertiary high lime	4.5	8139	15.0
Tertiary low lime	3.0	3311	9.2

Table 34 shows expected performance for centrifugation based on sludge type.

There are several variables that affect the performance of solid bowl centrifuges. Bowl speed is one of the most important since centrifugal force speeds up the separation process. At any given pool depth, an increase in bowl speed provides more gravity-settling force, providing greater clarification. For many years, G values for a solid bowl machine were about 3,000. In recent years, units which operate at G=700 have been developed. These "low" speed units work just as well as the high speed units only with less power consumption.

The use of polymers, has allowed more materials to be dewatered by centrifuges. The degree of solids recovery can be controlled over wide ranges depending on the amount of coagulating chemical used. When flocculation aids are used, wetter sludge cake usually result

Heat treatment also is used for conditioning before centrifuging. Heat treated sludges will dewater to 35-45% solids with no polymer required for 85% capture. Recovery of 92-99% of the solids from heat treatment (primary) sludges is possible with polymer dosage of 2-5 lbs per ton of dry solids. Dewatering of heat treated mixtures of activated sludge and raw primary sludge can produce cake solids of 40% at 95% recovery without chemicals. Dewatering of heat treated activated sludges alone has achieved 35% cake solids at 95% recovery without chemicals.

In evaluating performance:

1. Check the solids recovery against that shown as typical in Table 34. Solids recovery is the ratio of cake solids to feed solids for equal sampling times. It can be calculated with suspended solids and flow data or with only suspended solids data. The centrate solids must be corrected if chemicals are fed to the centrifuge, since

$$\text{Recovery} = \frac{\left(\text{wet cake flow, } \frac{\text{lb}}{\text{hr}}\right)(\text{cake solids, \%})\ (100)}{\left(\text{wet feed flow, } \frac{\text{lb}}{\text{hr}}\right)(\text{feed solids, \%})}$$

$$\text{Recovery} = \frac{(\text{cake solids, \%})\ (\text{feed solids, \% - centrate solids, \%})\ (100)}{(\text{feed solids, \%})\ (\text{cake solids, \% - centrate solids, \%})}$$

The centrate is diluted by the extra water from the chemical and chemical dilution water. The measured centrate solids, therefore, are less than the actual solids would be without the added water from the chemical feed. The correction for chemical addition is performed as follows:

TABLE 34. TYPICAL SOLID BOWL CENTRIFUGE PERFORMANCE

	Sludge cake characteristics		
Wastewater sludge type	Solids (%)	Solids recovery (%)	Polymer addition
Raw or digested primary	28-35	70-90	no
Raw or digested primary, plus trickling filter humus	20-30	80-95 60-75	5-15 lbs/ton no
Raw or digested primary, plus activated sludge	15-30	80-95 50-65	5-20 lbs/ton no
Activated sludge	8-9	80-85	5-10 lbs/ton
Oxygen activated sludge	8-10	80-85	3-5 lbs/ton
High-lime sludges	50-55	90	no
Lime classification	40	70	no

$$\text{correction factor} = \frac{(\text{feed rate, gpm})+(\text{chemical flow, gpm})+(\text{dilution water, gpm})}{\text{feed rate, gpm}}$$

corrected centrate solids = (measured centrate solids) (correction factor)

Solids feed rate is the dry solids feed to the centrifuge.

$$(\text{feed flow, gpm}) \left(\frac{8.33\ \text{lb}}{\text{gal}}\right) \left(\frac{\text{feed solids, \%}}{100}\right) \left(\frac{60\ \text{min}}{\text{hr}}\right)$$

2. Check the solids concentration of the cake against the typical values shown in Table 34. If the performance is not adequate, refer to the Troubleshooting Section.

Control Considerations

High centrate turbidity may result in fine solids build-up in the treatment process and loss of solids in the plant effluent (see Troubleshooting Guide, Item 1). Low turbidity usually results in lower cake solids since the fine solids are now being kept in the cake. As a result, there must be a careful balance between centrate clarity and cake solids.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Improper materials used and corrosion problems result.	1. Replace components affected with proper materials.
2. Washwater supply not strained, plugs nozzles.	2. Install washwater strainer.
3. No means for removal of conveyor.	3. Install overhead hoist.
4. Rigid piping connections to centrifuge.	4. Install flexible connections.
5. Lack of adequate degritting causes excessive wear.	5. Install degritting system.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Centrate clarity inadequate.	1a. Feed rate too high.	1a. Flow records.	1a. Reduce flow.
	1b. Wrong plate dam position.	1b. Setting of dam.	1b. Increase pool depth to improve clarity.
	1c. Conveyor flights worn.	1c. Vibration; excessive solids buildup in machine.	1c. Repair or replace conveyor.
	1d. Speed too high.	1d. Pulley setting.	1d. Change pulley setting for lower speed.
	1e. Feed solids too high.	1e. Spin test on feed sludge - should be <40% by volume.	1e. Dilute feed sludge.
	1f. Chemical conditioning improper.	1f. Chemical feed rate.	1f. Change chemical dosage.
2. Cake dryness inadequate.	2a. Feed rate too high.	2a. Flow records.	2a. Reduce flow.
	2b. Wrong plate dam position.	2b. Setting of dam.	2b. Decrease pool depth to improve dryness.
	2c. Speed too low.	2c. Pulley setting.	2c. Change pulley setting for higher speed.
	2d. Chemical conditioning too high.	2d. Chemical feed rate.	2d. Decrease chemical dosage.
	2e. Influent too warm.	2e. Influent temperature.	2e. Reduce influent temperature.
3. Centrifuge torque control keeps tripping.	3a. Feed rate too high.	3a. Flow records.	3a. Reduce flows.
	3b. Feed solids too high.	3b. Spin test on feed sludge - should be <40% by volume.	3b. Dilute feed sludge.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	3c. Foreign material such as tramp iron in machine.	3c. Inspect interior.	3c. Remove conveyor and remove foreign material.
	3d. Gear unit is mis-aligned.	3d. Vibration.	3d. Correct alignment.
	3e. Gear unit has faulty bearing, gear, or spline.	3e. Inspect gear unit.	3e. Replace faulty parts.
4. Excessive vibration.	4a. Improper lubrication.	4a. Check lubrication system.	4a. Correct lubrication.
	4b. Improper adjustment of vibration isolators.	4b. Vibration isolators.	4b. Adjust isolators.
	4c. Discharge funnels may be contacting centri-fuge.	4c. Position of funnels.	4c. Reposition slip joints at funnels.
	4d. Portion of conveyor flights may be plug-ged with solids causing imbalance.	4d. Interior of machine.	4d. Flush out centrifuge.
	4e. Gear box improperly aligned.	4e. Gear box alignment.	4e. Align gear box.
	4f. Pillow block bearings damage.	4f. Inspect bearings.	4f. Replace bearings.
	4g. Bowl out of balance.		4g. Return rotating parts to manu-facturer for rebalance.
	4h. Parts not tightly assembled.		4h. Tighten parts.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	4i. Uneven wear of conveyor.	4i. Inspect conveyor.	4i. Resurface, rebalance.
5. Sudden increase in power consumption.	5a. Contact between bowl and accumulated solids in centrifuge case.	5a. Solids plows; look for polished area on outer bowl.	5a. Apply hard surfacing to areas with wear.
	5b. Effluent pipe plugged.	5b. Check for free discharge of solids	5b. Clear effluent pipe.
6. Gradual increase in power consumption.	6a. Conveyor blade wear.	6a. Conveyor condition.	6a. Resurface blades.
7. Spasmodic, surging solids discharge.	7a. Pool depth too low.	7a. Plate dam position.	7a. Increase pool depth.
	7b. Conveyor helix rough.	7b. Improper hard surfacing or corrosion.	7b. Refinish conveyor blade areas.
	7c. Feed pipe (if adjustable) too near drainage deck.		7c. Move feed pipe to effluent end.
	7d. Machine vibration excessive (see Item 4).		
8. Centrifuge shuts down (or will not start).	8a. Blown fuses.	8a. Fuses.	8a. Replace fuses, flush mahcine.
	8b. Overload relay tripped.	8b. Overload relay.	8b. Flush machine, reset relay.
	8c. Motor overheated, thermal protectors tripped.	8c. Thermal protectors.	8c. Flush machine, reset thermal protectors.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	8d. Torque control tripped.	8d. See Item 3.	
	8e. Vibration switch tripped.	8e. See Item 4.	

VACUUM FILTRATION

Process Description

The vacuum filter is a device for separating solid matter from liquid. A vacuum filter has a round drum which rotates partially submerged in a tank of sludge. The filter drum is divided into sections by seal strips. A vacuum is applied between the drum deck and filter medium causing filtrate to be removed, and filter cake to stay on the medium. In the drum filter pictured in Figure 97, the cake of dewatered sludge is removed by a fixed scraper blade. There are other designs which use different methods for sludge removal.

Typical Design Criteria and Performance Evaluation

Table 35 lists design data and expected performance for vacuum filtration of different types of sludges. In evaluating performance:

1. Check the yield of the vacuum filter.

The performance of vacuum filters may be evaluated by the yield, the efficiency of solids removal and the cake characteristics. Yield is the most common measure of filter performance. The yield describes the filter output and is expressed in terms of pounds of dry total solids in the filter cake per square foot of filter area, per hour. Table 36 can be used to determine the filter area knowing the diameter of the drum and the length of the filter face.

2. Check the solids capture.

The second measure of filter performance is the efficiency of solids removal (the percentage of feed solids recovered in the filter cake). Solids removals on vacuum filters range from about 85 percent for coarse mesh media to 99 percent with close weave, long nap media. The recycled filtrate solids cause a load on the plant treatment units, and should normally be kept as low as possible. It may be necessary to reduce the filter efficiency to have a higher filter output in order to keep up with sludge production.

3. Check the filter cake solids content.

The filter cake quality is another measure of filter performance, depending upon cake moisture and heat value. Cake solids content varies from 20-40 percent by weight, depending on the type of sludge and the filter cycle time. Producing a very dry cake does not always mean good filter performance. Cake moisture should be adjusted to the method of final disposal. It is not efficient to dry the cake more than is neces-

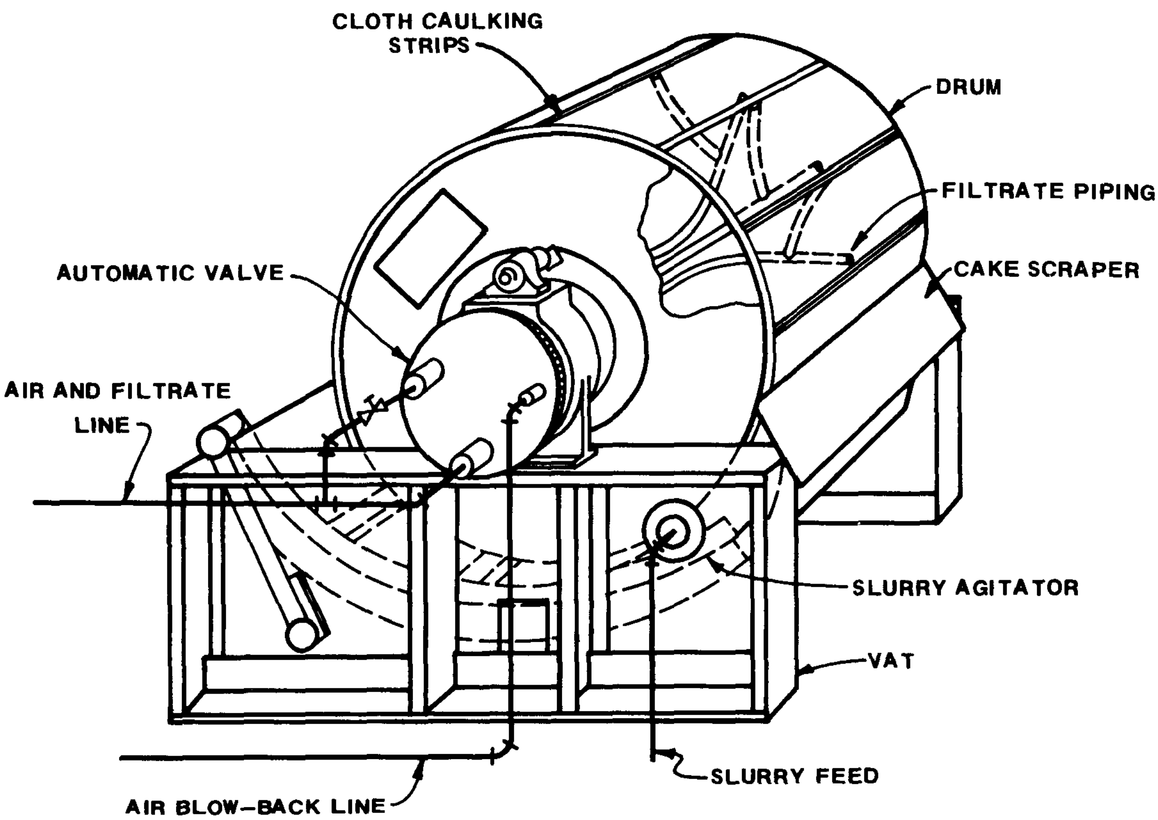


Figure 97. Cutaway view of a rotary drum vacuum filter.

TABLE 35. TYPICAL DESIGN AND PERFORMANCE DATA FOR VACUUM FILTRATION SYSTEMS

Sludge type	Design assumptions	Percent solids to VF	Typical loading rates, (psf/hr)	Percent solids VF cake
Primary	Thickened to 10% solids Polymer conditioned	10	8-10	25-38
Primary + $FeCl_3$	85 mg/l $FeCl_3$ dose Lime conditioning Thickening to 2.5% solids	2.5	1.0-2.0	15-20
Primary + low lime	300 mg/l lime dose Polymer conditioned Thickened to 15% solids	15	6	32-35
Primary + high lime	600 mg/l lime dose Polymer conditioned Thickened to 15% solids	15	10	28-32
Primary + WAS	Thickened to 8% solids Polymer conditoned	8	4-5	16-25
Primary + (WAS + $FeCl_3$)	Thickened to 8% solids $FeCl_3$ & lime conditioned	8	3	20
(Primary + $FeCl_3$) + WAS	Thickened primary sludge to 2.5% Flotation thickened WAS to 5% Dewater blended sludges	3.5	1.5	15-20
Waste activated sludge (WAS)	Thickened to 5% solids Polymer conditioned	5	2.5-3.5	15
WAS + $FeCl_3$	Thickened to 5% solids Lime + $FeCl_3$ conditioned	5	1.5-2.0	15
Digested primary	Thickened to 8-10% solids Polymer conditioned	8-10	7-8	25-38
Digested primary + WAS	Thickened to 6-8% solids Polymer conditioned	6-8	3.5-6	14-22
Digested primary + (WAS + $FeCl_3$)	Thickened to 6-8% solids $FeCl_3$ + lime conditioned	6-8	2.5-3	16-18
Tertiary alum	Diatomaceous earth precoat	0.6-0.8	0.4	15-20

TABLE 36. FILTERING AREA OF DRUM FILTERS IN SQUARE FEET

Diameter	Face (in ft)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
3'	9.4	18.8	28.2	37.7	47.1	56.5														
4½'		---	42.4	56.5	70.6	84.8	98.9	103	127											
6'				---	94.2	113	132	151	170	188	207	226								
8'						---	176	201	226	251	277	302	327	352	377	402				
10'								---	283	314	345	377	409	440	471	502	534	565	596	628
12'										377	415	452	490	528	565	603	641	679	716	754

sary. When incineration is practiced, a raw sludge cake having a high moisture content can be burned without auxiliary fuel because of the higher volatile content. On the other hand, a digested sludge cake will have to be dryed to burn well without make-up heat, since the sludge has low volatile solids content.

The effect of heat treatment before vacuum filtration is to make all types of sludges about equally dewaterable. Heat treatment produces a sludge that dewaters very easily. Raw primary sludges have been dewatered at rates as high as 40 psf/hr and waste activated sludges at 7 psf/hr. Mixtures of raw primary and secondary sludges that are heat treated should produce yields well over 10 psf/hr.

Control Considerations

The operator should determine the best conditioning chemical for the feed sludge. If the character of the feed sludge changes much, the conditioning agents should be evaluated after each change.

Once an effective conditioner has been selected, the next task is to see how performance is affected by machine variables and chemical dosage rates. One or more of the most sensitive variables should be held constant and the others changed one-by-one to develop a series of performance curves. The performance curves are checked to obtain proper operating procedures for the best sludge dewatering. These relationships should be checked periodically to see if small changes in the operating procedures are needed.

Usually, filtrate is sent to the primary treatment process where the most solids will be retained. When filtrate quality is poor, large amounts of fine particles build-up in the plant and reduce treatment efficiencies. In a plant with an activated sludge process, the filtrate may be directed to a flotation or thickener process.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Improper filter media specified resulting in (a) filter blinds or (b) inadequate solids capture occurs.	1. Run filter leaf tests with different media. Replace media with best one.
2. Improper chemical conditioning system specified.	2. Run filter leaf tests to determine proper conditioning chemical and dosage.
3. No provisions for cleaning of filtrate lines.	3. Install unions in filtrate line to permit ready cleaning.
4. Cake does not release well from belt-type filter.	4. Add doctor blade to supplement discharge roll.

Shortcoming	Solution
5. Filtrate pumps are easily air bound.	5. Install an equalizing line from high point of receiver to the eye of the pump.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. High solids in filtrate	1a. Improper coagulant dosage.	1a. Coagulant dosage.	1a. Change coagulant dosage.
	1b. Filter media blinding.	1b. Coagulant feeder calibration.	1b. Recalibrate coagulant feeder.
		1c. Visually inspect media.	1c. Synthetic cloth - detergent and steam wash steel coils - acid clean cloth - water wash or exchange for new.
2. Thin cake with poor dewatering.	2a. Filter media blinding.	2a. Inspect media.	2a. See 1b.
	2b. Improper chemical dosage.	2b. See 1a.	2b. See 1a.
	2c. Inadequate vacuum.	2c. Amount of vacuum, leaks in vacuum system, leaks in seals.	2c. Repair vacuum system (See 3 also).
	2d. Drum speed too high.	2d. Drum speed.	2d. Reduce drum speed.
	2e. Drum submergence too low.	2e. Drum submergence.	2e. Increase drum submergence.
3. Vacuum Pump stops.	3a. Lack of power.	3a. Heater tripped.	3a. Reset pump switch.
	3b. Lack of seal water.	3b. Source of seal water.	3b. Start seal water flow.
	3c. Broken V-belt.	3c. V-belt.	3c. Replace V-belt.
4. Drum stops rotating.	4a. Lack of power.	4a. Heater tripped.	4a. Reset drum rotation switch.
5. Receiver is vibrating.	5a. Filtrate pump is clogged.	5a. Filtrate pump output.	5a. Turn pump off and clean.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Receiver is vibrating. (Cont'd)	5b. Loose bolts and gasket around inspection plate.	5b. Inspection plate.	5b. Tighten bolts and align gasket.
	5c. Worn ball check in filtrate pump.	5c. Ball check.	5c. Replace ball check.
	5d. Air leaks in suction line.	5d. Suction line.	5d. Seal leaks.
	5e. Dirty drum face.	5e. Drum face.	5e. Clean face with pressure hose.
	5f. Seal strips missing.	5f. Drum.	5f. Replace seal strips.
6. High vat level.	6a. Improper chemical conditioning.	6a. Coagulant dosage.	6a. Change coagulant dosage.
	6b. Feed rate too high.	6b. Feed rate and solids yield.	6b. Reduce feed rate.
	6c. Drum speed too slow.	6c. Drum speed.	6c. Increase drum speed.
	6d. Filtrate pump off or clogged.	6d. Filtrate pump.	6d. Turn on (or clean) pump.
	6e. Drain line plugged.	6e. Drain line.	6e. Clean drain line.
	6f. Vacuum pump stopped.	6f. See Item 3.	6f. See Item 3.
	6g. Seal strips missing.	6g. Drum.	6g. Replace seal strips.
7. Low vat level.	7a. Feed rate too low.	7a. Feed rate.	7a. Increase feed rate.
	7b. Vat drain valve open.	7b. Vat drum valve.	7b. Close vat drain valve.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
8. High amperage draw by vacuum pump.	8a. Filtrate pump clogged.	8a. Filtrate pump output.	8a. Turn pump off and clean.
	8b. Improper chemical conditioning.	8b. Coagulant dosage.	8b. Change coagulant dosage.
	8c. High vat level.	8c. See Item 6.	8c. See Item 6.
	8d. Cooling water flow to vacuum pump to high.	8d. Cooling water flow.	8d. Decrease cooling water flow.
9. Scale buildup on vacuum pump seals.	9a. Hard, unstable water.	9a. Vacuum pump seals.	9a. Add sequestering agent.

PRESSURE FILTRATION

Process Description

The filter press is a batch device used to process sludges that are difficult to dewater. There are several types of presses available but the most common type is shown in Figure 98. This type of press has vertical plates held in a frame and pressed together between a fixed and moving end as pictured in Figure 98. A filter cloth covers each plate. The sludge is pumped into the press at pressures up to 225 psi and passes through feed holes in the trays along the length of the press. Filter presses usually need a precoat material (incinerator ash or diatomaceous earth) to reduce blinding and to help release the cake. The water passes through the cloth, while the solids stay on the cloth and form a cake. Sludge feeding is stopped when the sections between the trays are completely filled. There are drainage ports at the bottom of each press section where the filtrate is collected, taken to the end of the press, and discharged to a common drain. Filtrate quality should be very good (less than 100 mg/l suspended solids) if the system is properly operated. At the end of a cycle, the drainage from a large press can be 2,000 to 3,000 gallons per hour. This rate drops quickly to about 500 gallons per hour as the cake begins to form. When the cake completely fills the section, the rate is almost nothing. The dewatering step is finished when the filtrate is near zero. At this point, the pump feeding sludge to the press is stopped and any back pressure in the piping is released through a bypass valve. The press is opened electrically and each plate is moved to let the filter cake fall out. The plate moving step can be either manual or automatic. When all the plates have been moved and the cakes released, the complete set of plates is then pushed back by the electrical closing gear. The valve to the press is then opened, the sludge feed pump started, and the next dewatering cycle begins.

Filter presses are usually installed well above floor level, so that the cakes can drop onto conveyors or trailers set under the press. Filter presses can be operated at pressures ranging from 5,000 to 20,000 times the force of gravity. In comparison, a solid bowl centrifuge provides forces of 700-3,500 g and a vacuum filter, 1,000 g. Because of these greater pressures, filter presses may provide higher cake solids concentrations (30-50% solids) at lower chemical dosages. In some cases, ash from a downstream incinerator is recycled as a sludge conditioner.

Typical Design Criteria and Performance Evaluation

Table 37 lists normal loading rates and expected performance for pressure filtration systems. Loading rates depend on the length of the

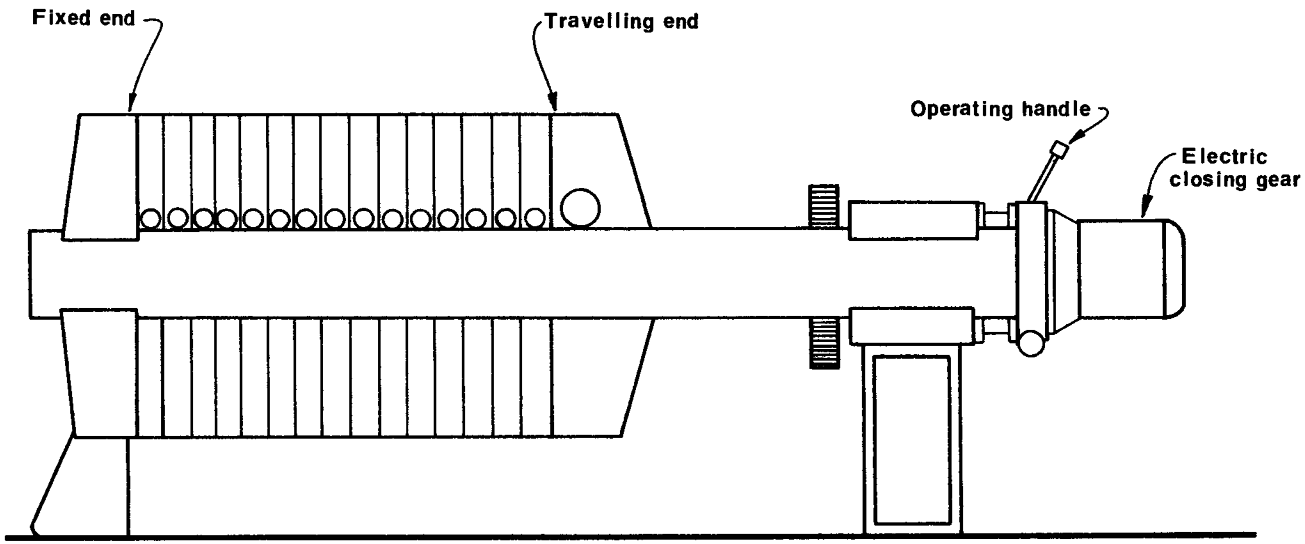


Figure 98. Side view of a filter press.

TABLE 37. TYPICAL RESULTS - PRESSURE FILTRATION

Sludge type	Conditioning	Percent solids to pressure filter	Typical cycle length	Percent solids filter cake
Primary	5% $FeCl_3$, 10% Lime	5	2 hrs	45
	100% Ash		1.5	50
Primary + $FeCl_3$	10% Lime	4*	4	40
Primary + 2 stage high lime	None	7.5	1.5	50
Primary + WAS	5% $FeCl_3$, 10% Lime	8*	2.5	45
	150% Ash		2.0	50
Primary + (WAS + $FeCl_3$)	5% $FeCl_3$, 10% Lime	8*	3	45
(Primary + $FeCl_3$) + WAS	10% Lime	3.5*	4	40
WAS	7.5% $FeCl_3$, 15% Lime	5*	2.5	45
	250% Ash		2.0	50
WAS + $FeCl_3$	5% $FeCl_3$, 10% Lime	5*	3.5	45
Digested primary	6% $FeCl_3$, 30% Lime	8	2	40
Digested primary + WAS	5% $FeCl_3$, 10% Lime	6-8*	2	45
	100% Ash		1.5	50
Digested primary + (WAS + $FeCl_3$)	5% $FeCl_3$, 10% Lime	6-8*	3	40
Tertiary alum	10% Lime	4*	6	35
Tertiary low lime	None	8*	1.5	55

*Thickening used to achieve this solids concentration.

cycle described above.

In evaluating performance:

1. Check the filter cake solids concentrations against typical values in Table 37.

2. Check the length of filter cycle against Table 37.

3. Check the quality of the filtrate. With proper operation and conditioning, the suspended solids concentration should be less than 100 mg/l.

Refer to the Troubleshooting section if unusual values are found.

Control Considerations

For any given filtrate flow rate, a certain filter cake concentration can be expected. Whether or not to precoat depends on operation. The purpose of precoat is to protect the filter media from early blinding and to reduce the frequency at which the filter media needs cleaning. If the investment in a precoat system has been made, its use should reduce manpower requirements for media cleaning. The influent sludge to the press should be thickened as greatly as possible.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Gravimetric Ash Feeders Installed - bulking problems with ash.	1. Install Volumetric Feeders.
2. Cake transport system inadequate (screw conveyors plug; belt conveyor limited to 15^{o} slope).	2. Install heavy-duty flight conveyor.
3. Mechanical Ash Conveyor Installed - noise and maintenance problems.	3. Install pneumatic ash conveying system.
4. Improper media specified - poor cake discharge, difficult to clean.	4. Change media - usually monofilament, relatively coarse media are used on municipal sludges.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Plates fail to seal.	1a. Poor alignment. 1b. Inadequate shimming.	1a. Alignment. 1b. Stay bosses.	1a. Realign plates. 1b. Adjust shimming of stay bosses.
2. Cake discharge is difficult.	2a. Inadequate precoat. 2b. Improper conditioning.	2a. Prevent feed. 2b. Conditioner type and dosage.	2a. Increase precoat, feet @ 25-40 psig. 2b. Change conditioner type on dosage based on filter leaf tests.
3. Filter cycle times excessive.	3a. Improper conditioning. 3b. Feed solids too low.	3a. Chemical dosage. 3b. Operation of thickening processes.	3a. Change chemical dosage. 3b. Improve solids thickening to increase solids concentration in press feed.
4. Filter cake sticks to solids conveying equipment.	4. Change chemical conditioning by using more inorganic chemicals.	4. Conditioning dosages.	4. Decrease ash, increase inorganic conditioners.
5. Precoat pressures gradually increase.	5a. Improper sludge conditioning. 5b. Improper precoat feed. 5c. Filter media pluggd. 5d. Calcium buildup in media.	5a. Conditioning dosages. 5b. Precoat feed. 5c. Filter media.	5a. Change chemical dosage. 5b. Decrease precoat feed substantially for a few cycles, then optimize. 5c. Wash filter media. 5d. Acid wash media (inhibited muriatic acid).
6. Frequent media blinding.	6a. Precoat inadequate. 6b. Initial feed rates too high (where no precoat used).	6a. Precoat feed.	6a. Increase precoat. 6b. Develop initial cake slowly.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
7. Excessive moisture in cake.	7a. Improper conditioning. 7b. Filter cycle too short.	7a. Conditioning dosages. 7b. Correlate filtrate flow rate with cake moisture content.	7a. Change chemical dosage. 7b. Lengthen filter cycle.
8. Sludge blowing out of press.	8. Obstruction, such as rags, in the press forcing sludge between plates.		8. Shutdown feed pump, hit press closure drive, re-start feed pump - clean feed eyes of plates at end of cycle.
9. Leaks around lower faces of plates.	9. Excessively wet cake soiling the media on lower faces.	9. Cake moisture content.	9. See Item 7.

SLUDGE DRYING BEDS

Process Description

Sand drying beds are often used for dewatering digested sludges. Digested and/or conditioned sludge is discharged onto a drying bed and allowed to dewater and dry under natural conditions. After digested sludge is applied to the sand bed, dissolved gases are released and rise to the surface, floating the solids and leaving a layer of liquor at the bottom. The liquor drains through the sand, is collected in the underdrain system and usually returned to a plant unit for further treatment. Drying beds drain very slowly in the beginning, but after about 3 days, the rate increases. After maximum drainage is reached, the dewatering rate gradually slows down and evaporation continues until the moisture content is low enough to permit sludge removal.

Dry sludge may be removed from the beds manually, by special conveyors, or with other loading equipment. Some users of sludge are allowed to remove the dried cake directly from the bed. Sludge cake is finally disposed of by land application as a soil conditioner.

Typical Design Criteria and Performance Evaluation

Figure 99 shows a sand bed cross-section.

Drying beds usually have 4 to 9 inches of sand placed over 8 to 18 inches of graded gravel or stone. The sand usually is 0.3 to 1.2 mm in size and a uniformity coefficient less than 5.0. Gravel is normally graded from 1/8 to 1.0 inches. Drying beds have underdrains that are spaced 8 to 20 feet apart. Underdrain piping is often vitrified clay laid with open joints, has a diameter no less than 4 inches, and a slope of at least 1 percent. Collected filtrate is usually returned to the treatment plant. Several beds are usually provided so that one will be free to accept sludge while the others are in different stages of drying.

Sandbeds are sometimes enclosed by glass or covered with a fiber glass or glass roof to protect the drying sludge from rain, control odors and insects, reduce the drying periods during cold weather, and improve the appearance of a waste treatment plant. Enclosed beds usually need only 67 to 75 percent of the area needed for an open bed. Good ventilation is important to control humidity and provide a good evaporation rate.

The area needed for open sand beds depends on climate, but typical criteria are:

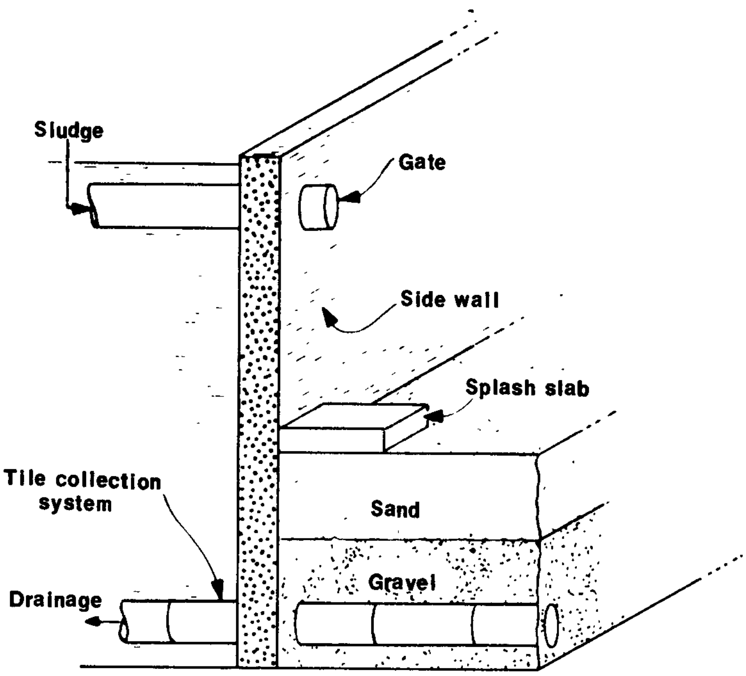


Figure 99. Cross-section of typical sand drying bed.

Type of digested sludge	Area (sq ft/capita)	Sludge loading dry solids (lb/sq ft/yr)
Primary	1.0	27.5
Primary and standard trickling filter	1.6	22.0
Primary and activated	3.0	15.0
Chemically precipitated	2.0	22.0

In evaluating performance:

1. Check the length of time needed for the sludge to dry to the point that it can be removed. In good weather, the sludge should be ready for removal in 2-3 weeks and a cake of 45 percent solids may only need six weeks using a well digested sludge. As with any dewatering method, the performance of a sand bed may be improved by chemical conditioning and the dewatering time may be reduced by more than 50 percent. With proper chemical conditioning, some sludges can be removed in less than one day. Sand beds can produce sludges with 85-90 percent solids content.

2. Check for odors. Odors indicate poor sludge digestion.

3. Check to see how much sand is left in the beds. If there is less than 4 inches, makeup sand should be added to replace sand hauled away with sludge.

Refer to the Control Considerations and Troubleshooting sections for guidance on solving any problems.

Control Considerations

The operator has less control over the sludge drying bed operation than with mechanical dewatering systems. Sludge drying bed performance is affected by weather, sludge characteristics, system design (including depth of fill), chemical conditioning, and drying time.

The type of sludge and its moisture content affect the drying process. Sludges containing grit dry rapidly; those containing grease more slowly; aged sludge dries slower than new sludge; primary sludge dries faster than secondary sludge; and digested sludge dries faster than fresh sludge. It is important that wastewater sludge be well digested for good drying. In well digested sludge, gases tend to float the sludge solids and leave a clear liquid layer, which drains through the sand.

Chemicals are especially useful for sludges that are hard to dewater or when drying beds are overloaded. The conditioning chemicals most commonly used are alum, ferric chloride, chlorinated copperas, and organic polyelectrolytes.

The useful capacity of the sand beds can be maximized by always removing sludge as soon as it has reached the desired dryness.

Sludge should never be added to a bed that contains partially dried sludge. Any weeds and other vegetation that might be present should be removed. Herbicides might be needed if there is much weed growth.

The sand bed should be leveled, and raked to make sure that it can drain the sludge properly. When necessary, sand should be added to keep at least 4 inches of depth.

After the sludge is applied to the beds, lines should be drained and flushed with water to prevent plugging and high pressures caused by gases resulting from the decomposing sludge.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Beds undersized.	1. Condition sludge with polymers.
2. Sludge distribution system results in uneven loading of beds.	2. Modify distribution piping.
3. Walls dividing beds are made of untreated wood and warp rapidly.	3. Replace with heavy creosoted lumber; pour concrete walls; build concrete block walls.
4. Beds sometimes built on flood plains.	4. Relocate beds on higher ground.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Excessive dewatering time.	1a. Applied sludge depth is too great.	1a. Typically, 8 inches of applied sludge is satisfactory.	1a. When bed has dried, remove sludge and clean. Apply a smaller depth of sludge and measure the draw down over a 3 day period. Next application, apply twice the 3 day draw down.
	1b. Sludge applied to improperly cleaned bed.	1b. Note condition of any empty beds.	1b. After sludge has dried, remove sludge and dirty sand and replace with 0.5-1 inch of clean sand.
	1c. Underdrain system has plugged or lines are broken.		1c. Backflush beds slowly by hooking clean water source to underdrain piping. Check sand bed and replace media as needed. Drain underdrain lines during freezing weather to keep them from freezing.
	1d. Beds undersized.	1d. Effects of adding polymer.	1d. Normally 5-30 lbs/ton of dry solids of cationic polymer provides improved dewatering rates.
	1e. Weather conditions.	1e. Temperature, precipitation.	1e. Cover or enclose bed to protect from weather.
2. Sludge feed lines are plugged.	2. Accumulation of grit and solids in lines.		2. Open valves fully at start of sludge application to clean lines; flush lines with water if necessary.
3. Very thin sludge being drawn from digester.	3. "Coning" occurring in digester with water being pulled out and sludge left behind.		3. Reduce rate of withdrawal from digester.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
4. Flies breeding in sludge beds.			4. Break sludge crust and use larvicides such as borax, or calcium borate or kill adult flies with suitable insecticide.
5. Odors when sludge is applied.	5. Inadequate digestion of sludge.	5. Operation of digestion process (see appropriate section of this manual).	5a. Establish correct operation of digestion process. 5b. As temporary solution, add lime to sludge. Lime may control odors but may tend to clog sand.

SLUDGE DRYING LAGOONS

Process Description

Sludge lagoons are like sand beds in that sludge is removed from a digester, placed in the lagoon, removed after a period of drying, and the cycle repeated. Unlike sand beds, drying lagoons do not have an underdrain system since most of the drying occurs by decanting supernatant liquor and by evaporation.

Typical Design Criteria and Performance Evaluation

Solids loading rates often used for drying lagoons are 2.2 to 2.4 lb/yr/cu ft of lagoon capacity. Other designs used are 1 sq ft/capita for primary digested sludges in a dry climate, and 3 to 4 sq ft/capita for activated sludge plants where the annual rainfall is 36 inches. A 2 foot high dike with a sludge depth of 15 inches (after decanting) often is used. Sludge depths of 2.5 to 4 feet have been used in warmer climates with longer drying periods. Draw off points are provided to remove supernatant and rainfall.

Except for treatment in very hot, arid climates, sludge will generally not dewater to the point that it can be lifted by a fork. If sludge is placed in depths of 15 inches or less, it may be removed with a front-end loader after 3 to 5 months. When sludge is to be used for soil conditioning, it may be good to stockpile it for added drying before use. One approach is to use a 3 year cycle where the lagoon is loaded for 1 year, dries for 18 months, is cleaned, and allowed to rest for 6 months.

Control Considerations

There is not much the operator can control in this process except for pretreatment and thickening of sludge prior to lagoon drying. Once discharged to the lagoon, the drying rate mostly depends on weather conditions. However, the operator should quickly remove supernatant liquor and rainwater so that the sludge cake is exposed to the air and can dry rapidly. Weeds and other vegetation always should be removed from the lagoon area before filling with sludge.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Odors from lagoons.	1a. Inadequately digested sludge.	1a. Operation of digestion process.	1a. Establish correct digester operation (see appropriate section of manual); apply lime to surface of lagoon.
	1b. Excess water in lagoon.		1b. Decant supernatant and rainwater promptly.
2. Insect breeding problems in lagoons.	2. Excess water in lagoon.		2. Decant supernatant and rainwater promptly; apply insecticides.
3. Supernatant decanted from lagoon is upsetting treatment process when recycled.	3a. Broken dikes between lagoons causing freshly drawn sludge to enter supernatant.	3a. Dike condition.	3a. Repair broken dikes.
	3b. Supernatant being drawn prematurely.	3b. Suspended solids of supernatant.	3b. Delay drawing of supernatant until sludge has settled.
	3c. Excessive sludge depths applied causing supernatant drawoff to be below sludge interface.	3c. Sludge application depths.	3c. Apply shallower sludge depths.

INCINERATION - MULTIPLE HEARTH

Process Description

Multiple hearth furnaces are the most often used furnace for municipal wastewater sludge incineration. As shown in Figure 100, a multiple hearth furnace has a steel shell around several solid refractory hearths and a central rotating shaft with rabble arms. The dewatered sludge enters at the top through a flapgate and drops down through the furnace from hearth to hearth by the action of the rabble arms. The hearths are made of high heat, heavy-duty fire brick. The capacity of these furnaces depends on the total area of the enclosed hearths. They are designed with diameters ranging from 54 inches to 21 feet 6 inches and with four to eleven hearths. Table 38 shows the effective hearth area for different size furnaces. Capacities of multiple hearth furnaces range from 200 to 8,000 lb/hr of dry sludge with operating temperatures of 1,700^{o}F.

Each hearth usually has 2 doors, fitted to cast iron frames and designed to close reasonably tight. Each door has an observation port which can be opened. Since the furnace may operate at temperatures up to 2,000^{o}F, the shaft and rabble arms are cooled by air supplied in controlled amounts from a blower located at the bottom of the shaft. The shaft is motor driven and speed can be adjusted from about 0.5 to 1.5 rpm. Two or more rabble arms are connected to the shaft at each hearth. Each rabble arm has a central tube for conducting air from the central shaft to the end of the rabble arm. The air may be discharged to atmosphere or returned to the bottom hearth as preheated air, for combustion.

The rabble arms provide mixing action as well as rotary and downward movement of the sludge. Combustion air flow is countercurrent to that of the sludge. Combustion air flow is countercurrent to that of the sludge. Some hearths have oil or gas burners to provide start-up or supplemental heat. Sludge is constantly turned and broken into smaller particles by the rotating rabble arms. This exposes the sludge surface to the hot furnace gases so that rapid and complete drying as well as burning of sludge occurs.

The multiple hearth system usually has an instrumentation system which sends operating data to a control panel. Temperature can be recorded for each hearth, cooling, and exhaust, and scrubber inlet gas. The temperature on each hearth can be controlled to within $\pm$ 40^{o}F. Breakdowns such as burner shutdown, furnace overtemperature, draft loss and feed belt shutdown can be monitored. If there is a power or fuel failure, the furnace should be shut down automatically and the shaft cooling air fan should be run on standby power to keep the shaft from melting.

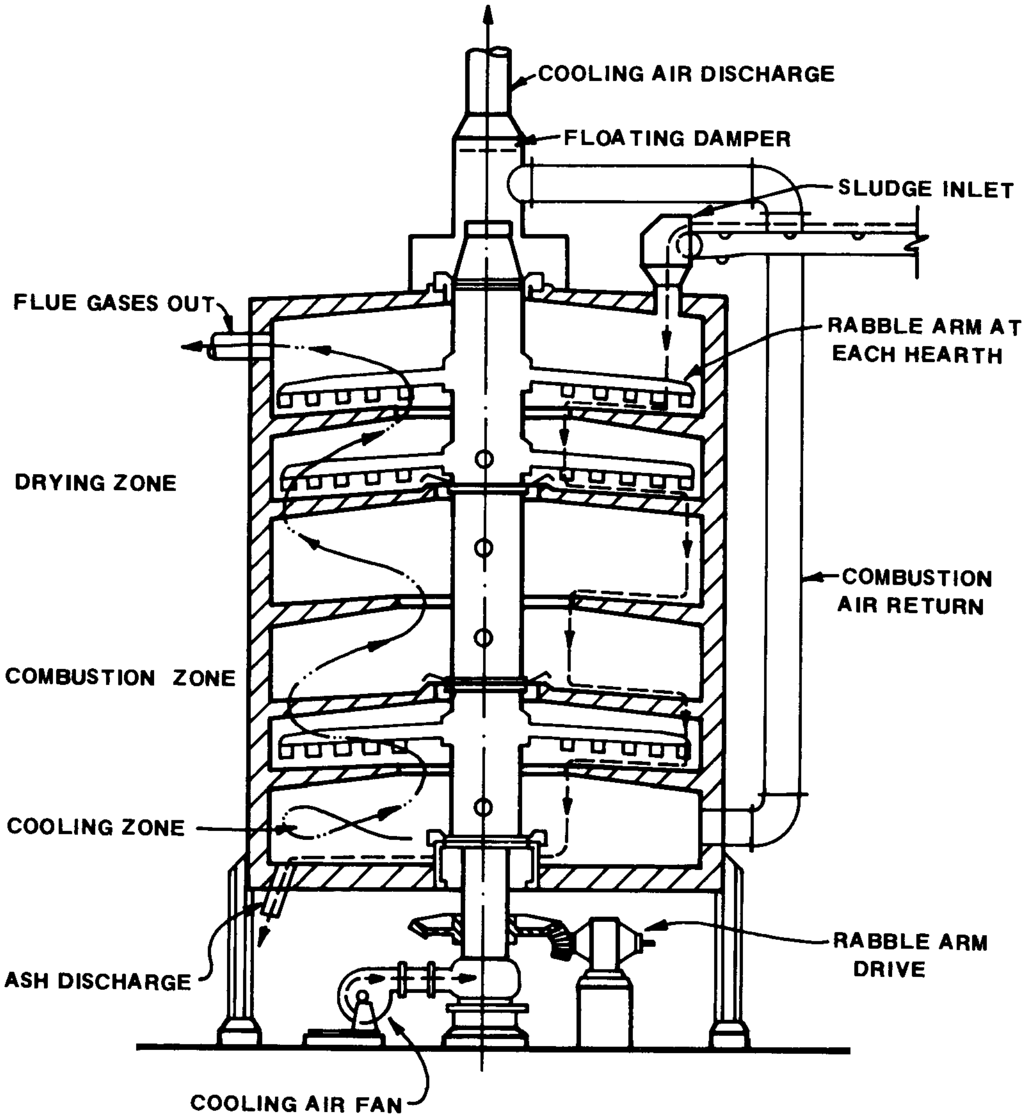


Figure 100. Cross section of a typical multiple hearth incinerator.

TABLE 38. STANDARD SIZES OF MULTIPLE-HEARTH FURNACE UNITS

Effective hearth area, sq ft	Outer diameter ft	Number hearths	Effective hearth area, sq ft	Outer diameter ft	Number hearths
85	6.75	6	988	16.75	7
98	6.75	7	1041	14.25	11
112	6.75	8	1068	18.75	6
125	7.75	6	1117	16.75	8
126	6.75	9	1128	14.25	12
140	6.75	10	1249	18.75	7
145	7.75	7	1260	16.75	9
166	7.75	8	1268	20.25	6
187	7.75	9	1400	16.75	10
193	9.25	6	1410	18.75	8
208	7.75	10	1483	20.25	7
225	9.25	7	1540	16.75	11
256	9.25	8	1580	22.25	6
276	10.75	6	1591	18.75	9
288	9.25	9	1660	20.25	8
319	9.25	10	1675	16.75	12
323	10.75	7	1752	18.75	10
351	9.25	11	1849	22.25	7
364	10.75	8	1875	20.25	9
383	9.25	12	1933	18.75	11
411	10.75	9	2060	20.25	10
452	10.75	10	2084	22.25	8
510	10.75	11	2090	18.75	12
560	10.75	12	2275	20.25	11
575	14.25	6	2350	22.25	9
672	14.25	7	2464	20.25	12
760	14.25	8	2600	22.25	10
845	16.75	6	2860	22.25	11
857	14.25	9	3120	22.25	12
944	14.25	10			

Typical Design Criteria and Performance Evaluation

Table 39 lists typical loading rates for several types of sludges. Combustion temperatures of about 1400°F are commonly used.

To avoid damaging the brick lining, the furnace must be carefully heated and cooled. Heat-up times usually are:

Effective hearth area, sq ft	Heatup time, hr
less than 400	18
400 - 800	27
800 - 1400	36
1400 - 2000	54
greater than 2000	108

TABLE 39. MULTIPLE HEARTH FURNACE OPERATION

Type of sludge	Percent solids	Percent VS	Chemical concentration* (mg/l)	Typical wet sludge loading rate** lb/hr/sq ft
1. Primary	30	60	N/A	7.0 - 12.0
2. Primary + $FeCl_3$	16	47	20	6.0 - 10.0
3. Primary + low lime	35	45	298	8.0 - 12.0
4. Primary + WAS	16	69	N/A	6.0 - 10.0
5. Primary + (WAS + $FeCl_3$)	20	54	20	6.5 - 11.0
6. (Primary + $FeCl_3$) + WAS	16	53	20	6.0 - 10.0
7. WAS	16	80	N/A	6.0 - 10.0
8. WAS + $FeCl_3$	16	50	20	6.0 - 10.0
9. Digested Primary	30	43	N/A	7.0 - 12.0

* Assumes no dewatering chemicals

** Low number is applicable to small plants, high number is applicable to large plants.

In some plants, the stack gases are passed through a heat exchanger to remove heat. This heat is used for preheating the incoming furnace air, for sludge conditioning by heat treatment, or for other uses in the plant. A boiler-generator system fueled by stack gas can be used to produce electricity.

To control air pollution, the stack gases often are passed through a wet scrubber.

Sludge incineration can reduce sludge volume by more than 90 percent. The ash from the incineration process is free of pesticides, viruses and pathogens. The metals in the ash are about the same as in the raw sludge; except that now, the metals are less soluble. The ash can be finally disposed in a landfill.

The following steps may be useful in evaluating performance:

1. Check temperature records to make sure that temperatures on each hearth are kept uniform and are within the range specified by the manufacturer.

2. Check carbon monoxide data for stack gas. Carbon monoxide indicates incomplete combustion.

3. Check maintenance records to see how often hearth and refractory repairs have been needed. Check shutdown and startup procedures if repairs are frequent.

4. Check for odors which indicate poor combustion.

5. Check furnace loading and fuel use:

   6 hearth, 14.25 ft outer diameter
   Primary + WAS feed, 18% solids, 69% volatile
   18000 lbs/day/dry solids
   Effective furnace area = 575 sq ft (Table 38)

   $$\text{Wet feed rate} = \frac{18000 \text{ lbs/day/dry}}{0.18\% \text{ solids}} = 100{,}000 \text{ lbs/day wet solids} = 4167 \text{ lbs/hr}$$

   $$\text{Loading rate} = \frac{\text{Feed rate}}{\text{Area}} = \frac{4167}{575} = 7.25 \text{ lbs/hr/sq ft}$$

   From Figure 101, approximate heat needed = 0.5×10^6 BTU/ton VS
   Volatile solids = 18,000 lbs/day x 0.69 = 12,420 lbs/day
   = 6.2 tons/day
   Fuel needed = 3.1×10^6 BTU/day or 93×10^6 BTU/month

   If the furnace is shut down and started up during the month, fuel will also be needed for startup. If fuel used is drastically different than above, consult troubleshooting guide.

Control Considerations

An incinerator is usually part of a sludge treatment system which includes sludge thickening, a disintegrating system, a dewatering device (such as a vacuum filter, centrifuge, or filter press), an incinerator feed system, air pollution control devices, ash handling facilities, and related controls. The operation of the incinerator cannot be separated from these other parts of the system. The thickening and dewatering processes are very important because the moisture content of the sludge has a major effect on the amount of fuel needed for incineration. The amount of fuel needed for different sludge solids contents is shown in Figure 101. Incineration usually is self-sustaining at sludge solids concentrations of about 26 percent for primary sludge and 23 percent for primary plus WAS. Incineration will always need some fuel for startup operations. Fuel also may be needed for air pollution control equipment.

However, as shown in Figure 101, incineration of high solids sludge can produce more heat than is needed.

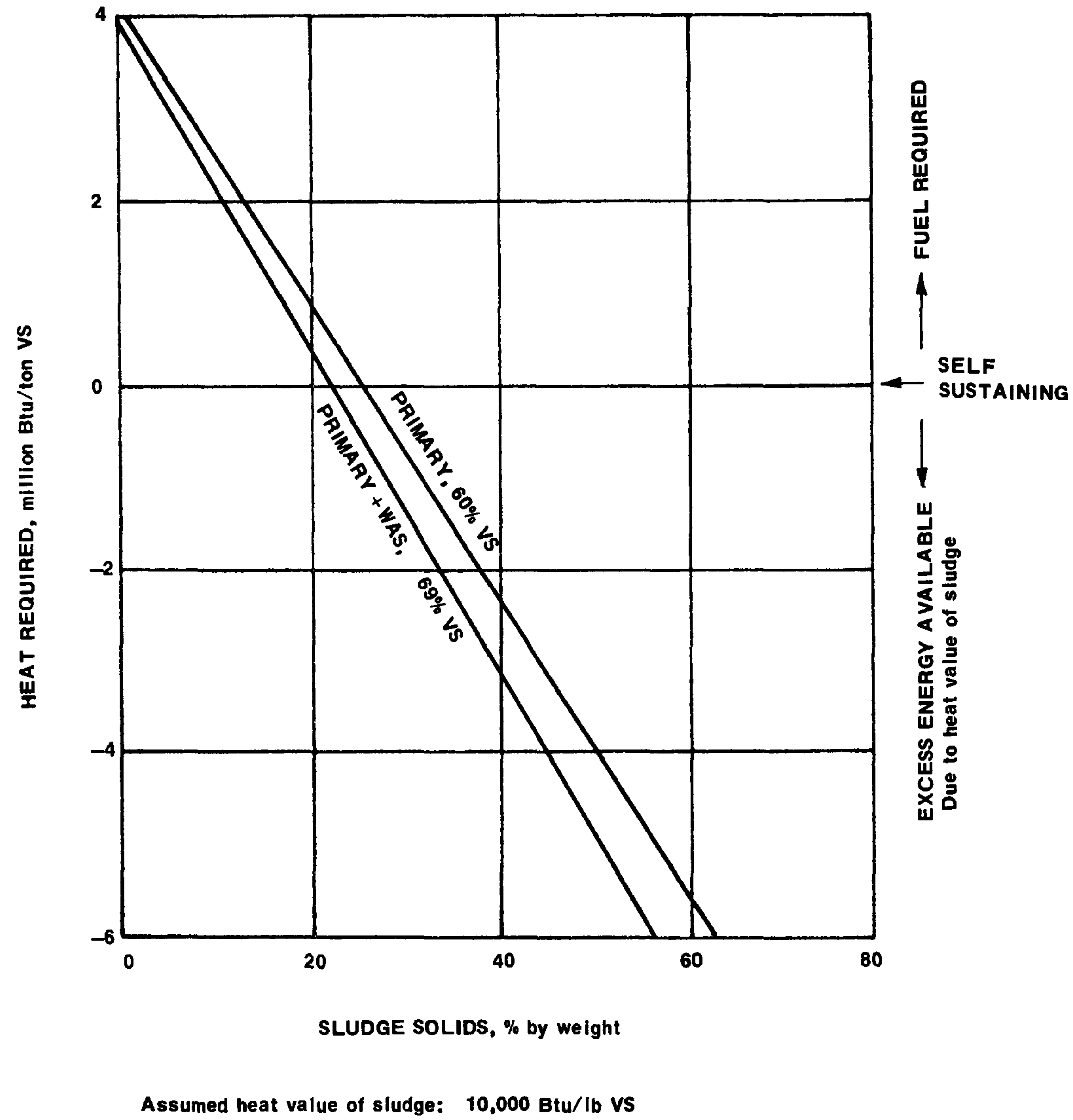


Figure 101. Auxiliary heat required to sustain combustion of sludge.

The fuel value of the sludge itself is also important in determining fuel consumption. Typical heat values of various sludges and their constituents are:

Type of sludge	Heating value (Btu/lb of dry solids)
Raw primary	10,000-12,500
Activated	8,500-10,000
Anaerobically digested primary	5,500
Raw (chemically precipitated) primary	7,000
Biological filter	8,500-10,000
Grease and scum	16,700
Fine screenings	7,800
Ground garbage	8,200
High organic grit	4,000

Auxiliary fuel requirements are lower for sludges with a high percentage of volatiles. The volatile content of a sludge may be maximized by

- removing sludge inorganics such as grit,
- avoiding the use of inorganic chemicals such as ferric chloride and lime in the dewatering process, and
- avoiding biological processes such as digestion before incineration.

When burning a normal load of sludge, a multiple hearth furnace provides three separate zones:

1. Two or more upper hearths where most of the moisture is evaporated.
2. Two or more middle hearths where the sludge burns at temperatures greater than 1500°F.
3. A bottom hearth that cools the ash by giving up heat to the cooler incoming air.

During moisture evaporation in the first zone, the sludge temperature is not raised higher than about 140°F. At this temperature not much volatile matter is driven off, so there are no bad odors. Distillation of volatiles from sludge containing 75 percent moisture does not occur until 80-90 percent of the water has been driven off. By this time, the sludge is down far enough in the incinerator to reach hot gases that burn the volatiles and could cause odors. Generally, when fuel is needed to maintain combustion in a multiple hearth furnace, a gas outlet temperature above 900°F means that too much fuel is being burned.

For good incinerator operation, more air must be supplied than the calculated amounts. This provides better contact between fuel and oxygen which is necessary for burning to occur. When there is not enough excess air, only partial combustion occurs. This results in the formation of carbon monoxide, soot and odorous hydrocarbons in the stack gases. Multiple hearth incineration normally is operated at 75 to 100 percent excess air; more than 100 percent excess air only wastes fuel. For best thermal economy, excess air flow should be controlled, based on stack gas composition. Oxygen, carbon dioxide, and carbon monoxide may be monitored automatically in the stack and compared with preset values. If the carbon monoxide level increases, this means that incomplete burning is occurring, and more excess air may be needed. However, if at the same time, the oxygen level agrees with the preset value, then either mixing of sludge and combustion air is poor, or the temperature is low because the sludge cake is wetter than normal.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Furnace temperature too high.	1a. Excessive fuel feed rate.	1a. Fuel feed rate.	1a. Decrease fuel feed rate.
	1b. Greasy solids.	1b. If fuel is off and temperature is rising, this may be the cause.	1b. Raise air feed rate or reduce sludge feed rate.
	1c. Thermocouple burned out.	1c. If temperature indicator is off scale, this is the likely cause.	1c. Replace thermocouple.
2. Furnace temperature too low.	2a. Moisture content of sludge has increased.	2a. Moisture content and dewatering system operation.	2a. Increase fuel feed rate until dewatering system operation is improved.
	2b. Fuel system malfunction.	2b. Check fuel system (valve position, pressure, fuel supply, etc.).	2b. Establish proper fuel feed rate.
	2c. Excessive air feed rate.	2c. If oxygen content of stack gas is high, this is the likely cause.	2c. Reduce air feed rate or increase sludge feed rate.
	2d. Flame out.	2d. Visual check.	2d. Relight furnace.
3. Oxygen content of stack gas is too high.	3a. Sludge feed rate too low.	3a. Check for blockage of sludge feed system and check feed rate.	3a. Remove any blockages and establish proper feed rate.
	3b. Air feed rate too high.	3b. Air feed rate.	3b. Decrease air feed rate.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
4. Oxygen content of stack gas is too low.	4a. Volatile or grease content of sludge has increased.	4a. Sludge composition.	4a. Increase air feed rate or decrease sludge feed rate.
	4b. Air feed rate too low.	4b. Check for malfunction of air supply and check feed rate.	4b. Increase air feed rate.
5. Furnace refractories have deteriorated.	5. Furnace has been started up and shutdown too quickly.	5. Operating records.	5. Replace refractories and observe proper heating up and cooling down procedures in future.
6. Unusually high cooling effect from one hearth to another.	6. Air leak.	6. Hearth doors, discharge pipe, center shaft seal, air butterfly valves in inactive burners.	6. Stop leak.
7. Short hearth life.	7. Uneven firing.	7. Have hearths been operated with only one burner on.	7. Fire hearths equally on both sides.
8. Center shaft drive shear pin fails.	8. Rabble arm is dragging on hearth or foreign object is caught beneath arm.	8. Inspect each hearth.	8. Correct cause of failure and replace shear pin.
9. Furnace scrubber temperature too high.	9. Low water flow to scrubber.	9. Scrubber water flow.	9. Establish adequate scrubber water flow.
10. Stack gas temperatures too low (500-600°F) and odors noted.	10. Inadequate fuel feed rate or excessive sludge feed rate.	10. Fuel and sludge feed rates.	10. Increase fuel or decrease sludge feed rates.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
11. Stack gas temperatures too high (1200-1600°F).	11. Excess heat value in sludge or excessive fuel feed rate.	11. Sludge characteristics and fuel rate.	11. Add more excess air or decrease fuel rate.
12. Furnace burners slagging up.	12. Burner design.		12. Replace burners with newer designs which minimize slagging.
13. Rabble arms are drooping.	13. Excessive hearth temperatures or loss of cooling air.	13. Operating records; is grease or scum being injected into the hearth.	13. Maintain temperatures in proper range and maintain backup systems for cooling air in working condition; discontinue scum injection into hearth.
14. Stack gases contain excessive air pollutants.	14a. Incomplete combustion due to insufficient air. 14b. Inoperative air pollution control equipment.	14a. Monitor stack gases for unburned HC, NO_x, CO.	14a. Increase air fuel ratio to provide for more complete combustion. 14b. Repair or replace damaged equipment.
15. Flashing or explosion.	15. Scum or grease.	15. Sludge characteristics.	15. Provide for scum and grease removal before incineration.

INCINERATION-FLUIDIZED BED

Process Description

The fluidized bed incinerator is a cylindrical vessel with a grid near the bottom to support a sandbed. A typical fluid bed reactor used for combustion of wastewater sludges is shown in Figure 102. Dewatered sludge enters above the bottom grid, and air flows upward at a pressure of 3.5-5.0 psig to fluidize the mixture of hot sand and sludge. Extra fuel can be supplied by burners located above or below the grid. The reactor is a single chamber unit where moisture evaporation and combustion occur at 1,400-1,500^{o}F. Because of the large heat reservoir in the bed and a rapid distribution of fuel and sludge throughout the bed, there is good contact between fuel and oxygen. The sand bed keeps the organic particles until they are reduced to mineral ash. The motion of the bed grinds up the ash material which is constantly stripped from the bed by the upflowing gases. The heat reservoir provided by the sandbed also allows faster start-up when the unit is shut down for short periods (overnight). As an example, a unit can be operated 4-8 hours a day with little reheating after restarting, because the sandbed is such a large heat reservoir.

Exhaust gases are usually scrubbed with treatment plant effluent and ash is separated from the liquid in a hydrocyclone, with the liquid stream returned to the head of the plant. An oxygen analyzer in the stack controls the air flow into the reactor. The auxiliary fuel feed rate is controlled by a temperature recorder.

As shown in Figure 103, an air preheater can be used with a fluidized bed to lower fuel costs.

Typical Design Criteria and Performance Evaluation

In evaluating performance:

1. Check data on oxygen content of stack gas. It should be 3-6%.

2. Check fluidized bed temperatures. They should be 1250-1300^{o}F.

3. Check bed temperature records to see if temperatures are constant or show major changes.

4. Check records on depth of sand to see if sand is being lost from the system.

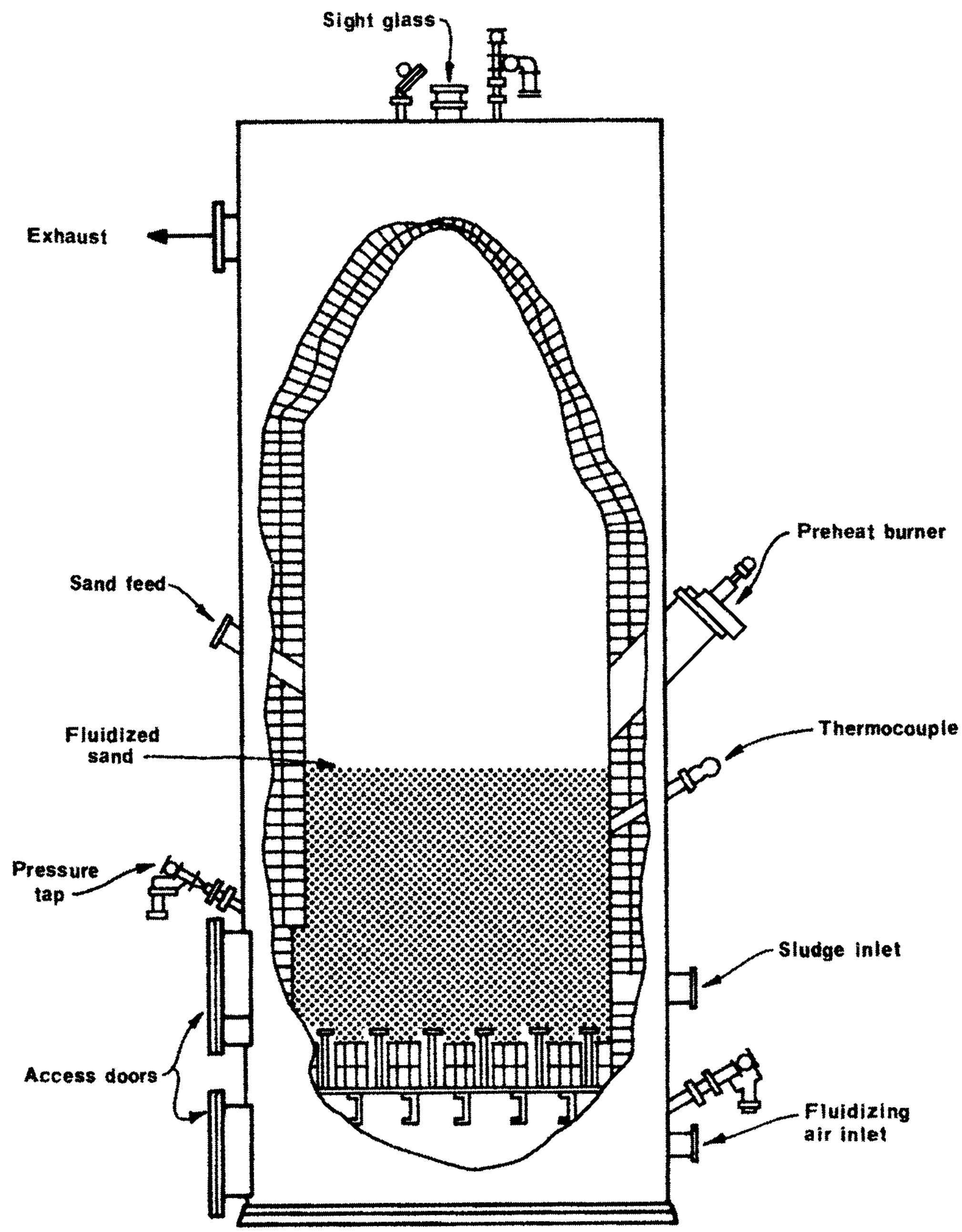


Figure 102. Cross section of a fluid bed reactor.

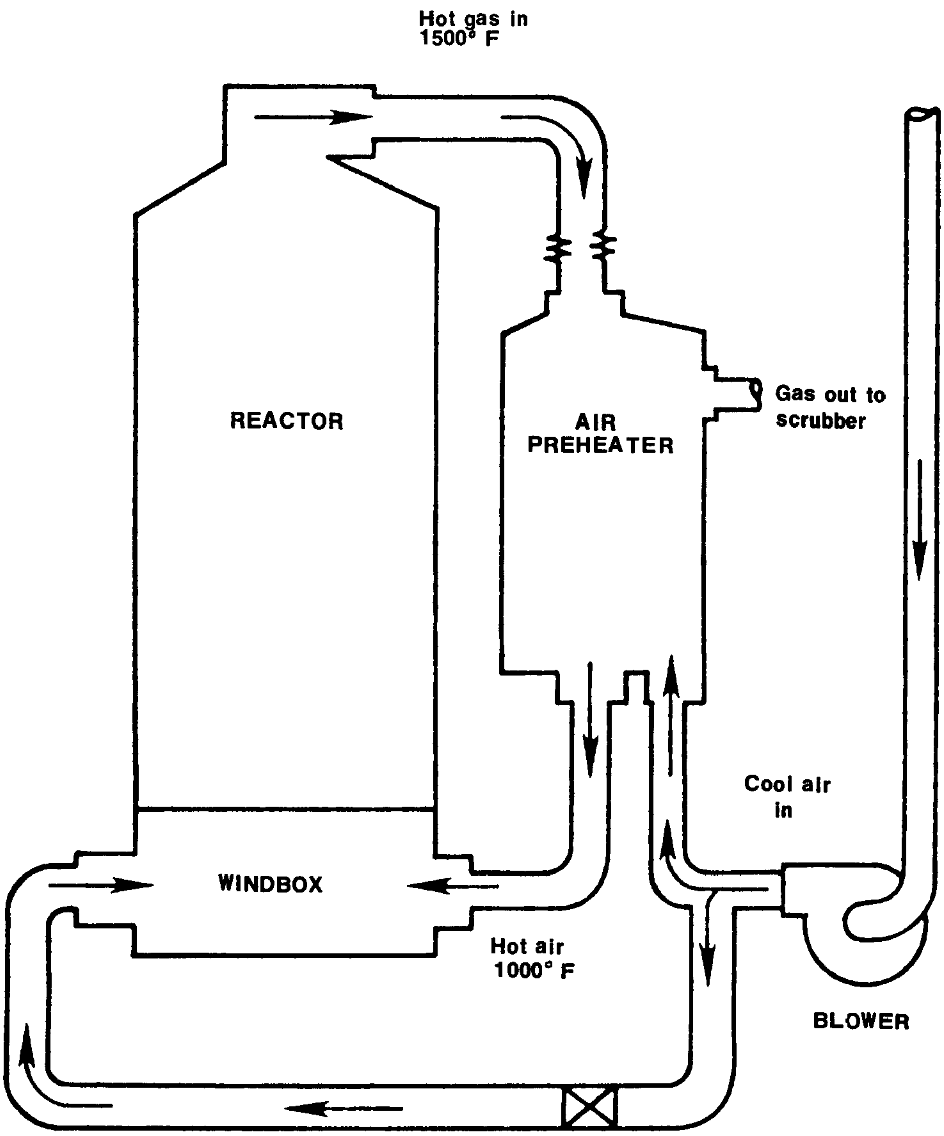


Figure 103. Fluidized bed system with air preheater.

Table 40 lists typical design criteria and field performance for several operating fluidized bed systems. These data and the Control Consideration Section can be used as a guide for evaluating fluidized bed performance. If the system does not operate near its expected performance, the Trouble-shooting Guide should be read for possible solutions to the problem.

Control Considerations

The amount of air fed into the reactor is very important. Too much air would blow sand and unburned sludge into the fuel gases and would result in needless fuel consumption.

Since the theoretical amount of air is never enough for actual fuel combustion, "excess air" must be added. The extra air is expressed as a percentage of the theoretical air requirement, e.g., if a fuel requires 1000 standard cubic feet of air per minute (SCFM) based on theoretical air requirements, and the actual air rate is 1200 SCFM, the percent excess air is:

$$\frac{\text{Actual Air Rate - Theoretical}}{\text{Theoretical}} = \frac{(1200 - 1000) \times 100\%}{1000} = 20\% \text{ excess air}$$

Fluidized bed systems usually are operated with 20-40% excess air. In practice, this rate is controlled by measuring the oxygen in the reactor exhaust gases and adjusting the air rate to maintain 3-6% oxygen. If not enough air is added, unburned particles leave the reactor, and if too much air is added, fuel is wasted.

Auxiliary fuel is used during start-up to raise the sand bed temperature to about 1200°F. As soon as sludge is fed into the furnace, the auxiliary fuel rate must be lowered to get the most heat from the sludge and to avoid wasting fuel. This is done by slowly reducing the fuel feed rate to the minimum that is necessary to keep bed temperatures between 1250 and 1300°F.

TABLE 40.

FLUIDIZED BED REACTOR PERFORMANCE DATA

Plant	Type of Sludge	FS Reactor Dia.	Heat Recovery	Capacity #/Hr. D.S.		Aux. Fuel Gal./Ton D.S.		Power KWH/Ton D.S.		% Volatile in Ash		Stack Emissions Grains/SCF	
				Design	Actual	Design	Actual	Design	Actual	Design	Actual	Design	Actual
Liberty, N.Y	Prim + T.F.	6'	No	282	338	102.8	53.3	—	—	3.0	0.31	—	—
Ocean City, Md.	Prim	6'	No	350	445	48.0	22.9	—	—	3.0	0.85	—	—
Barstow, Cal.	Prim	7'	No	500	552	36.0	31.9	239	210	—	—	0.1	0.025
Northwest Bergen, New Jersey	Prim + WAS	12'	Yes	1100	1169	41.5	57.0	267	243	4.0	0.59	0.1	0.018
Upper Merion Twp. Penn.	Prim + T.F.	9'	Yes	865	918	18.4	14.4	—	—	—	—	—	—
Port Washington, New York	Prim + T.F.	9'-6"	No	860	865	64.5	85.5	252	261	3.0	0.4	0.1	0.025
Arlington, N.Y.	Prim + WAS	9'	No	700	742	—	—	—	—	3.0	0.3	—	—
New Windsor, N.Y.	Prim + T.F.	7'	No	570	666	56.6	75.5	—	—	3.0	0.4	—	—
Bath, N.Y.	Prim + WAS	9'-6"	No	605	657	113.9	85.5	400	344	3.0	0.4	0.1	0.044
Lorain, Ohio	Prim + WAS	14'	No	1400	1635	40.0	32.2	274	181	3.0	0.7	—	—
Somerset-Raritan	Prim + WAS	12'	Yes	1170	1376	55.0	23.8	247	247	3.0	0.5	0.2	0.047

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Bed temperature is falling.	1a. Inadequate fuel supply.	1a. Fuel system operation.	1a. Increase fuel feed rate or repair any fuel system malfunctions.
	1b. Excessive rate of sludge feed.	1b. Sludge feed system.	1b. Decrease sludge feed rate.
	1c. Excessive sludge moisture.	1c. Dewatering system.	1c. Improve dewatering system operation (see appropriate section of this manual).
	1d. Excessive air flow.	1d. Oxygen content of exhaust gas should not exceed 6%.	1d. Reduce air rate.
2. Low (<3%) oxygen in exhaust gas.	2a. Low air flow.	2a. Air flow rate.	2a. Increase air blower rate.
	2b. Fuel rate too high.	2b. Fuel rate.	2b. Decrease fuel rate.
3. Excessive (>6%) oxygen in exhaust gas.	3. Sludge feed rate too low.	3. Sludge feed rate.	3. Increase sludge feed rate and adjust fuel rate to maintain steady bed temperature.
4. Erratic bed depth readings on control panel.	4. Bed pressure taps plugged with solids.		4a. Tap a metal rod into pressure tap pipe when reactor is not in operation.
			4b. Apply compressed air to pressure tap while the reactor is in operation after reviewing manufacturer's safety instructions.
5. Preheat burner fails and alarm sounds.	5a. Pilot flame not receiving fuel.	5a. Fuel pressure and valves in fuel line.	5a. Open appropriate valves and establish fuel supply.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Preheat burner fails and alarm sounds. (Cont'd)	5b. Pilot flame not receiving spark.	5b. Remove spark plug and check for sparks; check transformer.	5b. Replace defective part.
	5c. Pressure regulators defective.		5c. Dissemble and thoroughly clean regulators.
	5d. Pilot flame ignites but flame scanner malfunctions.	5d. Scanner operation.	5d. Clean sight glass on scanner; replace defective scanner.
6. Bed temperature too high.	6a. Fuel oil feed rate too high through bed guns.		6a. Decrease fuel oil flow rate through bed guns.
	6b. Bed guns have been turned off but temperature still too high due to greasy solids or increased heat value of sludge.		6b. Raise air flow rate or decrease sludge feed rate.
7. Bed temperature reads off-scale.	7. Thermocouple burned out.		7. Replace thermocouple.
8. Scrubber inlet shows high temperature.	8a. No water flowing in scrubber.	8a. Water pressure and valve positions.	8a. Open valves.
	8b. Spray nozzles plugged.	8b. Check nozzles by removing and connecting them to external water source.	8b. Clean nozzles and strainers.
	8c. Ash water not recirculating.	8c. Pump operation, clogged scrubber.	8c. Return pump to service or remove clogging from scrubber.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
9. Reactor feed pump fails.	9a. Bed temperature interlocks may have shut pump down.	9a. Bed temperature.	9a. See Items 1 and 6.
	9b. Pump is blocked.	9b. Sludge too concentrated.	9b. Dilute feed sludge with water.
10. Poor bed fluidization.	10. During shutdowns, sand has leaked through support plate.		10. Once per month, clean windbox.

LIME RECALCINING

Process Description

Lime often is used as a coagulant either as a tertiary step or ahead of the primary clarifier for removal of phosphorus from wastewaters. In recalcining, the dewatered calcium-containing sludge is heated to about 1,850°F. This drives off water and carbon dioxide leaving calcium oxide (or quicklime): $CaCO_3 \xrightarrow{1850^{\circ}F} CaO + CO_2$

In municipal wastewater treatment, multiple hearth furnaces have been used for recalcining. Although fluidized bed furnaces have been used for industrial and water treatment purposes, these furnaces have not been used for municipal wastewater recalcining.

In wastewater treatment, the calcium carbonate sludge is mixed with the wastewater solids and other chemical precipitates. After recalcining, these other solids leave an inert ash mixed with CaO. The plant design must provide a method for removing these inert solids from the system. One way is to use a centrifuge to classify the phosphate and other inert solids into the centrate and leave the calcium carbonate in the dewatered cake sent to the recalcining furnace. A second centrifuge is used to dewater the centrate from the first machine producing about 50% solids in the dewatered sludge. This cake is sent to a separate sludge disposal system. By operating the first centrifuge at only 70-75 percent solids capture, it is possible to remove most of the inert solids from the lime recovery system. Figure 104 shows the lime recalcining system using a multiple hearth furnace and series centrifuges at South Lake Tahoe, California. In tertiary treatment, centrifugal systems usually remove enough inert solids. Where lime is added to the raw wastewater, however, there are more inert solids, and other classification may be needed. This may be done after recalcination by passing the ash through a dry classification device. Using these two techniques in series, enough inert material is removed to allow lime reuse when coagulating raw wastewater.

The recalcined lime usually is discharged into a hammermill to break up any lumps that might form in the furnace. The material is forced against a grinding plate by the rotating hammers. The lumps are broken up until they are small enough to fit through the openings in a metal screen.

After the hammermill, the material goes to a thermal disc cooler. The cooler has a series of hollow discs mounted in tubular shafts, inside

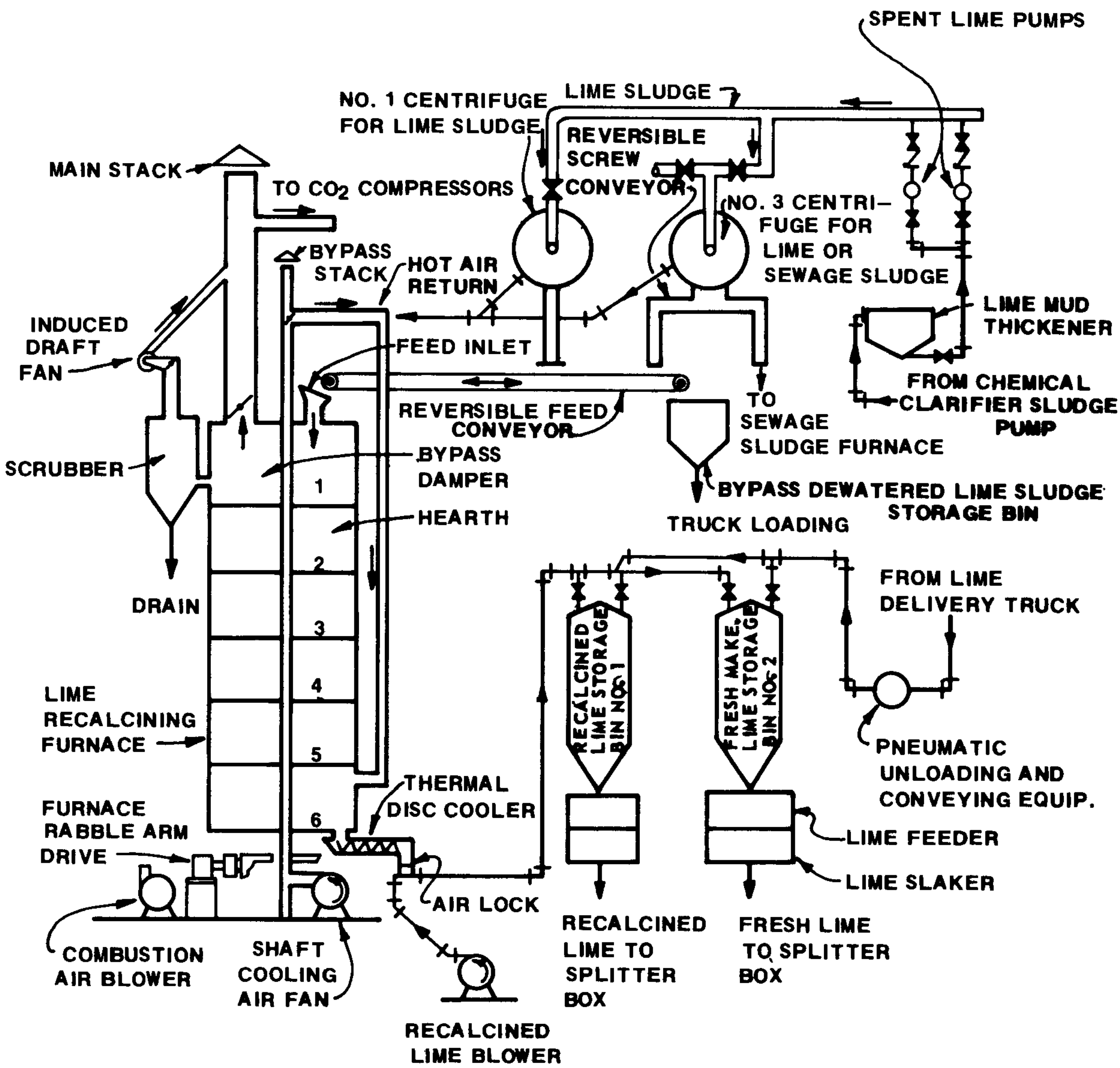


Figure 104. The lime recalcining system at South Lake Tahoe.

a rectangular housing. Cooling water passes through the shafts and discs, while a chain and sprocket motor rotates the discs. A variable height weir at the discharge is used to control the operating depth. The thermal disc cooler usually moves cooled recalcined lime to storage bins using a rotary air lock.

Typical Design Criteria and Performance Evaluation

The capacity of a multiple hearth furnace depends on solids loading per unit of hearth surface area. Sizing also depends on the nature of the sludge cake, including moisture, volatile solids, inerts content, and heat value. Loading rates of 7-12 lb/hr/sq ft are common based on wet sludge. Rates for recalcining are generally in the low end of this range.

Tables 41 and 42 list common temperature profiles for both six and eleven hearth furnaces.

The furnace usually has a wet scrubber for air pollution control.

In evaluating performance of a recalciner:

1. Check CaO content of recalcined lime. It should be at least 70%.

2. Check actual feed rates against the design rate.

3. Check hearth temperatures using Tables 41 and 42 as guide.

4. Check slaking characteristics of recalcined lime (see Control Considerations Section).

5. Check for odors which may indicate incomplete combustion.

6. Check amounts of make-up lime being used.

Control Considerations

With tertiary lime systems, the recalcined lime should contain at least 70 percent CaO. If the percentage is less, the classification processes need adjustment. When raw sewage is lime coagulated, the recalcined lime content usually is 60-70%. Classifying centrifuges should be operated to provide only about 70-75 percent solids capture; higher solids capture allows too much inert material to stay with the lime.

There are two important characteristics of the recalcined lime which must be controlled.

1. Activity, and

2. Slaking characteristics

TABLE 41. TYPICAL TEMPERATURE PROFILE IN SIX HEARTH FURNACE

Hearth No.	Temperature	
	C	F
1 (Top)	427	800
2	649	1,200
3	899	1,650
4	788	1,450
5	649	1,200
6 (Bottom)	149	300

TABLE 42. TEMPERATURE PROFILE IN ELEVEN HEARTH FURNACE

Hearth No.	Temperature	
	C	F
1 (Top)	760[a]	1,400[a]
2[b]	427	800
3	677	1,250
4	899	1,650
5	1,010	1,850
6	1,010	1,850
7	1,010	1,850
8	1,010	1,850
9	1,010	1,850
10	677	1,250
11 (Bottom)	399	750

[a] Top hearth used as afterburner
[b] Feed hearth

Recalcined lime may be classified according to the AWWA Standard for quicklime (CaO) and hydrated lime ($Ca(OH)_2$) (AWWA B202-65):

	Time for 40^{o} rise in temp., (min)	Time for complete reaction (min)
High-reactive, soft burned lime	3 or less	10
Medium-reactive, medium burned lime	3-6	20
Low-reactive, hard burned lime	More than 6	More than 20

It is possible to produce quicklime with the same CaO content, but with very different slaking properties.

The most important variables in the operation of the recalcining furnace are temperature and feed rate. The rabble arm rate in a multiple hearth furnace has little effect on recalcined lime if it is within 1.5-2 rpm.

At South Lake Tahoe with a six hearth furnace, increasing the temperature on hearth 5 from $1600^{o}F$ to $1900^{o}F$ resulted in an increase of CaO from 76 percent to 86 percent while still maintaining an acceptable slaking rate. Also, at $1600^{o}F$, there was some unburned organic material in the recalcined lime. Thus, temperature is very important in providing good operation of the recalcining system.

There are a number of critical mechanisms involved in the handling of recalcined lime discharge from a furnace system. In order of flow, these are:

- Lime Grinder - If the lime grinder stops, this usually means that some object such as a wrench or a piece of firebrick has fallen into the grinder and must be removed.

- Thermal Disc Cooler - When it is operating, this unit must have a supply of cooling water at all times. The system could be damaged by steam if there is no cooling water. Safety valves are usually provided to limit pressures. Temperatures greater than $600^{o}F$ will damage the rotary air lock which discharges cooled reclaimed lime to the conveying system.

- Rotary Air Lock - This unit must never get hotter than $600^{o}F$ and must never be operated unless the air seal system is working. The rotary air lock bearings must be kept clear with clean air at all times.

Common Design Shortcomings and Ways to Compensate

(Also refer to Lime Feeding Section of this manual)

Shortcoming	Solution
1. The area around the recalcining system gets coated with lime dust.	1. Install bag-type air filters on exhaust air streams from lime storage area.
2. Recalciner making too much noise.	2. Install acoustic enclosures on fan and blower assembly; add sound absorbing materials to building walls.

TROUBLESHOOTING GUIDE

(NOTE: Incineration - Multiple Hearth Section should also be reviewed for guidance related to furnace & chemical feeding section for lime handling).

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Recalcined lime has less than: . 70% CaO for tertiary applications. . 60% CaO for raw wastewater applications.	1a. Furnace temperatures too low. 1b. Classification of lime sludges inadequate permitting too many inerts to enter recalcining furnace.	1a. Temperature on fired hearths should be 1850°F. 1b. Solids capture in first stage centrifuge too high.	1a. Increase temperatures. 1b. Reduce solids capture in first stage centrifuge (see Centrifuge Section), if not adequate, evaluate dry classification of recalcined lime with your consultant.
2. Large clinkers forming in furnace.	2. Inadequate air.	2. Excess air is usually 70-100% for recalcining.	2. Increase air flow.
3. Recalcined lime tends to agglomerate into soft particles ¼ inch in diameter or larger rather than having desired flour-like appearance.	3. Furnace temperatures too low.	3. See 1a.	
4. Furnace shaft stops.	4a. Foreign material caught between rabble arm and hearth or arm may have come loose or sagged. 4b. Excessive clinker formation.	4a. Inspect hearths. 4b. See Item 2.	4a. Repair arm or remove obstruction.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Lime grinder stops.	5. Foreign object stuck in grinder.	5. Inspect grinder.	5. Remove obstruction.
6. Thermal disc cooler overheats.	6. Lack of cooling water.	6. Cooling water flow.	6. Open cooling water valves and establish adequate flow.
7. Cooling air temperature too high.	7. Cooling air fan malfunction.	7. Fan operation.	7. Repair fan.
8. Cooling air pressure too low.	8. See Item 7.		
9. Furnace temperature too high.	9. Firing rate of fired hearths too high.	9. Is temperature rising or falling?	9. If temperature is still rising, reduce firing rate.
10. Furnace scrubber temperature too high.	10. Low water flow to scrubber.	10. Scrubber water flow.	10. Establish adequate scrubber water flow.
11. Offensive odor in recalcining area.	11. Insufficient combustion air.	11. See Item 2.	

CARBON REGENERATION

Process Description

After the adsorptive capacity of activated carbon has been exhausted, the carbon can be restored by high temperature heating to drive off the adsorbed organics. Keeping oxygen at very low levels in the furnace prevents the carbon from burning. The organics are passed through an afterburner to prevent air pollution. In small plants where the cost of an onsite regeneration furnace is too high, the spent carbon may be shipped to a central regeneration facility for processing. Today, only granular carbon is regenerated, and this is accomplished in multiple hearth furnaces. Multiple hearth furnaces already have been described in the sludge incineration section of this manual.

As shown in Figure 105, the basic steps for regenerating carbon are:

- The granular carbon is pumped in a water slurry to the regeneration system for dewatering by gravity drainage.
- After dewatering, the carbon is fed to a furnace and is heated to 1,500 - 1,700^{o}F to volatilize and oxidize the impurities.
- The hot regenerated carbon is quenched in water.
- The cooled carbon may be washed to remove fine material and then transported to the adsorption equipment or to storage.
- The furnace off-gases are scrubbed, (the scrubber water is returned to the plant for processing) and also may pass through an afterburner.

Typical Design Criteria and Performance Evaluation

Multiple hearth furnaces used for regenerating carbon have a hearth area of about one sq ft per 40 lbs of carbon to be regenerated per day. An allowance also should be made for 10-40 percent downtime. Usually, about 1 lb of steam per lb of carbon is fed to the furnace to make the temperatures within the furnace uniform. Maximum operating temperatures are usually 1650-1700^{o}F. Air pollution control equipment is included in the design of the carbon regeneration furnace. Some systems have an afterburner for removal of smoke and odors, and a wet scrubber or bag filter for removal of particulates. A variable-throat Venturi-type scrubber with 20 inch pressure drop can be used to meet strict air quality standards.

The total amount of fuel needed for regeneration is about 3,000-3,500

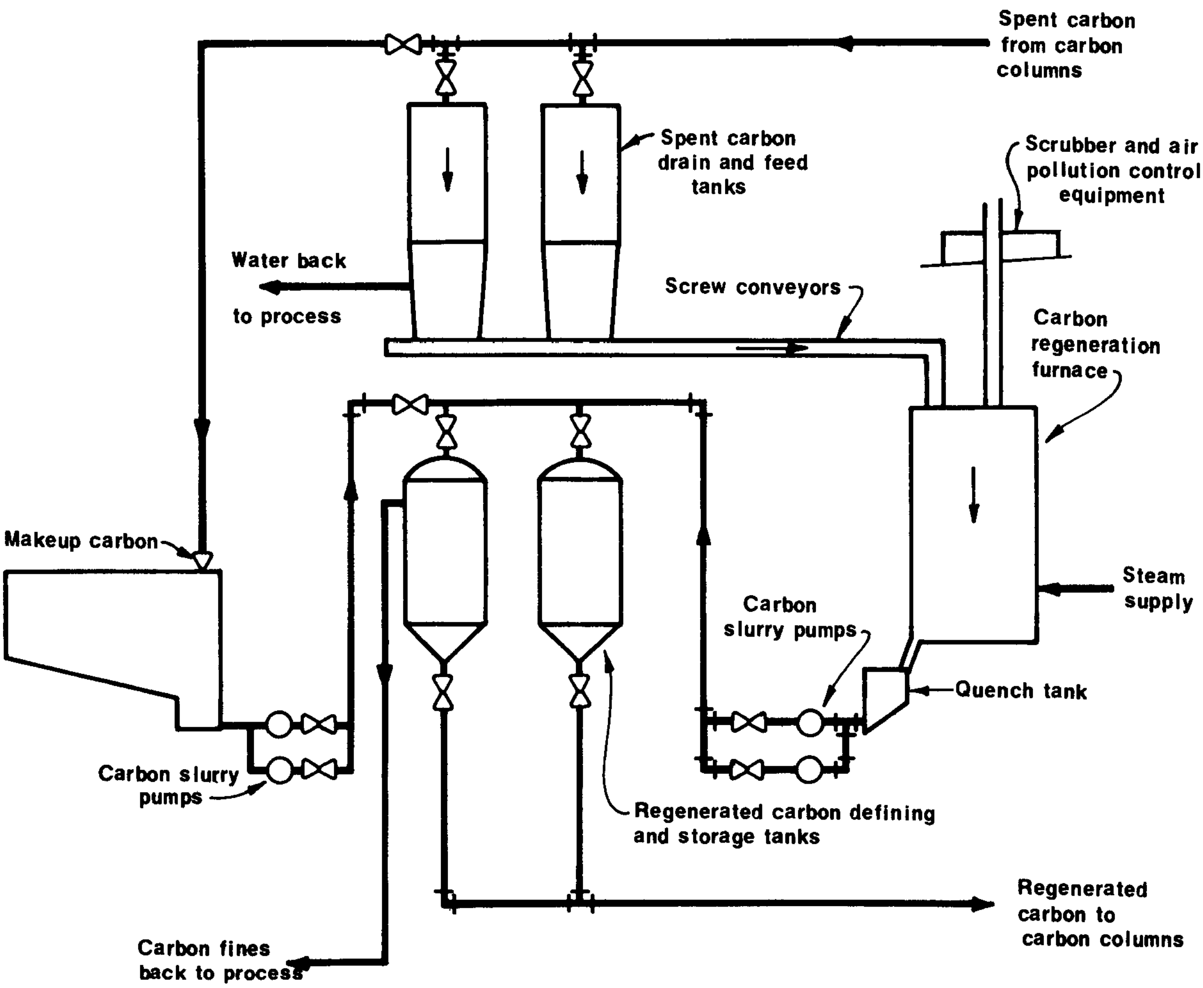


Figure 105. Typical carbon regeneration system schematic.

Btu/lb of carbon for furnace heat, about 1,250-1,600 Btu/lb of carbon for steam generation, and about 2,400 Btu/lb for afterburner fuel.

The results of plant-scale regeneration of granular carbon at South Lake Tahoe, California are as follows:

Carbon property	Virginal carbon	Spent carbon	Carbon after regeneration
Apparent density	0.48	0.52-0.59	0.47-0.50
Iodine number	935	550-843	743-969
Ash (%)	5.0	4.5	4.7-8.2

Although these values cannot be used as an absolute measure or standard for performance at all plants, the figures can be used as a general guide for performance evaluation. Through laboratory tests, the apparent density, iodine number and ash content of the carbon should be determined after each regeneration. If a system does not perform as expected, the troubleshooting guide should be checked.

Control Considerations

The quality of regenerated carbon is controlled by measuring the apparent density (A.D.) of the regenerated carbon. A typical A.D. of virgin granular carbon is about 0.48 gm/cc. As carbon becomes saturated with adsorbed organics, the A.D. may increase to 0.50 or more. As the carbon is regenerated, organics are removed, and the carbon loses weight. If properly regenerated, the A.D. will return to 0.48. The A.D. is quickly and easily determined by weighing a known volumn of carbon.

If the apparent density of the regenerated carbon is greater than 0.49, the carbon is not getting enough heat to remove much of the organic material. If the apparent density is less than 0.48, the carbon is getting too much heat, and carbon is being burned in the furnace.

The A.D. of the regenerated carbon can be changed by changing the following process conditions:

1. Temperature is the most important factor in carbon regeneration; a higher temperature will give a lower A.D. and a lower temperature will give a higher A.D.

2. Carbon feed rate is the next most important in carbon regeneration. Increasing the carbon feed rate will increase the carbon depth on the furnace hearths and will reduce the amount of heat supplied to the carbon. This change will give the carbon a higher A.D. Lowering the carbon feed rate will decrease the depth of carbon and increase the amount of heat supplied to the carbon. This will lower the A.D.

3. Increasing the steam feed rate will decrease the A.D. Decreasing the steam feed rate will increase the A.D.

4. Furnace drive speed regulates the contact time in the furnace. Increasing the drive speed will reduce the contact time. This is not as important as temperature and carbon feed rate.

The ash content of carbon may be used to detect any buildup of calcium or other unwanted material. The ash content of virgin carbon usually is about 5.2 percent. Just before the first regeneration, the ash content may increase to about 5.7 percent, and after the first regeneration, to about 6.4 percent. In later regenerations, there should not be much change in the values for spent and regenerated carbon. Greater ash buildups can be expected for lesser degrees of pretreatment.

Common Design Shortcomings and Ways to Compensate

Shortcoming	Solution
1. Regeneration furnace too small.	1. Contract for carbon regeneration with commercial carbon supplies while expanding regeneration facility.
2. Carbon storage and dewatering equipment corrodes because it is not properly coated.	2. Partially dewatered carbon is very corrosive. Recoat equipment.
3. No way to remove carbon fines from regenerated carbon, and packed beds show excessive headloss.	3. Remove some carbon from packed bed and vigorously backwash to remove carbon fines.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Apparent density of regenerated carbon is greater than virgin carbon.	1. Insufficient heat being applied to carbon.	1. Furnace temperature should be 1650-1700°F on fixed hearths.	1a. Increase furnace temperatures by 50°F increments until virgin carbon AD is achieved. 1b. If temperature is in correct range, decrease carbon feed rate. 1c. Increase steam feed rate if less than 1 lb/lb of carbon. 1d. Increase furnace drive speed.
2. Apparent density of regenerated carbon is less than virgin carbon.	2. Too much heat being applied to carbon.	2. Furnace temperature should be 1650-1700°F on fixed hearths.	2a. Decrease furnace temperatures by 50°F increments until virgin carbon AD is achieved. 2b. If temperature is in correct range, increase carbon feed rate. 2c. Decrease steam feed rate. 2d. Decrease furnace drive speed. 2e. If above adjustments don't solve problem, check for air leaks at feed entry, discharge pipe, hearth doors, bottom shaft seal, etc. 2f. Change fuel/air ratio to produce more CO at burners but not more than 4% CO.
3. Carbon losses exceed 5%.	3. Substantial carbon loses due to frequent startup and	3. Operating schedule for furnace.	3. Store enough spent carbon to prevent more continuous operation of furnace at less

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	3. (Cont'd) shutdown of furnace and loss of carbon in furnace.		3. (Cont'd) frequent intervals.
4. Center shaft drive shear pin fails.	4. Rabble arm is dragging on hearth or foreign object is caught beneath arm.	4. Inspect each hearth.	4. Correct cause of failure and replace shear pin.
5. Furnace temperature too high on upper, unfired hearths.	5a. Too much heat being applied to fired hearths.	5a. Fired hearth temp.	5a. Reduce firing rate on uppermost fired hearth or turn it off.
	5b. Steam rate low.	5b. Steam rate.	5b. Increase steam rate on uppermost fired hearth.
	5c. Carbon feed rate too low.	5c. Carbon feed rate.	5c. Increase feed rate.
6. Furnace temperature too high on lower, fired hearths.	6a. Firing rate too high.	6a. Fired hearth temp.	6a. Reduce firing rate.
	6b. Steam rate low.	6b. Steam rate.	6b. Increase steam rate on lowest fired hearth.
	6c. Air leaks.		6c. Repair air leaks.
7. Furnace temperature too low.	(Reverse procedures in Items 5 and 6)		
8. Furnace refractories have deteriorated.	8. Furnace has been started up and shutdown too quickly.	8. Operating records.	8. Replace refractories and observe proper heating up and cooling down procedures in future.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
9. Unusually high cooling effect from one hearth to another.	9. Air leak.	9. Hearth doors, discharge pipe, center shaft seal, air butterfly valves in inactive burners.	9. Stop leak.
10. Short hearth life.	10. Uneven firing.	10. Have hearths been operated with only one burner on.	10. Fire hearths equally on both sides.

APPLICATION OF SLUDGES TO LAND

Process Description

Some of the section on land treatment of wastewater has troubleshooting guidance which will be useful in sludge applications. The Land Treatment Section should be reviewed because it will not be repeated in this section.

It should be cautioned that there are two Acts which may affect the application of sludges to land; the Resource Conservation & Recovery Act, Section 4004; and the Clean Water Act, Section 405. EPA will be issuing guidelines through these Acts, and these guidelines should be carefully checked before using this treatment method.

Before being applied to the land, sludge is stabilized to reduce odors and health hazards. The most common method of treatment is either anaerobic or aerobic sludge digestion.

The sludge application site usually is not very close to the treatment plant, so the sludge must be transported by truck, barge, railroad or pipeline. For large plants, pipeline transportation of sludge is usually the cheapest, while smaller plants use trucks.

Sludge must be stored between treatment and land disposal because treated sludge is generated at nearly a constant rate while the sludge disposal rate depends on weather, field conditions, and the application method. Many plants use the second-stage anerobic digester for storage. Lagoons are also used for storage.

The main methods for applying sludge to the land are:

		Principal sludge form
DISPOSAL	Sanitary landfill	Dewatered cake or ash
	Sites dedicated to sludge disposal	Liquid or dewatered
REUSE	Cropland application	Liquid, cake dried, or compost.
	Land reclamation	Liquid or dewatered

Sludge may be applied to land, (1) which will be used for growing crops, parkland or forests, or (2) which will be used for sludge disposal with no attempt to grow crops. Managing crop growth using sludge is more difficult because the needs of the crop must be carefully balanced against sludge disposal considerations.

Sludge may be applied to the land in several ways. Small plants may spread liquid sludge directly from tank trucks. In some cases, shallow trenches may be dug, filled with sludge, and covered. Sludge may also be applied using sprinkler systems with large spray nozzles where the site is isolated enough. In some cases, sludge has been injected into the soil under pressure. Ridge and furrow systems have also been used and this solves the problem of aerosols from spray systems. The method used usually depends on the amount of sludge to be disposed and whether crops are to be grown on the site.

Typical Design Criteria and Performance Evaluation

The sludge application rate is one of the most important design criteria. The effect of viruses, organics, cysts, and parasites in sludge are a concern in land application. However, they do not usually limit the application rate of sludge to the land. Application rate mostly depends on the amount of water, nitrogen, and heavy metals in the sludge.

If surface runoff is to be prevented, the application of water to land cannot exceed the amount of water lost by percolation, evaporation, and transpiration. This is not a problem with dewatered sludges, but many systems apply liquid sludge to the land. The amount of water which may be applied depends on the climatic conditions, the type of soil, whether vegetation grows on the disposal site, and the type of vegetation which may be grown on the disposal site.

If nitrogen pollution of the groundwater is a concern, the amount of nitrogen in the sludge may limit the annual sludge application rate. The nitrogen content of sludges should be measured for each sludge. Usually, the total nitrogen in each sludge varies, and can range from 60 to 120 pounds nitrogen per ton of dry weight sludge solids. To avoid nitrate pollution of the ground waters, there must be a balance between the nitrogen in the sludge and the amount removed by the crop.

In a single growing season, crop uptake of nitrogen may range from 50-450 lbs/acre/yr depending on the type of crop. When the nitrogen balance is not a concern, sludge loading rates may be 100 dry tons/acre/yr, while loading rates as low as 5 tons/acre/yr may be needed if nitrogen is a problem.

Heavy metals also may affect the application rate of sludge to land. Cadmium, copper, molybdenum, nickel, and zinc can accumulate in plants and may be a hazard to plants, animals, or humans. High metal concentrations from industrial sources may limit application rates to less than 5 tons/acre/yr.

In actual practice, sludge application rates to cropped areas often range from 10-30 tons/acre/yr.

Other important design variables are runoff control, crop selection, groundwater control, monitoring systems, and land application equipment.

For landfill operations, the landfill should have limited access and the waste should be spread evenly in layers not over 2 feet thick, followed by compaction. The compacted wastes should have at least six inches of compacted earth cover at the end of each working day. When each portion of the landfill is completed, at least 2 feet of earth cover should be placed over it, and grasses planted to prevent erosion.

Adequate monitoring of any land application or landfill site is most important. This plan must be designed for local conditions and should include monitoring groundwater observation wells, surface water, sludge and soils for heavy metals, persistent organics, pathogens, and nitrates. Human food chain products grown in soils with sludge should also be monitored for heavy metals, persistent organics, and pathogens.

Because some pathogens can survive the sludge digestion process, liquid sludges usually should not be applied to root crops or crops intended for humans in the raw form.

Pastureland and farmland used to grow forage crops are often used as land disposal sites. There is not much problem of disease transmission via livestock grazing on these fields.

Control Considerations

As noted above, it is important to keep a balance between nitrogen applications and nitrogen uptake by crops in order to prevent nitrate pollution of groundwaters.

It is important to keep the soil pH near 7.0, since a metal content which is safe at pH 7 can be lethal to most crops at pH 5.5. Land application may lower the soil pH because of nitrification. Proper soil amendments can be used to take care of this problem.

Adequate monitoring of a landfill site is vital, as discussed above. Leachate and runoff from a sanitary landfill should be minimized and when necessary collected and treated to prevent pollution of ground and surface waters.

Where crops are grown, close cooperation is needed between the treatment system management and farming operation. Scheduling of sludge application with farm operations such as planting, tilling, spraying and harvesting is most important to successful managment.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Odors from sludge storage lagoons.	1a. Improperly digested sludge.	1a. pH, alkalinity, and volatile acids of anaerobically digested sludge. 1b. VSS content of aerobically digested sludge.	1a. (1) Correct digester operation. (2) Apply lime to lagoon surface. (3) Flood lagoon with heavily chlorinated water. 1b. (1) Correct digester operation. (2) Install temporary floating aeration in lagoon.
2. Crop suddenly dies or shows signs of poor health.	2a. Downward shift in soil pH.	2a. Soil pH should be maintained above 6.5, preferably 7.0.	2a. Add lime to soil.
	2b. Excessive nitrogen application.	2b. Determine nitrogen applied and consult with agricultural extension service.	2b. Reduce loading rate.
	2c. Excessive heavy metal concentrations.	2c. Heavy metal content of sludge and crop.	2c. Reduce loading rate or reduce heavy metal content through enforcement of pretreatment requirements.
	2d. Excessive phosphorus application causing nutrient imbalance.	2d. Determine phosphorus application and consult with agricultural extension service.	2d. Reduce application rate.
3. Surface runoff of sludge.	3a. Excessive application rate.		3a. Reduce application rate.
	3b. Ground saturated with rainfall.		3b. Discontinue application until soil has dried out.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
4. Aerosols drifting out of disposal area.	4. Wind carrying aerosols		4a. Discontinue spraying during windy periods. 4b. Convert spray nozzles to larger openings. 4c. Reduce spray pressure. 4d. Increase buffer area.
5. Trucks getting stuck in fields.	5. Need to apply sludge during wet periods.		5. Acquire a portable "rain gun" which can spray sludge over 200-300 ft. diameter circle.
6. Mosquitoes breeding on site.	6. Ponding of sludge.	6. Stagnant ponds of sludge.	6. Grade site to eliminate ponding, reduce application rate.
7. Flies breeding and/or odors at landfill.	7. Landfill operation inadequate.	7. Is fill being covered at end of day?	7. Cover fill with at least 6 inches of compacted soil at the end of each day.
8. Leachate from landfill causing pollution of ground or surface waters.	8. Excessive liquid application.	8. Application rates and leachate quality.	8a. Intercept and treat leachate. 8b. Reduce liquid applied to landfill by improving sludge dewatering or reducing application rates.
9. Nitrate pollution of groundwater occurring.	9. Excessive nitrogen applications.	9. Nitrogen application rates and nature of cover crops.	9a. Reduce application. 9b. Replace crop with one with higher nitrogen uptake.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
10. Coverage of sludge in subsurface plow injection system not adequate.	10. Plow is being pulled at excessive speed and soil is thrown away from shank.	10. Plow speed.	10. Pull plow at 1 mph or less.
11. Drying of soil - sludge mixture is slow in subsurface injection system.	11. Sludge being injected too deeply.	11. Injection depth.	11. Inject at 4-inches or less.
12. Subsurface injection plugging.	12. Large sludge solids.		12. Install grinder on sludge.

(See Land Treatment Section for irrigation equipment related information and other troubleshooting guidance.)