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EPA-600/2-82-001d

TREATABILITY MANUAL

VOLUME IV. COST ESTIMATING

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

APRIL 1983
(REVISED)

PREFACE

In January, 1979, USEPA's Office of Enforcement and Office of Water and Waste Management requested help from the Office of Research and Development in compiling wastewater treatment performance data into a "Treatability Manual."

A planning group was set up to manage this activity under the chairmanship of William Cawley, Deputy Director, Industrial Environmental Research Laboratory - Cincinnati. The group includes participants from: 1) the Industrial Environmental Research Laboratory - Cincinnati; 2) Effluent Guidelines Division; 3) Office of Water Enforcement and Permits; 4) Municipal Environmental Research Laboratory - Cincinnati; 5) R.S. Kerr, Environmental Research Laboratory - Ada; 6 Industrial Environmental Research Laboratory - Research Triangle Park; 7) WAPORA, Incorporated; and 8) Burke-Hennessy Associates, Incorporated.

The objectives of this program are :

- to provide readily accessible data and information on treatability of industrial waste streams;
- to provide a basis for research planning by identifying gaps in knowledge of the treatability of certain pollutants and waste streams.

The primary output from this program is a five volume Treatability Manual. This was first published in June 1980, with revisions made in September 1981 and August 1982. This publication replaces Volume I in its entirety, and updates Volumes II, III, IV, and V. The individual volumes are named as follows:

Volume I - Treatability Data
Volume II - Industrial Descriptions
Volume III - Technologies
Volume IV - Cost Estimating (In the process of revision for later publication)
Volume V - Summary

ACKNOWLEDGEMENT

The development of this revision to the Treatability Manual has resulted from efforts of a large number of people. It is the collection of contributions from throughout the Environmental Protection Agency, particularly from the Office of Water Enforcement, Office of Water and Waste Management, and the Office of Research and Development. Equally important to its success were the efforts of the employees of WAPORA, Inc., and Burke-Hennessy Associates, Inc., who participated in this operation.

A list of names of contributors would not adequately acknowledge the effort expended in the development of the manual. This document exists because of the major contributions of numerous individuals within EPA and the EPA contractors, including:

Effluent Guidelines Division
    Office of Water Regulations and Standards, Office of Water

Permits Division
    Office of Water Enforcement and Permits, Office of Water

National Enforcement Investigation Center
    Office of Enforcement

Office of Research and Development

    Center for Environmental Research Information

    Municipal Environmental Research Laboratory

    Robert S. Kerr Environmental Research Laboratory

    Industrial Environmental Research Laboratory
        Research Triangle Park, NC

    Industrial Environmental Research Laboratory
        Cincinnati, OH

As Committee Chairman, I would like to express my sincere appreciation to the Committee Members and others who contributed to the success of this effort.

William A. Cawley, Deputy Director,
IERL-Ci
Chairman, Treatability Coordination
Committee

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IV.1 INTRODUCTION

This volume presents procedures and cost data for estimating the cost of industrial wastewater treatment systems on a unit process basis. The emphasis in this volume is cost, with supporting technical information concerning process design and performance included only as necessary to develop costs from these data.

A brief overview of the cost estimating procedure used in this volume is presented as a framework for understanding subsequent cost data presentations. The unit process cost presentations are grouped according to physical-chemical, biological, sludge treatment, and disposal technologies and are numbered to correspond to the technology descriptions in Volume III. A chapter has been reserved for the possible future presentation of waste treatment system cost data for various levels of treatment on an industry by industry basis. Information is also presented on computer based cost estimating models.

Chapter 2 presents a brief overview of some of the major considerations involved in the preparation of a cost analysis and detailed instructions on the use of the cost estimating data presented in Chapter 3. In addition, information on appropriate levels of detail for a cost estimate and a table summarizing the CE Plant Construction Cost Index are provided.

Information for estimating the costs of a variety of wastewater treatment unit processes is presented in Chapter 3. Table IV.1-1 shows those technologies included in Chapter 3 as well as those technologies which are addressed in Volume III but not in Volume IV at this time.

The unit process data were derived from the BAT Effluent Limitation Guidelines engineering study for the Organic Chemicals/ Plastics and Synthetic Fibers Industries. Each unit process section contains two major sections. First is a description of the design procedure and the steps and procedures required to determine the capital and O & M costs for the unit process. Each presentation follows a standard format:

1. Basis of Design
2. Capital Costs
3. Operation and Maintenance Costs
4. Miscellaneous Costs
5. Modifications

Each unit process section includes descriptions of the key design parameters, a flow diagram, capital cost curves, equations for calculating the fixed and variable O & M requirements, and explanations of possible variations on the design procedures presented.

TABLE IV.1-1. TECHNOLOGIES INCLUDED IN VOLUME IV CHAPTER 3

Section	Category	Included
IV.3.1.1A	Activated Carbon Adsorption	X
IV.3.1.1B	Carbon Regeneration	X
IV.3.1.2A	Chemical Oxidation	X
IV.3.1.4	Chemical Reduction	
IV.3.1.5A	Precip. and Coag/Floc	X
IV.3.1.6	Distillation	
IV.3.1.7	Electrodialysis	
IV.3.1.8	Evaporation	
IV.3.1.9A	Multi-Media Filtration	X
IV.3.1.10A	Flotation	X
IV.3.1.11	Flow Equalization	X
IV.3.1.12	Ion Exchange	
IV.3.1.13A	Neutralization	X
IV.3.1.13B	Liming to a High pH	X
IV.3.1.13C	Lime Handling	X
IV.3.1.14	Oil Separation	X
IV.3.1.15	Polymeric Adsorption	
IV.3.1.16	Reverse Osmosis	
IV.3.1.17	Screening	
IV.3.1.18	Sedimentation	X
IV.3.1.19A	Ammonia Stripping	X
IV.3.1.19B	Steam Stripping	a
IV.3.1.20	Solvent Extraction	
IV.3.1.21	Ultrafiltration	
IV.3.2.1A	Activated Sludge	X
IV.3.2.1B	Aeration	X
IV.3.2.1C	Nutrient Addition	X
IV.3.2.1D	Heating/Cooling	X
IV.3.2.2	Lagoons	
IV.3.2.3A	Nitrification	X
IV.3.2.3B	Denitrification	X
IV.3.2.4	Rotating Biological Contactors	
IV.3.2.5	Trickling Filters	
IV.3.3.1	Deep Well Injection	
IV.3.3.2	Incineration	
IV.3.3.3	Land Application	
IV.3.3.4	Recycling	
IV.3.4.1	Gravity Thickening	X
IV.3.4.2A	Aerobic Digestion	X
IV.3.4.3A	Vacuum and Pressure Filtration	X
IV.3.4.4	Incineration (sludge)	X
IV.3.4.5A	Landfill	X
IV.3.4.5B	Outside Contractor	X
IV.3.5	Miscellaneous Costs	X

a) May be available at a later date.

The second major section presented for each unit process is a programmed worksheet designed to assist the user in making the necessary calculations to estimate capital and O & M costs. Each worksheet set includes a Summary Work Sheet which focuses on the development of capital cost estimates and yearly O & M costs from the components that contribute to the unit process costs. Also included is a technical Work Sheet or series of technical Work Sheets and work tables which provide the detailed equations and tabulation formats for developing the design and cost factors needed to complete component costs in the Summary Work Sheet. The Summary and technical Work Sheets are each separated into six identical sections:

I. DESIGN FACTOR
II. CAPITAL COST
III. VARIABLE O & M
IV. FIXED O & M
V. YEARLY O & M
VI. UNCOSTED ITEMS

A separate set of worksheets is included under the unit process heading of Miscellaneous Costs to assist the user in calculating common plant costs and in making final adjustments to cost estimates.

All unit process cost estimating methods have been verified to the extent feasible by comparing the hand estimated results against information from the BAT engineering study [4-2]. This test does not necessarily guarantee the results of the method will reflect "real world" costs, only that the study and the work sheet approach yield similar results.

Cost data for various levels of treatment by industry will be presented on a unit cost basis as they are compiled. These data will be presented in Chapter 4.

Chapter 5 presents information on computer based cost estimating methods. Specifically it presents an overview of the model from which the technology cost sections in Chapter 3 were derived. Information on other models may be presented in the future.

IV.2 COST ANALYSIS APPROACH

IV.2.1 INTRODUCTION

This chapter provides a brief overview of the major elements of cost analysis for industrial wastewater treatment facilities and information on their presentation in the Treatability Manual. This is not a complete reference on cost analysis; the user is encouraged to study additional references if a more complete understanding of the subject is required.

This chapter focuses on the major elements and various levels of detail of a cost analysis. It also introduces the unit process based cost estimating procedure in Chapter 3 of this volume.

The source of information for developing the Chapter 3 technology costing procedures was mainly the technical study performed for the Organic Chemicals Branch at Effluent Guidelines Division of the USEPA. The proposed method for developing the cost estimates is based largely on the computerized method used by the contractor's model for estimating costs for the Organic Chemicals/ Plastics and Synthetic Fibers Industries technical studies. The cost estimating method for all of the technology sections has been simplified to some extent to allow the easy calculation by hand. The cost estimating method presented for several technologies in Chapter 3 has been simplified to a very significant degree. These technologies include: Activated Carbon Adsorption (3.1.1A), Chemical Oxidation (3.1.2A), Coagulation/Flocculation (3.1.5A), and Activated Sludge (3.2.1A). The cost estimates developed using the methods in Chapter 3 may lead to slightly different results than would be achieved using the cost model (when it is available). The significance of any differences would have to be determined on the basis of the situation under consideration.

IV.2.2 GENERAL FACTORS IN COST ANALYSIS

This overview of the standard elements of a cost analysis is intended to provide the reader with an idea of the context within which cost information such as that in Chapter 3 is typically used. Special emphasis is placed on the relative levels of detail and reliability of cost estimates prepared during the planning stages of a project and on the additional costs involved in retrofit projects versus new construction.

IV.2.2.1 Standard Elements of a Cost Analysis

A cost estimate should provide sufficient information to allow a good understanding of the basic project, the major technical and cost assumptions, the estimated costs, and the overall economic and financial merits of the project [4-3]. The level of detail of this information may vary depending on the projected use or relative stage of development of the project, but the same types of information are generally required for any cost analysis. For purposes of this discussion, a complete cost analysis is considered to be composed of the following six elements:

Element 1	Project Background Information
Element 2	Specified Cost Factors
Element 3	Capital Cost Estimate
Element 4	Annual Cost Estimate
Element 5	Project Feasibility Assessment
Element 6	Reliability Assessment

The general nature and scope of each of these elements is indicated in Table IV.2-1. This document will focus only on Element 3 (Capital Cost Estimates), Element 4 (Annual Cost Estimates), and to a limited degree Element 2 (specified cost factors such as the construction cost index). However, it should be kept in mind that all of the elements should be addressed in a complete cost analysis.

IV.2.2.2 Basic Levels of Capital Cost Estimating

A cost estimate includes capital cost, annual cost, and financial cost elements. Of these, the capital cost estimate is generally the most difficult to make and has the greatest overall variability [4-3]. Therefore, the level of effort involved in the capital investment estimate usually determines the level of effort for the entire cost analysis. The annual cost and financial aspects of the estimate are also subject to variation, but are not as site-specific or as difficult to analyze at the early stages of a project as are the capital costs.

In general there are five basic levels of capital cost estimates. The general characteristics and relative degree of accuracy of each of the levels is described in Table IV.2-2.

The information presented in Chapter 3 of Volume IV is suitable for developing Level 1 order-of-magnitude or Level 2 study level cost estimates. This level of accuracy and effort is appropriate for cost estimates developed during the early or conceptual stages of a project since technical process information is typically not sufficient to warrent a greater level of effort.

The cost information in Chapter 3 is unit process based.. The Level 2 study estimate can be developed when there are sufficient data on the wastewater characteristics and the application of the technologies available in Chapter 3 to allow full use of the cost factors presented in the methods. When there are insufficient data on the wastewater or the treatment technology use in the specific industry does not agree well with the methods in Chapter 3, then the best estimate that can be developed would be the Level 1 order-of-magnitude estimate.

TABLE IV.2-1. STANDARD ELEMENTS OF A COST ANALYSIS

Element 1.	Project Background Information Includes basic facility description, performance specifications, and project status assessment
Element 2.	Specified Cost Factors Identifies key financial factors such as interest rates, depreciation assumptions, reference year for costs, and cost index
Element 3.	Capital Cost Estimate a) Direct Costs - equipment, structures, ancillary facilities b) Indirect Costs - engineering, contingencies, fees c) Financial and Other Costs
Element 4.	Annual Costs Estimate a) Variable O & M - varies with rate of throughput b) Fixed O & M - fixed by the size of facilities
Element 5.	Project Feasibility Analysis Presents an assessment of the profitability or financial feasibility of undertaking the proposed project
Element 6.	Reliability Assessment of the Cost Estimate Presents an assessment of the overall reliability of the cost estimate based on known and unknown factors, available data correlations, sensitivity analysis, or other formal assessment techniques

TABLE IV.2-2. DEFINITION OF FIVE BASIC TYPES OF ESTIMATES OF TOTAL PLANT COST [4-3]

Level(a) (Each has several designations)	Characteristics	Purpose	Relative Reliability(b)
1. Order-of-magnitude(c) Ratio	Rapid. Very rough.	Preliminary indication. Check on result by more detailed method.	About + 30% -60%
2. Study(c) (commonly a so-called factored estimate)	Requires flow diagram, material and energy balance, type and size equipment or unit process designs	For generalized evaluations. Guidance for further investigation. Basis for process selection. R&D guidance.	± 30%
3. Preliminary(c) Budget Authorization	In addition to type 2 information, includes surveys and some engineering of foundations, transportation facilities, buildings, structures, lighting, etc.	Basis for decision to undertake detailed engineering. Sometimes basis for budget authorization. Can be for generalized evaluation, but usually for site-specific installation.	± 20%
4. Definitive Project Control	More detailed engineering, but usually short of complete specifications and working drawings. Requires experienced estimating organization and substantial outlay.	Sometimes the basis for budget authorization. Provides improved estimate of project to be built. For site specific installations.	± 10%
5. Detailed Firm Contractor's	Complete site surveys, specifications, working drawings.	Made to control cost of project being built. For site specific installations.	± 5%

(a)This is one representation of a comprehensive list of the types of estimates for total plant cost. Other such lists differ in the number of estimate types and their descriptions.

(b)These apply for well established technologies. For newer technologies, the ranges may be wider, particularly for the first three types of estimates.

(c)The first three types of estimates are also termed "conceptual estimates."

IV.2.2.3 Consideration of Retrofit Costs

Many outside factors can affect the magnitude and accuracy of a cost estimate. Factors such as location, climate, and inflation can significantly alter a cost estimate. Such factors may be considered by the person making the estimate as appropriate for the intended use of the estimate.

One of the most significant factors which should be considered is whether the project under consideration is a retrofit of an existing facility or new construction. This can have a very significant effect on the final costs. When an addition is made to an existing plant, it is termed a retrofit and the cost normally is more than for the construction of the same unit at a new plant. The considerations regarding retrofit costs apply when a unit process type cost estimate is prepared. Besides the complex design problems, there is also the physical difficulty of integrating the process into the design scheme and constructing the retrofit unit on the plant site. Some of the factors that contribute to the additional costs are as follows:

Plant Age - May require structural modifications to plant and process alterations.

Available Space - May require extensive steel support construction and site preparation. Existing equipment may require removal and relocation. New equipment may require custom design to meet space allocations.

Utilities - Electrical, water supply, waste removal, and waste disposal facilities may require expansion.

Production Shut-down - Loss of production during retrofit must be included in overall costs.

Direct (Field) Labor - If retrofitting is accomplished during normal plant operations, installation time and labor hours will be increased. If installation occurs during off-hours, overtime wages may be necessary.

Engineering - Increased engineering costs to integrate control system into existing process.

As a rule of thumb, equivalent retrofit installation costs from 25 to 40 percent more than that for construction on a new facility [4-3].

In cases where there are multiple trains of the same unit process the cost of installing the second and third trains is about 90 to 95 percent of the cost of the first one [4-3]. This reduction in cost per unit results from the common series of engineering, purchasing, supervision, and administration of construction for the multiple train facility.

IV.2.3 COST DATA FORMAT

Chapter 3 presents a unit process based cost estimating method for wastewater treatment processes. The user of this information must have available a preliminary design of the wastewater treatment facility to be costed, including a list of unit processes which are to be used, their relative order in the system, and necessary influent and effluent conditions. The Chapter 3 technology cost presentations can then be used to estimate the capital and operation and maintenance costs of the wastewater treatment system or units under consideration. Each of the technology cost presentations includes two types of information; a text section and a cost worksheet. A patterned description of the steps and procedures required to determine the capital and O & M costs is included as text for each technology. This text includes the required design parameters for using the cost estimating method, a flow diagram of the unit process, capital cost curves, and variable O & M cost factors. The second type of information included for each technology cost presentation is a programmed worksheet series to assist the user in calculating the capital and O & M costs for the specific treatment application using the methodology for that technology. It is anticipated that the typical user of these technology cost sections could work mainly from the worksheets, relying upon the text for reference and background information.

IV.2.3.1 Technology Cost Sections

Each major technology cost section begins with an introduction that identifies the techology, its general application, and references the corresponding section in Volume III for more detailed technical information. This is followed by a standard five element presentation that identifies the design basis and capital cost basis, presents the cost curves, presents the variable and fixed O & M elements and useful factors for their calculation, and indicates methods to estimate quantities of items which will affect the subsequent design and costing of other units (e.g., land required, sludge generation). A generic technology cost section is presented in Table IV.2-3 illustrating the type of information that is typically contained in each of the five standard sections. NOTE: COMMON PLANT COSTS SUCH AS ENGINEERING, YARD PIPING, AND ADMINISTRATION BUILDINGS ARE NOT INCLUDED IN THE CAPITAL COSTS FOR INDIVIDUAL UNIT PROCESSES. COMMON PLANT COSTS MUST BE CALCULATED AS A SEPARATE ITEM, SEE MISCELLANEOUS COSTS, IV.3.5.

TABLE IV.2-3. GENERIC TECHNOLOGY/COST SECTION

A1 Basis of Design

Focuses on the development of the primary factor needed to use the cost curves but also gives a general description of the design procedure.

a) Source

Identifies the source of the information and industry for which this cost estimating method was developed.

b) Required Input Data

Identifies the data that the user must have in order to cost the system using this method.

c) Limitations

Identifies circumstances under which the technology was not considered applicable in the original study from which it was developed.

d) Pretreatment

Identifies required pretreatment systems and criteria for application.

e) Design Factor

Identifies the procedure and equations in both metric and English units needed to determine the primary factor(s) used in the cost curves. In addition any scale factors or correction factors required to properly use the cost curves are described.

f) Subsequent Treatment

Identifies any subsequent units which are required when the technology is used (e.g., clarification following activated sludge).

A2 Capital Costs

Introduces the cost factor and references the cost curves.

a) Cost Data

Identifies equipment included in the capital cost estimates for each of the systems used to develop the cost curve. The size of the equipment also is described.

b) Capital Cost Curves

Identifies the basis (e.g., size of systems) and scale of the cost curves. The specific cost points used to develop the cost curve are identified in the text, and these points are indicated on the cost curve (as a boxed point).

c) Cost Index

Identifies the date of the cost estimate and a standard engineering cost index for that date.

A3 Operation and Maintenance Costs

Introduces the major elements of the fixed and variable O & M costs.

a) Variable Cost

Presents the equations and performance variations necessary to determine the variable O & M costs (e.g., those costs that will vary in magnitude according to the type and quantity of wastewater treated). This includes costs such as power, chemicals, process water, steam, and fuel. This section is often the most technically complex part of a technology cost section since variable costs are significantly influenced by the performance and scale of the unit process.

b) Fixed Cost

Presents the fixed O & M cost factors such as labor, supervision, overhead, maintenance, and taxes, which are not influenced by the performance of the unit. These factors are based on the original study with the base year and unit cost information included.

A4 Miscellaneous Costs

Introduces the need for computing required miscellaneous costs such as yard piping, engineering, and buildings that are not directly associated with any one unit process. The computation of these normally required costs are deferred to a separate technology cost presentation on Miscellaneous Costs (Section IV.3.5). The most important information provided by this section relates to computing sludge quantities, aeration requirements, land requirements, and other items which are not directly costed for the unit process in question but which affect the costing of subsequent systems such as sludge dewatering units.

A5 Modifications

Presents supplemental information on design factors and costing methods which may be of assistance to the user.

IV.2.3.2 Worksheets

Each technology cost section is accompanied by worksheets designed to assist the user in developing cost estimates. Although the Technology cost sections present both metric and English versions of the design and O & M equations, the worksheets present only the English versions. Basically each worksheet set consists of a Summary Work Sheet which focuses on development of capital cost estimates and yearly O & M costs for the unit process, and a technical Work Sheet or series of technical Work Sheets and work tables which provide detailed equations and tabulation formats for developing the design and cost factors needed to complete the Summary Work Sheet. The Summary Work Sheet is separated into six major parts:

I	DESIGN FACTOR
II	CAPITAL COST
III	VARIABLE O & M
IV	FIXED O & M
V	YEARLY O & M
VI	UNCOSTED ITEMS

The technical Work Sheet includes the same six headings as the Summary but also includes a Section in which to list any cost factors and unit costs. Generic examples of both a Summary Work Sheet and technical Work Sheet are presented in Tables IV.2-4 and IV.2-5 respectively illustrating their typical order and format. In the following sections, a general introduction is provided on the content and use of the worksheets.

IV.2.3.2.1 Technical Work Sheet (Table IV.2-4)

Use of the worksheets should start with the technical Work Sheet for the technology of interest. The name of the technology will appear at the top of the page. In general, technical computations will be completed on this worksheet and the results transferred to the Summary Work Sheet for costing. Following is a step-by-step walkthrough of the sections of the technical Work Sheet (Table IV.2-5) and a discussion of its use in costing.

Required Cost Factors and Unit Costs

This section is provided for the user to identify the cost factors such as labor rates, cost index, and chemical costs which will be used when completing the Summary Work Sheet. A current capital cost index must be selected to adjust the costs derived using the capital cost curve (e.g., based on July 1977, St. Louis, CE Plant Index = 204.7) to the time and place of current interest. The next group of factors concerns unit costs for chemicals and utilities. These factors are highly variable depending on location and quantity purchased so some discretion is advised in selecting a unit cost. As a point of reference Table IV.2-6

TABLE IV.2-4. GENERIC SUMMARY WORK SHEET

TECHNOLOGY NAME
SUMMARY WORK SHEET — REFERENCE: Section No.

I. DESIGN FACTOR		CAPITAL
a. Factor = ________ units		
b. Scale Factor if required		
II. CAPITAL COST		
Cost = ________ (Cost from curve) × (________ (current index) ÷ 204.7)		$ ________
III. VARIABLE O & M	$/day	O & M
a. Power = ________ (Hp) × ________ (EC, $/Kw-hr) × 17.9	= ________	
b. Chemical = ________ (lb/day) × ________ ($/lb)	= ________	
c. Fuel = ________ (gal/day) × ________ ($/gal)	= ________	
d. Steam = ________ (lb/day) × ________ ($/lb)	= ________	
IV. FIXED O & M	$/day	
a. Labor: ________ (hr/day) × ________ ($/hr)	= ________	
b. Supervision: ________ (hr/day) × ________ ($/hr)	= ________	
c. Overhead: ________ (Labor, $/day) × ________ (%/100)	= ________	
d. Lab Labor: ________ (hr/day) × ________ ($/hr) %	= ________	
e. Maint, Service, I&T: ________ (capital, $) × ________ (%/100) ÷ 365	= ________	
f. Service Water: ________ (thou gpd) × ________ ($/thou gal)	= ________	
V. YEARLY O & M 365 (day/yr) × ________ (sum, $/day)		= ________ $/yr
VI. UNCOSTED ITEMS		
a. Land = ________ ft^2	b. Sludge = ________ lb/day	

TABLE IV.2-5. GENERIC technical WORK SHEET

TECHNOLOGY NAME WORK SHEET				
REQUIRED COST FACTORS AND UNIT COSTS				
1. Current Index =	______	Capital Cost Index		
2. EC: Electricity Cost =	______	\$/Kw-hr		
3. Chemical =	______	\$/lb		
4. Fuel =	______	\$/gal		
5. Steam =	______	\$/lb		
6. Labor =	______	\$/hr		
7. Supervision =	______	\$/hr		
8. Overhead =	______	% Labor ÷ 100 =	______	%/100
9. Lab Labor =	______	\$/hr		
10. Maintenance =		% Capital		
Services =		% Capital		
Insurance/Taxes =	______	% Capital		
Other O & M Factor sum =		% ÷ 100 =	______	%/100
11. Service Water =	______	\$/thou gal		

I. DESIGN FACTOR

a. Factor = ______ (Unit) × equation = ______ units

b. Scale factor

II. CAPITAL COST

III. VARIBLE O & M

a. Power Requirements

HP = ______ (factor, unit) × equation = Hp

b. Other factors

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Factors as required

TABLE IV.2-6. BASE UNIT COSTS FOR UTILITIES AND CHEMICALS (YEAR 1977) [4-2]

ITEM	UNIT COST
POWER	\$0.02/kw-hr
FUEL OIL	\$0.46/gal
STEAM	\$0.0045/lb
LIME	\$0.0149/lb
SULFURIC ACID	\$0.0215/lb
AMMONIA	\$0.0789/lb
PHOSPHATE	\$0.604/lb
SODIUM SULFIDE	\$0.1375/lb
FERRIC CHLORIDE	\$0.045/lb
ALUM	\$0.0645/lb
POLYMER	\$2.00/lb
ACTIVATED CARBON	\$0.52/lb
METHANOL	\$0.0696/lb
WASTE HAULING	\$0.0004/lb-mile
RESIDUE DISPOSAL	\$0.018/lb
SOLVENT-UNDECANE	\$0.137/lb
SOLVENT-TRICRESYL	\$0.76/lb
CAUSTIC	\$0.1575/lb
CHLORINE	\$0.0713/lb
P. PERMANGANATE	\$0.48/lb
H. PEROXIDE	\$0.386/lb
SODIUM CHLORIDE	\$0.0199/lb

Source - These costs are derived from the BAT Effluent Limitations Guidelines Engineering Study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-1].

provides the 1977 values for chemicals, electricity, steam, contract hauling, etc., which were used in the original cost source [4-1]. The user may either scale these costs to a current date or use unit cost data available from other sources (e.g., local utilities, equipment supply vendors).

The final group of factors is concerned with labor and other "fixed" operation costs. Here again current local rates may be used if known or the labor rates used by the original source may be scaled. The fixed O & M factors used by the source are indicated in a Fixed O & M table in each technology cost section. A generic fixed O & M table is shown in Table IV.2-7 to illustrate the information provided in each technology cost section. Information on items such as Maintenance, Services, and Insurance and Taxes, which are typically calculated as a percent of capital cost, is also contained in the fixed O & M table. The values included with the Chapter 3 text may be used unless substitute values more suited to local conditions are available. In any case, the percentages for maintenance, service, and insurance and taxes would be summed and this sum divided by 100 as indicated in Table IV.2-5 in order to obtain the factor which will subsequently be used to determine part IV e. of the O & M costs on the Summary Work Sheet.

I DESIGN FACTOR

This section provides a programmed approach to determining the key design factor that is used to estimate costs from the capital cost curve. For example, surface area is the key design and cost factor for sedimentation units. Therefore, a fill-in-the-blanks equation is provided in this section to determine surface area in English units. It is expected that if the user has any questions about the meaning of the equations, reference would be made to the technology cost section where the equations and terms are defined in detail.

The effort involved in determining the key design factor varies widely from one technology to another. In many cases the key factor is simply the influent flow adjusted by a simple scale factor. In other cases, the design factor is specific to the influent waste requiring more difficult calculations. In such cases Work Tables are provided in which each component of the influent waste matrix is analyzed separately in determining the overall value of the key design factor for the unit process. When Work Tables are used, detailed instructions are presented in the DESIGN FACTOR section and space is provided for performing final computations or listing the design factor which will be transferred to the Summary Work Sheet for costing purposes.

TABLE IV.2-7. GENERIC FIXED O & M TABLE FROM A TECHNOLOGY COST SECTION.

FIXED O & M COST BASIS AND UNIT COST FACTORS FOR TECHNOLOGY [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	____ Weeks (_______ hr/day)	$ 9.80/hr
Supervision (1)	____% Labor (_______ hr/day)	$11.76/hr
Overhead (1)	____% Labor Cost	NA
Laboratory Labor (3)	____ Shifts (_______ hr/day)	$10.70/hr
Maintenance	____% Capital	NA
Services	____% Capital	NA
Insurance & Taxes	____% Capital	NA
Service Water	____ Thou gpd	$ 0.50/thou gal

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

II CAPITAL COST

Capital cost computations rarely require any additional space in the technical Work Sheet. However, for some technologies a scale factor may be computed under the capital cost section. The cost from the cost curve and any scale factor are entered and adjusted using a current index on the Summary Work Sheet.

III VARIABLE O & M

Variable O & M calculations in the technical Work Sheet may be simple or complex. The horsepower requirements are presented as a regression function of the design factor computed in the DESIGN FACTOR section. Other variable O & M items such as chemical requirements may require extensive calculations to reflect the specific influent waste characteristics. In such cases supplemental work tables are provided along with detailed instructions on their use.

IV FIXED O & M

As in the case of capital cost computations, fixed O & M estimates are relatively simple and are rarely addressed in the technical Work Sheet. Using the unit cost factors for each unit process (see Table IV.2-7) or the revised factors from the REQUIRED COST FACTORS AND UNIT COSTS section, most fixed O & M cost computations may be performed on the Summary Work Sheet. However, in a few cases such as for landfill operations and for unit processes consisting of several distinct units (e.g., ammonia stripping and ammonium sulfate recovery) some computation may be required to determine the fixed O & M factors for the unit process as a whole. In these cases programmed calculation formulas are provided, with the results to be transferred to the Summary Work Sheet for final cost calculations.

V YEARLY O & M

This calculation is always performed on the Summary Work Sheet for the technologies in this report. This heading is included in the technical Work Sheet in the event that a separate estimate is developed.

VI UNCOSTED ITEMS

Uncosted items include land requirements and sludge generation which do not directly enter into the cost computations for the unit process but which affect the cost of subsequent unit processes (e.g., sludge handling) or the cost of the plant as a whole. The kinds of calculations involved in quantifying the uncosted items are similar to those involved in quantifying the design factors and variable O & M factors. Once calculated, the uncosted items are transferred to the Summary Work Sheet from which they can be easily located and transferred when needed for subsequent costing operations.

IV.2.3.2.2 Summary Work Sheet (Table IV.2-4)

Almost all of the costing calculations for an individual unit process are performed on the Summary Work Sheet (see Table IV.2-4). As noted previously, the design factors and required quantities of O & M items are calculated on the technical Work Sheet and transferred to the Summary Work Sheet for costing. Following is an introduction to the Summary Work Sheet and a discussion of its use in costing.

I DESIGN FACTOR

The key design factor as computed in the technical Work Sheet is transferred to this section along with any necessary scale factor. This provides a quick reference point for verifying the factor to be used when selecting the capital cost from the cost curve.

II CAPITAL COST

The capital cost of the unit process as designed is computed in this section. The capital cost from the cost curve in the associated technology cost section is entered along with the current cost index, with the current capital cost estimate for the unit process computed. In those instances where the scale factor is applied to the cost rather than to the design factor, a space for entering it will also be shown in the capital cost equation.

III VARIABLE O & M

The daily cost of the variable O & M items are computed in this section. The required quantities of power, chemicals, etc., are transferred from section III of the technical Work Sheet and multiplied by the current unit cost from the REQUIRED COST FACTORS AND UNIT COSTS section to yield daily cost.

IV FIXED O & M

Fixed O & M item costs are estimated as a daily cost in a manner very similar to variable O & M. The exception is that the quantities of labor, supervision, laboratory labor, and service water must be transferred from the Fixed O & M table in the technology cost section (see Table 4 for example) rather than from the technical Work Sheet. The cost quantities are then multiplied by the current unit costs from the REQUIRED COST FACTORS AND UNIT COSTS section to yield daily cost. Maintenance, Services, and Insurance and Taxes are determined as a specified percentage of capital cost. For these items the capital cost is multiplied by the sum of percentages from the REQUIRED COST FACTORS AND UNIT COSTS section and divided by 365 to yield daily cost.

V YEARLY O & M

Yearly O & M is the sum of the daily variable and fixed O & M costs multiplied by 365 days/yr. Note that this sum may not reflect the actual O & M cost for the unit process, since several of these O & M cost items may be adjusted to reflect the size of the treatment facility. This is addressed in Miscellaneous Costs, Section IV.3.5.

VI UNCOSTED ITEMS

The quantities of uncosted items computed in the technical Work Sheet are recorded in this section for subsequent costing operations.

IV.2.3.2.3 Summary on the Use of Work Sheets

The work sheets are provided to facilitate the use of costing information provided in the technology cost sections. Calculations and decision points in the work sheets are often abbreviated or combined for the sake of conciseness and do not show all of the elements individually that contribute to the equation (e.g., several conversion factors or design factors will be combined into one number). Thus, the work sheets are not intended to stand alone as a cost estimating tool but need to be used in conjunction with the technology cost section in order to clarify the meaning of variables and variable names, fixed O & M cost factors, and critical decision points in system design.

IV.2.4 COST INDEX

The cost curves presented in Chapter 3 are based on CE Plant construction cost index of 204.7. This reflects construction costs in St. Louis in July 1977. The CE Plant index appears bimonthly in Chemical Engineering Magazine and an annual update is published in April of each year. It is a useful indicator of changes in construction costs for process type projects requiring steel and skilled erection labor. The CE Plant index reflects a weighting of current costs as follows: equipment, machinery and supports, 61%; erection and installation labor, 22%; buildings, material and general labor, 7%; and engineering and supervision 10%.

A summary of recent values for the CE Plant construction index is presented in Table IV.2-8.

TABLE IV.2-8. SUMMARY OF CE PLANT CONSTRUCTION COST INDEX

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Average
1970													125.7
1971													132.2
1972													137.2
1973													144.1
1974													165.4
1975													182.4
1976													192.1
1977			199.3	200.3	201.4	202.3	204.7	206.4	208.8	209.0	209.4	210.3	204.1
1978	210.6	213.1	214.1	215.7	216.9	217.7	219.2	221.6	221.6	223.5	224.7	225.9	218.8
1979	229.8	231.0	232.5	234.0	236.6	237.2	239.3	240.7	243.4	245.8	245.8	247.6	238.7
1980	248.5	250.8	253.5	257.3	258.5	259.2	263.6	264.9	266.2	268.6	269.7	272.5	261.2
1981	276.6	280.5	286.3	290.3	295.2	298.2	303.1	305.2	307.8	308.4	306.6	305.6	297.0
1982	311.8	310.7	311.4	313.2	314.5	313.3	314.2	315	315.6	316.3	315.1	316.1	313.9
1983	315.3*												

Based on St. Louis construction and labor rates.
*Revised not final.

IV.3 TECHNOLOGY COST DATA

Cost data are presented in this chapter for industrial wastewater unit processes. The format used in these Technology cost sections is described in Chapter 2. The user who is not familiar with the format of these sections is advised to review the Chapter 2 information to fully understand the limits and use of these cost data.

IV.3.1.1 ACTIVATED CARBON ADSORPTION

Introduction

Activated carbon adsorption is a physical separation process in which organic and inorganic materials are removed from wastewater by sorption onto the carbon surface. The typical process may use either a granular carbon in a fixed or moving bed for the sorbent or may use a powdered carbon in a slurry system. Further details describing this process can be found in Volume III, Section III.3.1.1 of the Treatability Manual. Costing methodologies and cost data for industrial wastewater treatment applications are presented below.

IV.3.1.1-A. Granular Activated Carbon Adsorption

A 1. Basis of Design

This cost estimate is for a granular activated carbon adsorption system using fixed beds. The primary cost factor is the bed volume required for attaining the desired pollutant removal. A small bed system (volume ≤34 m^3 (≤1200 ft^3)) and a large bed system (volume >34 m^3 (>1200 ft^3)) of the type considered are illustrated in Figure IV.3.1.1-A1 and Figure IV.3.1.1-A2, respectively.

Bed volume may be estimated based on the empty column hydraulic contact time. It is assumed that for low order systems (bed volume ≤34 m^3 (≤1200 ft^3)) the contact time with all units operating is 30 min while for high order systems (bed volume >34 m^3 (>1200 ft^3)) the contact time with all units operating is 20 min [4-2]. Hydraulic surface loadings were used to develop column designs with respect to depth and surface area. Surface loadings were assumed to be in the range of 3.4 L/s/m^2 (5 gpm/ft^2) for high order systems and 1.15 L/s/m^2 (1.7 gpm/ft^2) for low order systems. The lower surface loading for low order systems is due to the fact that a minimum of three columns is used and each column is designed on the basis of a 3.4 L/s/m^2 (5 gpm/ft^2) surface loading rate for the entire flow [4-2].

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2].

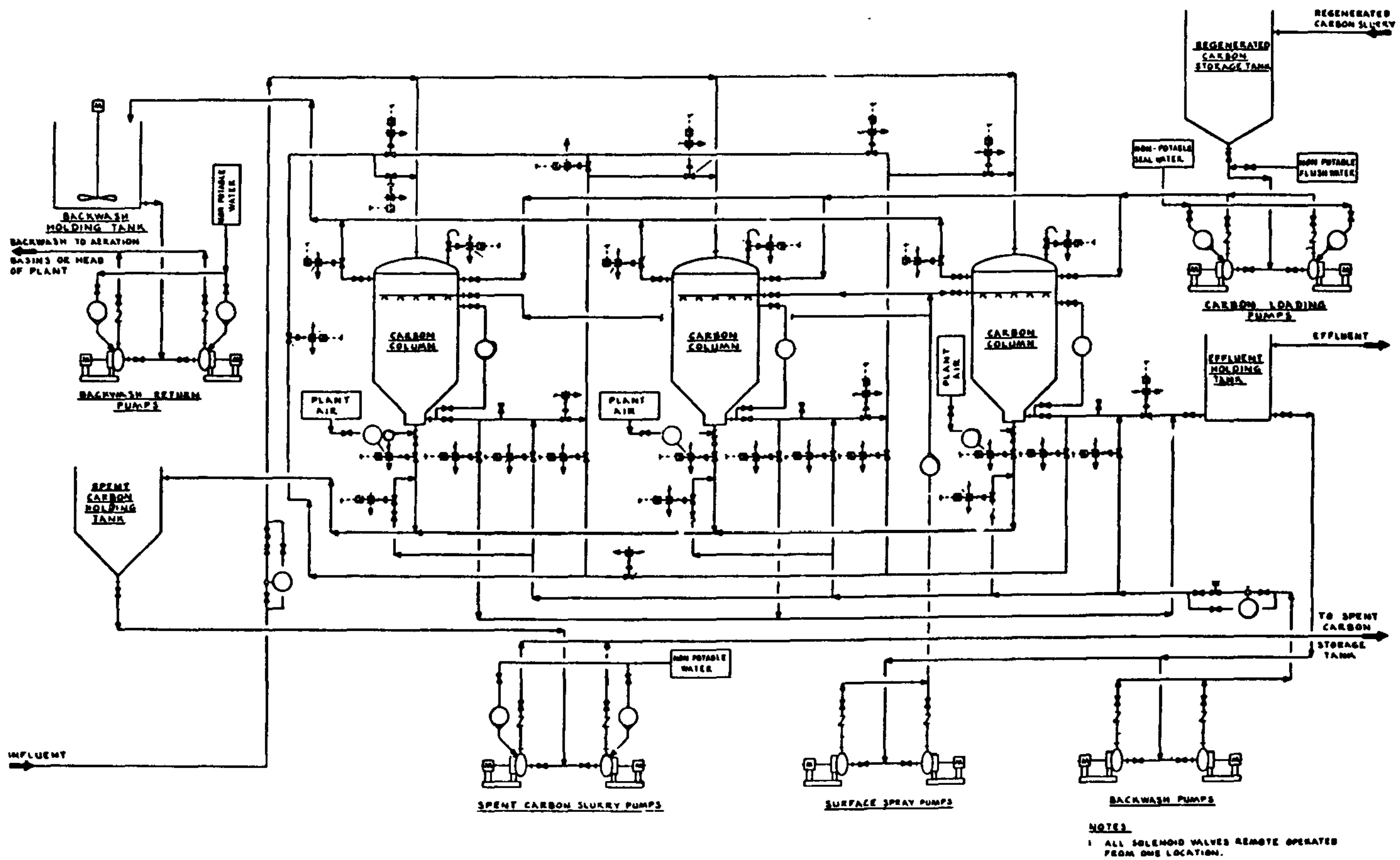


FIGURE IV.3.1.1-A1. PROCESS FLOW DIAGRAM FOR ACTIVATED CARBON ADSORPTION (LOW ORDER) [4-1]

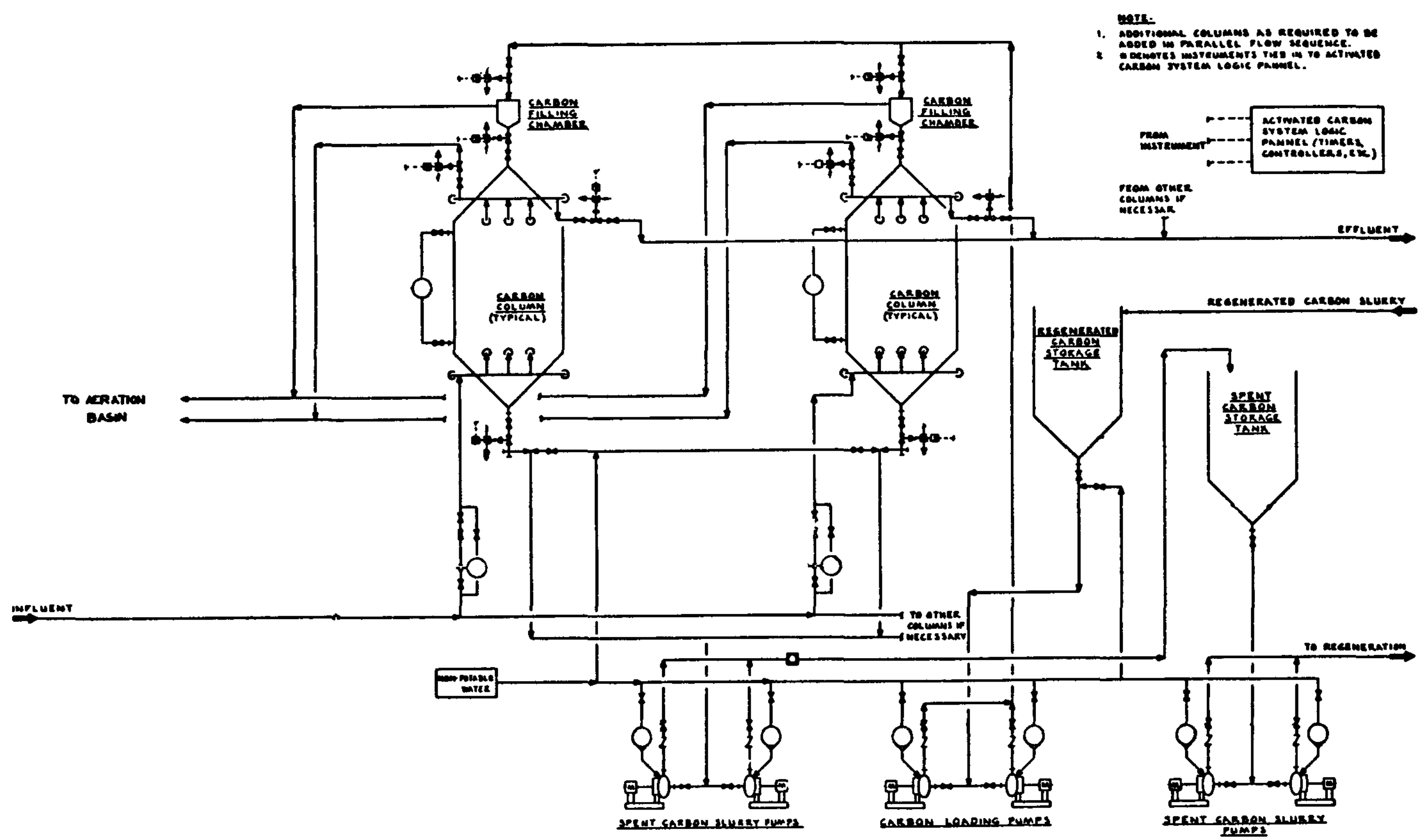


FIGURE IV.3.1.1-A2. PROCESS FLOW DIAGRAM FOR ACTIVATED CARBON ADSORPTION (HIGH ORDER) [4-1]

b) Required Input Data

Wastewater flow, L/s (mgd)
Carbon use rate, Kg carbon/L (lb carbon/1,000 gal)
Priority pollutants of concern (mg/L)
Oil and grease (mg/L)
TSS (mg/L)

c) Limitations

Granular activated carbon adsorption is not considered applicable if all treatable pollutants including organic priority pollutants are present in concentrations less than their lowest expected effluent value.

d) Pretreatment

Pretreatment should be provided as indicated for the following conditions:

i) If influent TSS >25 mg/L, then multi-media filtration should be provided upstream of carbon adsorption.

ii) If influent oil >35 mg/L, then oil removal should be provided upstream of carbon adsorption.

(e) Design Factor

The primary capital cost factor used for the granular activated carbon adsorption system is the bed volume required. Bed volume is determined from the flow and the hydraulic contact time as follows:

Metric

$$BV = (FLOW \times CT \times 60 \times 0.001)$$

where: BV = bed volume, m^3
FLOW = influent flow, L/S
CT = contact time, min
60 = seconds/min
0.001 = m^3/L

English

$$BV = (FLOW \times 10^6 \times CT) \div (1440 \times 7.48)$$

where: BV = bed volume, ft^3
FLOW = influent flow, mgd
10^6 = conversion factor, mgd to gpd
CT = hydraulic contact time, min
1440 = min/day
7.48 = gal/ft^3

The low order cost curve (Figure IV.3.1.1-A3) reflects vertical, downflow type systems designed with an empty column hydraulic contact time of approximately 30 minutes while the high order curve (Figure IV.3.1.1-A4) reflects pulsed bed upflow type systems designed with an empty column hydraulic contact time of approximately 20 minutes (Range 17 to 29). This should be taken into account during column sizing and costing.

(f) <u>Subsequent Treatment</u>

None specified, but spent carbon must be regenerated or replaced.

A 2. Capital Costs

The activated carbon adsorption capital cost estimate is based on the bed volume required. The capital cost may be estimated using Figure IV.3.1.1-A3 for low order systems (bed volumes $\leq 34\ m^3$, $1200\ ft^3$). The capital cost for high order systems may be estimated using Figure IV.3.1.1-A4 (bed volumes $>34\ m^3$, $1200\ ft^3$). Costs estimated using these curves must be adjusted to a current value using an appropriate current cost index.

a) <u>Cost Data</u>

The items included in the capital cost estimates are as follows [4-2]:

i) Low Order Systems Bed Volume $\leq 34\ m^3$ ($\leq 1200\ ft^3$)
Carbon columns (pressurized, steel, rubber lined, downflow with 100% bed expansion volume)
0.876 L/s - 3@ 0.61 m diam, 7.32 m height, 60 min contact
(0.02 mgd - 3@ 2 ft diam, 24 ft height, 60 min contact)

4.38 L/s - 3@ 1.22 m diam, 4.88 m height, 30 min contact
(0.10 mgd - 3@ 4 ft diam, 16 ft height, 30 min contact)

8.76 L/s - 3@ 1.83 m diam, 4.27 m height, 30 min contact
(0.20 mgd - 3@ 6ft diam, 14 ft height, 30 min contact)

17.5 L/s - 3@ 2.59 m diam, 4.27 m height, 30 min contact
(0.40 mgd - 3@ 8.5 ft diam, 14 ft height, 30 min contact)

Carbon holding tanks (2)
Backwash holding tank
Initial carbon charge 0.762, 3.81, 7.58, and 15.1 Mg, respectively (0.84, 4.2, 8.36, and 16.7 tons, respectively)

FIGURE IV.3.1.1-A3.
CAPITAL COST ESTIMATE FOR
ACTIVATED CARBON ADSORPTION
(LOW ORDER) [4-10]

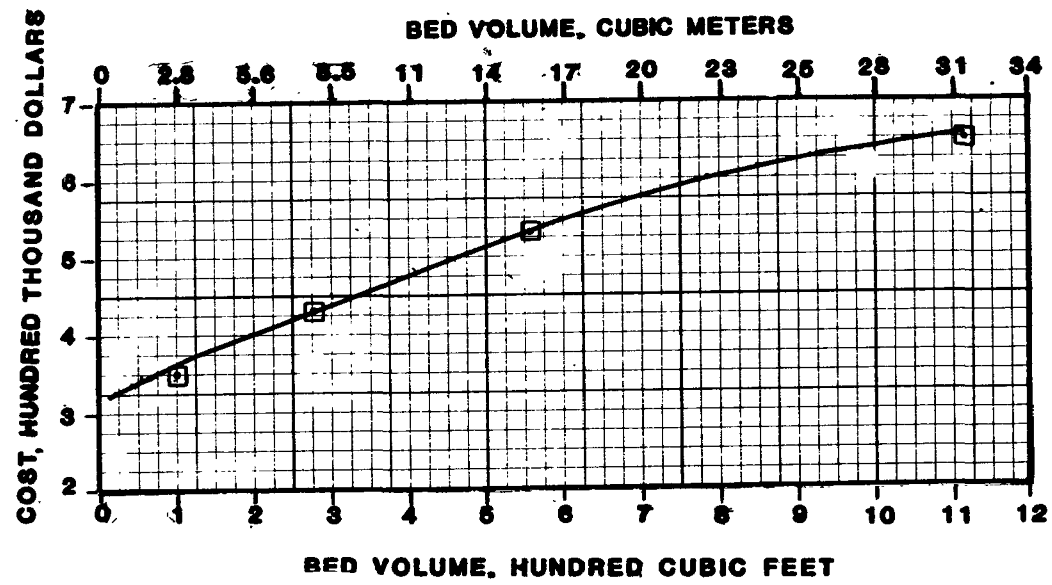
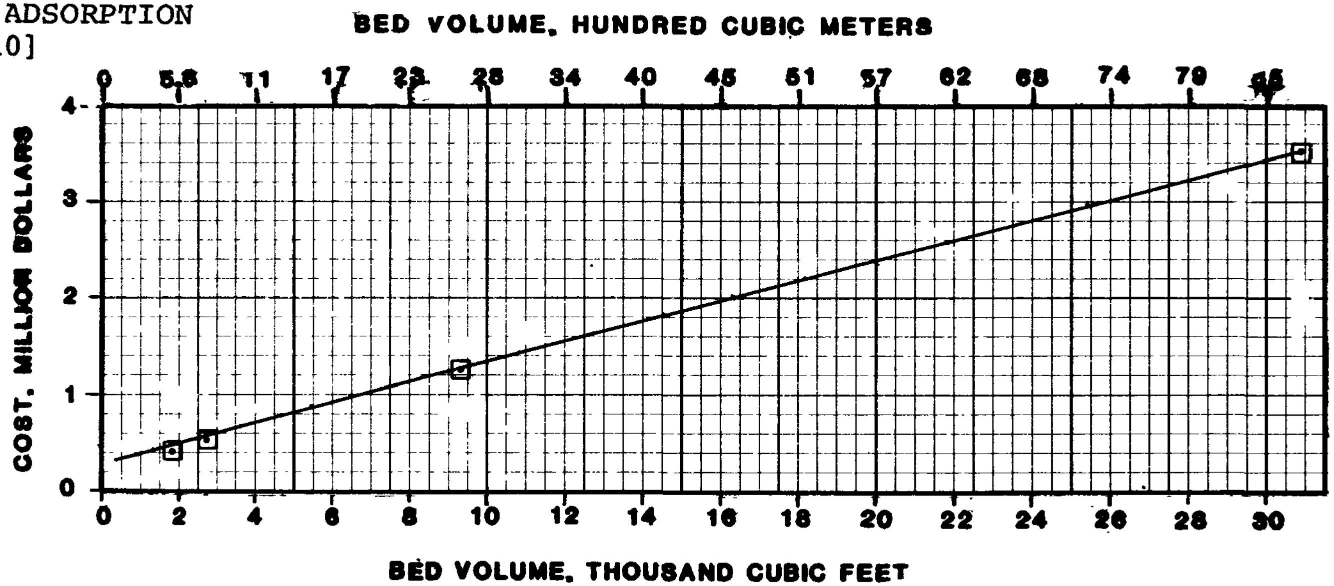


FIGURE IV.3.1.1-A4.
CAPITAL COST ESTIMATE FOR
ACTIVATED CARBON ADSORPTION
(HIGH ORDER) [4-10]



Pumps (feed, backwash, surface spray, carbon transfer, backwash return)
Agitators for carbon holding tanks
Instruments, piping, electrical

ii) High Order Systems Bed Volume >34 m^3 (>1200 ft^3)
Carbon columns (pulsed bed, steel, rubber lined, upflow)
21.9 L/s - 2 plus spare @ 2.59 m diam, 4.88 m height, 39 min contact
(0.5 mgd - 2 plus spare @ 8.5 ft diam, 16 ft height, 39 min contact)

43.8 L/s - 3 plus spare @ 2.59 m diam, 4.88 m height, 29 min contact
(1.0 mgd - 3 plus spare @ 8.5 ft diam, 16 ft height, 29 min contact)

219 L/s - 7 plus spare @ 3.35 m diam, 4.27 m height, 20 min contact
(5.0 mgd - 7 plus spare @ 11 ft diam, 14 ft height, 20 min contact)

876 L/s - 21 plus spare @ 3.66 m diam, 3.96 m height, 17 min contact
(20.0 mgd - 21 plus spare @ 12 ft diam, 13 ft height, 17 min contact)

Spent carbon holding tank
Regenerated carbon holding tank
Initial carbon charge 37.2, 49.9, 145, and 440 Mg, respectively (41, 55, 160, and 485 tons, respectively)
Pumps (feed, spent carbon, regenerated carbon)
Instruments, piping, electrical

b) <u>Capital Cost Curves</u>

i) Low Order Systems (bed volume ≤34 m^3 or ≤1200 ft^3) - Figure IV.3.1.1-A3.
- Cost (hundred thousand dollars) vs. bed volume (m^3 or ft^3)
- Curve basis, cost estimate on four systems at flow rates of 0.876, 4.38, 8.76, and 17.5 L/s (0.02, 0.10, 0.20, and 0.40 mgd) (carbon bed volumes 3.17, 7.88, 15.8, and 31.6 m^3 (112, 278, 557, and 1,115 ft^3))

ii) High Order Systems (bed volume >34 m^3 or >1200 ft^3) - Figure IV.3.1.1-A4.
- Cost (millions of dollars) vs. bed volume (m^3 or ft^3)
- Curve basis, cost estimate on four systems at flow rates of 21.9, 43.8, 219, and 876 L/s (0.5, 1.0, 5.0 and 20 mgd) (carbon bed volumes 51.3, 77, 263 and 874 m^3 (1,814, 2,721, 9,310, and 30,870 ft^3)

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable component of operating cost is the power for pumps. Costs for simple replacement of carbon for a small system may be calculated as shown in Section A4. Costs for carbon regeneration are estimated as shown in Carbon Regeneration (Section IV.3.1.1-B). Fixed operating costs include labor, supervision, overhead, maintenance, laboratory labor, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Costs

i) Power Requirement - pumps, low order systems (bed volume $\leq 34\ m^3$ ($\leq 1200\ ft^3$)) [4-1]. This equation was developed using regression analysis procedures.

Metric

$$KW = (0.564 \times BV) + 4.75$$

where: KW = power, kilowatts
BV = bed volume, m^3

English

$$HP = (0.0214 \times BV) + 6.37$$

where: HP = power, Hp
BV = bed volume, ft^3

ii) Power Requirement - pumps, high order systems (bed volume $>34\ m^3$ ($>1200\ ft^3$)) [4-1]. This equation was developed using regression analysis procedures.

Metric

$$KW = (0.116 \times BV) + 11.1$$

where: KW = power, kilowatts
BV = bed volume, m^3

English

$$HP = (0.00441 \times BV) + 14.9$$

where: HP = power, Hp
BV = bed volume, ft^3

iii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, \$/day
KW = power, kilowatts
24 = hr/day
EC = electricity cost, \$/KW

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, \$/day
EC = electricity cost, \$/Kw-hr
24 = hr/day
0.746 = KW-hr/Hp-hr

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.1.1-A1, including the cost basis and unit costs [4-11].

A 4. Miscellaneous Costs

Costs for engineering, and common plant items such as piping and buildings, are calculated after design and costing for all unit processes are completed (see Section IV.3.5).

The amount of carbon required by the system is calculated to facilitate design and cost estimates for subsequent systems.

Spent carbon must be regenerated or replaced. The decision whether to replace or regenerate is based on the carbon use rate. Carbon regeneration may be appropriate (see Section IV.3.1.1-B) for systems using more than 454 Kg/day (1000 lb/day) of carbon. For smaller systems exhausted carbon may be replaced and discarded. The carbon use rate is highly dependent on the characteristics of the waste being treated. Carbon use rates observed for wastewaters from several different industrial categories are presented in Table IV.3.1.1-A2 for guidance. Also see Section III.3.1.1 of Volume III for more information on this subject.

i) Quantity of Carbon Use

Metric

$$CU = FLOW \times CUR \times 86{,}400$$

TABLE IV.3.1.1-A1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR ACTIVATED CARBON ADSORPTION [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.30 Weeks (7.20 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.72 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.25 Shifts (1.43 hrs/day)	$10.70/hr
Maintenance	5.5% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.16 L/s (3.56 Thou gpd)	$ 0.13/thou. L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

TABLE IV.3.1.1-A2. REPRESENTATIVE CARBON ADSORPTION DESIGN DATA FOR VARIOUS INDUSTRIAL CATEGORIES [4-7]

SIC Code	Industrial Category	Adsorption, Phenol Kg/Kg (lb/lb) carbon	Adsorption TOC Kg/Kg (lb/lb) carbon	Empty Bed Hydraulic contact time, min	Carbon Use Rates Kg/L (lb/1000 gal)
286	Industrial Organic Chemicals	0.004	0.04	90-540	1.1-168 (9.5-1400)
287	Pesticides	0.03	0.01	72-760	5.16 (43)
282	Plastics	0.009	-	30-190	-
2911	Refinery	-	0.36	50-109	0.120 (1)
2899	Specialty Organics	-	-	60	-
2892	Explosives		0.08	9.2	-
2272	Textiles	-	0.08	9	-
283	Drugs	-	-	120	-
2999	Coke Products	-	-	116	4.20 (35)

where: CU = carbon use, Kg/day
FLOW = influent flow, L/s
CUR = carbon use rate, Kg carbon/L
86,400 = s/day

English

$$CU = FLOW \times CUR \times 1000$$

where: CU = carbon use, lb/day
FLOW = influent flow, mgd
CUR = carbon use rate, lb carbon/1000 gal (see Table IV.3.1.1-A2)
1000 = conversion, mil gal to 1000 gal

ii) Cost of Carbon Replacement

- *if* CU >454 Kg/day (>1000 lb/day) see Section IV.3.1.1-B, Carbon Regeneration

- *if* CU <454 Kg/day (<1000 lb/day) estimate cost of replacement carbon as shown below

$$CRC = CU \times CP$$

where: CRC = carbon replacement cost, $/day
CU = carbon use, Kg/day or lb/day
CP = price of replacement carbon, $/Kg or $/lb

A 5. Modifications

None required.

ACTIVATED CARBON ADSORPTION
SUMMARY WORK SHEET

REFERENCE: IV.3.1.1-A

I. DESIGN FACTOR — CAPITAL

a. Bed Volume = ______ ft^3

II. CAPITAL COST

Cost = ______ (Cost from curve) × (______ (current index) ÷ 204.7) — $ ______

III. VARIABLE O & M — $/day — O & M

a. Power = ______ (Hp) × ______ (EC, $/Kw-hr) × 17.9 = ______

b. Carbon Cost = ______ (CU, lb/day) × ______ (CP, $/lb) = ______

IV. FIXED O & M

a. Labor: ______ (hr/day) × ______ ($/hr) = ______

b. Supervision: ______ (hr/day) × ______ ($/hr) = ______

c. Overhead: ______ (Labor, $/day) × ______ (%/100) = ______

d. Lab Labor: ______ (hr/day) × ______ ($/hr) = ______

e. Maint, Service, I&T: ______ (capital, $) × ______ (%/100) ÷ 365 (day/yr) = ______

f. Service Water: ______ (thou gpd) × ______ ($/thou gal) = ______

V. YEARLY O & M — 365 (day/yr) × ______ (sum, $/day) = ______ $/yr

VI. UNCOSTED ITEMS

a. Carbon Use (to be regenerated) = ______ lb/day

ACTIVATED CARBON ADSORPTION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ \$/Kw-hr

3. CP: Replacement Carbon = ________ \$/lb

4. Labor = ________ \$/hr

5. Supervision = ________ \$/hr

6. Overhead = ________ % Labor ÷ 100 = ________ %/100

7. Lab Labor ________ \$/hr

8. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor Sum = % ÷ 100 = ________ %/100

9. Service Water = ________ \$/thou gal

I. DESIGN FACTOR

1. Hydraulic Contact Time

   CT = ________ min

2. Bed Volume

$$BV = (\underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times \underset{\text{CT, min}}{\underline{\qquad\qquad}}) \times 92.8 = \underline{\qquad\qquad}\ ft^3$$

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements, low order systems

$$HP = (0.0214 \times \underset{BV,\ ft^3}{\underline{\hspace{3cm}}}) + 6.37 = \underline{\hspace{2cm}}\ Hp$$

b. Power Requirements, high order systems

$$HP = (0.00441 \times \underset{BV,\ ft^3}{\underline{\hspace{3cm}}}) + 14.9 = \underline{\hspace{2cm}}\ Hp$$

c. Carbon replacement cost, for carbon use less than 1000 lb/day

$$CRC = \underset{CU,\ lb/day}{\underline{\hspace{2cm}}} \times \underset{CP,\ \$/lb}{\underline{\hspace{2cm}}}$$

see part a. VI.2 for determination of carbon use (CU)

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Carbon Requirement

1. Carbon Use Rate

$$CUR = \underline{\hspace{2cm}}\ \text{lb carbon/1000 gpd}$$

2. Daily Carbon Use Requirement

$$CU = \underset{FLOW,\ mgd}{\underline{\hspace{2cm}}} \times \underset{CUR\ lb/1000\ gpd}{\underline{\hspace{3cm}}} \times 1000 = \underline{\hspace{2cm}}\ lb/day$$

- If CU >1000 lb/day, see Section IV.3.1.1-B to estimate cost of carbon regeneration.
- If CU <1000 lb/day, see III c. above to estimate cost of carbon replacement.

IV.3.1.1-B. Carbon Regeneration

B 1. Basis of Design

This cost estimate is for the thermal regeneration of granular activated carbon using a hydraulic conveyance system and a multiple-hearth regeneration furnace. A system of the type considered is illustrated in Figure IV.3.1.1-B1. The primary cost factor is the required surface area of the regeneration furnace. A maximum furnace size of $48.3 m^2$ ($520 ft^2$) is used, with the number of furnaces varied to provide the total required furnace capacity. The total carbon use is the basis for determining the required hearth surface area for the furnace, based on an assumed carbon loading rate of 195 $Kg/day/m^2$ (40 $lb/day/ft^2$).

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

Carbon use Kg/day (lb/day) from the carbon adsorption unit process

c) Limitations

Carbon regeneration is used only when carbon usage exceeds 454 Kg/day (1000 lb/day). Below that level, spent carbon is disposed to landfill and replaced with unused carbon.

d) Pretreatment

None specified.

e) Design Equation

The principal factor used to estimate capital costs is the required hearth surface area for the carbon regeneration furnace. This is computed based on the carbon usage as follows:

Metric

$$TFSA = 1.2 \times CU \div RRATE$$

where: TFSA = total furnace surface area, m^2
CU = carbon usage, Kg/day (see Section 4a of Carbon Adsorption)

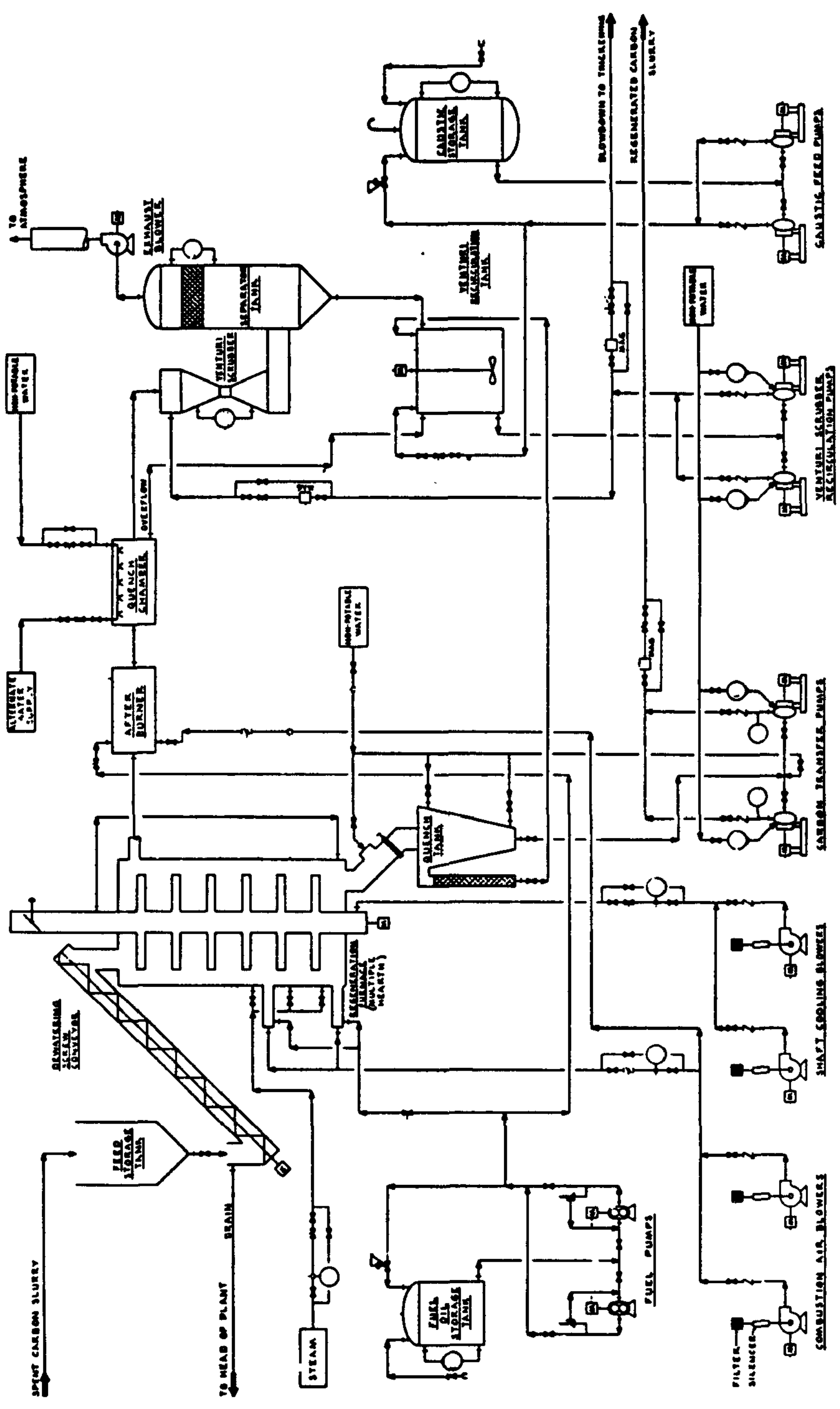


FIGURE IV.3.1.1-B1. PROCESS FLOW DIAGRAM FOR ACTIVATED CARBON REGENERATION [4-1]

RRATE = rate of carbon loading in furnace, $Kg/day/m^2$ (195 $Kg/day/m^2$ is the default value)
1.2 = allowance factor for 20% down time

English

$$TFSA = 1.2 \times CU \div RRATE$$

where: TFSA = total furnace surface area, ft^2
CU = carbon usage, lb/day (see Section 4a of Carbon Adsorption)
RRATE = rate of carbon loading in furnace, $lb/day/ft^2$
= 40 $lb/day/ft^2$ (default value) (see Table IV.3.1.1-A1) [4-2]
1.2 = allowance factor for 20% down time

The number of furnaces must be adjusted so that the average size is less than $48.3m^2$ (520 ft^2).

Metric

$$CN = TFSA \div 48.3$$

where: CN = computed number of furnaces
48.3 = maximum individual furnace size, m^2

English

$$CN = TFSA \div 520$$

where: CN = computed number of furnaces
520 = maximum individual furnace size, ft^2

The actual size of each furnace is computed after rounding to the next highest whole unit (N)

$$DFSA = TFSA \div N$$

where: DFSA = design furnace surface area, m^2 or ft^2
N = design number of furnaces
CN rounded up to next whole number

f) Subsequent Treatment

None specified, although scrubber water from the air cleaning system might require treatment.

A 2. Capital Costs

The design surface area for each regeneration furnace is the primary cost factor necessary for estimating capital costs. The number of furnaces required is used to determine a scale factor for adjusting the total capital cost, based on the cost estimate per furnace presented in Figure IV.3.1.1-B2.

a) Cost Data

Items included in the capital cost curve estimates are as follows [4-2]:

Multiple Hearth Incinerator Package including feed hopper, dewatering screw, blowcase, afterburner, venturi, and scrubber (sizes 3.34, 7.9, 17.7, 40.3, and 48.3 m^2 hearth area (36, 85, 191, 434, and 521 ft^2 hearth area))
Oil Storage Tank
Venturi Recirculation Tank
Caustic Storage Tank
Pumps (venturi recirculation, caustic transfer, carbon transport, carbon slurry sump, fuel oil)
Agitators
Piping
Instrumentation

b) Capital Cost Curves

i) Curve - Figure IV.3.1.1-B2.
- Cost per furnace (thousands of dollars) vs. hearth area (square meters or square feet).
- Curve basis, cost estimate for five systems designed with hearth surface areas of 3.34, 7.9, 17.7, 40.3, and 48.3m^2 (36, 85, 191, 434, and 521 ft^2)

ii) Scale factor to convert cost per furnace to total capital cost

$$COST = CPF \times (N)^{0.8}$$

where: COST = total capital cost
CPF = cost per furnace based on design furnace surface area (DFSA)
N = design number of required furnaces

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. Variable operating costs include power, steam, fuel oil, and service water. Fixed operating costs include labor, supervision, overhead, maintenance, laboratory labor, services, insurance and

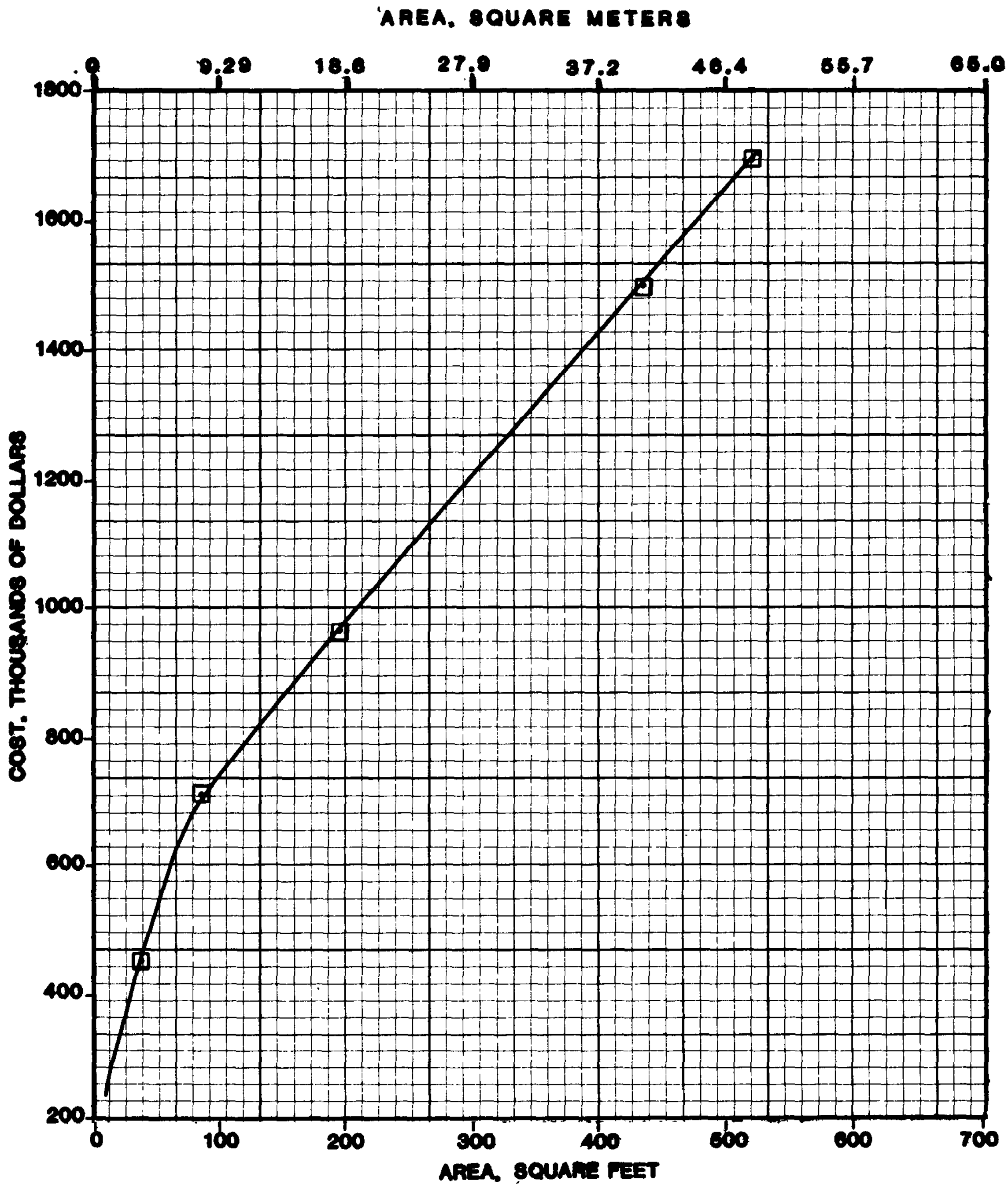


FIGURE IV.3.1.1-B2. CAPITAL COST ESTIMATE FOR CARBON REGENERATION [4-10] taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Costs

i) Power Requirements - combustion air blower, shaft cooling blower, venturi recirculation pumps, caustic transfer pumps, carbon transfer pumps, carbon sump pumps, and fuel oil pump agitator. The following equation was developed using regression analysis procedures [4-1].

Metric

$$KW = (0.5 \times TFSA) + 2.93$$

where: KW = power, kilowatts
TFSA = total furnace surface area, m^2

English

$$HP = (0.0623 \times TFSA) + 3.93$$

where: HP = power, Hp
TFSA = total furnace surface area, ft^2

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, \$/day
KW = power, kilowatts
24 = hour/day
EC = electricity cost, \$/Kw-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, \$/day
HP = power, Hp
24 = hr/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, \$/Kw-hr

iii) Steam Requirements - steam is added to the furnace at the rate of one pound of steam per pound of carbon

$$STEAM = 1.0 \times CU$$

where: STEAM = steam usage, Kg/day or lb/day
CU = carbon usage, Kg/day or lb/day
1.0 = Kg steam/Kg carbon or lb steam/lb carbon

iv) Steam Cost

$$TSC = STEAM \times CPP$$

where: TSC = total steam cost, $/day
STEAM = steam usage, Kg/day or lb/day
CPP = cost per Kg or lb of steam, $/Kg or $/lb

v) Fuel Requirement - this is based on total heat, supplied with fuel oil

Metric

$$FUEL = JPD \div (41900 \times 0.869)$$

where: FUEL = fuel, L/day
JPD = heat required, KJ/day
= CU × 18600 × 1.2 × 1.1
CU = carbon usage, Kg/day
18600 = KJ/Kg carbon
1.2 = allowance for 20% downtime
1.1 = allowance for 10% carbon loss during regeneration
41900 = fuel heating value, KJ/Kg
0.869 = conversion factor, Kg fuel/L fuel

English

$$FUEL = BTU \div (18000 \times 7.25)$$

where: FUEL = fuel, gal/day
BTU = heat required, BTU/day
= CU × 8000 × 1.2 × 1.1
CU = carbon usage, lb/day
8000 = BTU/lb carbon
1.2 = allowance for 20% down time
1.1 = allowance for 10% carbon loss during regeneration
18,000 = fuel heating value, BTU/lb
7.25 = conversion, lb fuel/gal fuel

vi) Fuel Cost

$$TFC = FUEL \times FCPG$$

where: TFC = total fuel cost, \$/day
FUEL = fuel, L/day or gal/day
FCPG = fuel cost, \$/L or \$/gal

vii) Service Water Requirements - this is for scrubber water and for carbon quenching

- Scrubber Water

Metric

SCRWT = ACFM × 2.01 ÷ 60

where: SCRWT = scrubber water, L/s
ACFM = furnace air requirement, m^3/min
= (FUEL × 0.869 ÷ 1440) × 0.5 × 24.2 × (367 ÷ 294) × 1.1
FUEL = fuel required, L/day
0.869 = conversion factor, Kg fuel/L fuel
1440 = min/day
0.5 = 0.5 Kg-mole air/Kg fuel
24.2 = m^3 air/Kg-mole air (at 21°C)
367 ÷ 294 = volumetric ratio, 93°C to 21°C (367°K to 294°K)
1.1 = 10% excess air factor
2.01 = L water/m^3 air
60 = seconds/minute

English

SCRWT = ACFM × 0.015 × 1440 ÷ 1000

where: SCRWT = scrubber water, thousand gal/day
ACFM = furnace air requirement, ft^3/min
= (FUEL × 7.25 ÷ 1440) × 0.5 × 387 × (660 ÷ 530) × 1.1
FUEL = fuel required, gal/day
7.25 = conversion factor, lb fuel/gal fuel
1440 = conversion, min/day
0.5 = 0.5 lb-mole air/lb fuel
387 = ft^3 air/lb-mole air (at 70°F)
660 ÷ 530 = volumetric ratio, 200°F to 70°F (660°R to 530°R)
1.1 = 10% excess air factor
0.015 = gal water/ft^3 air
1440 = conversion, min/day
1000 = conversion, gal to thousand gal

- Quench Water

Metric

QUNWT = JPD ÷ (2400 × 1.0 × 86400)

where: QUNWT = quench service water, L/s
JPD = heat required, KJ/day [see (v) Fuel Requirement]
2400 = heat of vaporization, KJ/Kg water
1.0 = Kg water/L water
86400 = conversion, s/day

English

$$QUNWT = BTU \div (1030 \times 8.34 \times 1000)$$

where: QUNWT = quench service water, thousand gal/day
BTU = heat required, BTU/day [see (v) Fuel Requirement]
1030 = heat of vaporization, BTU/lb water
8.34 = lb water/gal water
1000 = conversion, gal to thousand gal

viii) Service Water Cost

Metric

$$WC = (SCRWT + QUNWT) \times WCPL \times 86400$$

where: WC = service water cost, $/day
SCRWT = scrubber water, L/s
QUNWT = quench water, L/s
WCPL = water cost, $/L
86400 = seconds/day

English

$$WC = (SCRWT + QUNWT) \times WCPG$$

where: WC = service water cost, $/day
SCRWT = scrubber water, thousand gal/day
QUNWT = quench water, thousand gal/day
WCPG = water cost, $/thousand gal

ix) Carbon Replacement - a 10% loss of carbon per cycle is assumed during regeneration.

$$CR = CU \times 0.1$$

where: CR = carbon replacement rate, Kg/day or lb/day
CU = carbon use, Kg/day or lb/day
0.1 = 10% replacement factor

x) Carbon Cost

$$CRBCOST = CR \times CCPP$$

where: CRBCOST = cost of replacement carbon, \$/day
CR = carbon replacement rate, Kg/day or lb/day
CCPP = carbon cost per pound, \$/Kg or \$/lb

b) <u>Fixed Costs</u>

The fixed O & M components for this technology are listed in Table IV.3.1.1-B1, including the cost basis and the unit costs [4-11].

A 4. Miscellaneous Costs

Costs for engineering and common plant items such as land, piping, and buildings, are calculated after completion of costing for individual units (See Section IV.3.5).

A 5. Modifications

None required.

TABLE IV.3.1.1.-B1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR CARBON REGENERATION [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.30 Weeks (7.20 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.72 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.10 Shifts (0.57 hrs/day)	$10.70/hr
Maintenance	6.32% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.08 L/s (1.72 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

CARBON REGENERATION
SUMMARY WORK SHEET — REFERENCE: IV.3.1.1-B

I. DESIGN FACTOR	CAPITAL
a. Design Furnace Surface Area = ________ ft^2	
b. Scale Factor = ________	

II. CAPITAL COST	
Cost = ________ (Cost from curve) × ________ (F) × (________ (current index) ÷ 204.7)	$ ________

III. VARIABLE O & M	$/day	O & M
a. Power = ________ (Hp) × ________ (EC, $/Kw-hr) × 17.9	= ________	
b. Steam = ________ (STEAM, lb/day) × ________ ($/lb)	= ________	
c. Fuel = ________ (FUEL, gal/day) × ________ ($/gal)	= ________	
d. Water = ________ (WATER, thou gal) × ________ ($/thou gal)	= ________	
e. Carbon = ________ (CR, lb/day) × ________ ($/lb)	= ________	
IV. FIXED O & M		
a. Labor: ________ ($/hr) × ________ (hr/day)	= ________	
b. Supervision: ________ ($/hr) × ________ (hr/day)	= ________	
c. Overhead: ________ (LABOR, $/day) × ________ (%/100)	= ________	
d. Lab Labor: ________ ($/hr) × ________ (hr/day)	= ________	
e. Maint, Service, I&T: ________ (capital, $) × ________ (%/100) ÷ 365 (day/yr)	= ________	
f. Service Water: ________ (thou gpd) × ________ ($/thou gal)	= ________	
V. YEARLY O & M — 365 (day/yr) × ________ (sum, $/day)		= ________ $/yr
VI. UNCOSTED ITEMS		

CARBON REGENERATION

WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ \$/Kw-hr

3. Steam Cost = ________ \$/lb

4. Fuel cost = ________ \$/gal

5. Water Cost = ________ \$/thou gal

6. Activated Carbon Cost = ________ \$/lb

7. Labor = ________ \$/hr

8. Supervision = ________ \$/hr

9. Overhead = ________ % Labor ÷ 100 = ________%/100

10. Lab Labor = ________ \$/hr

11. Maintenance = % Capital
    Services = % Capital
    Insurance/Taxes = ________ % Capital
    Other O & M Factor Sum = % ÷ 100 = ________%/100

12. Service Water = ________ \$/thou gal

I. DESIGN FACTOR

a. Total Furnace Surface Area

$$TFSA = 1.2 \times (\underset{\text{*CU, lb/day}}{\underline{\qquad\qquad}} \div 40) = \underline{\qquad\qquad} \text{ ft}^2$$

*See Section 4a of Activated Carbon Adsorption, IV.3.1.1-A

b. Number of Furnaces Required

$$CN = \underset{\text{TFSA, ft}^2}{\underline{\qquad\qquad}} \div 520 = \underline{\qquad\qquad}$$

The number of furnaces (CN) should be rounded up to the nearest whole number (N): N = ________.

c. Individual Design Furnace Surface Area (DFSA)

$$DFSA = \underset{\text{TFSA, ft}^2}{\underline{\qquad\qquad}} \div \underset{N}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ ft}^2$$

d. Scale Factor for Costs

$$SF = \left(\frac{\_\_\_\_\_\_\_\_}{N}\right)^{0.8} = \_\_\_\_\_\_\_\_$$

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements

$$HP = (0.0623 \times \underset{\text{TFSA, ft}^2}{\_\_\_\_\_\_\_\_\_\_}) + 3.93 = \_\_\_\_\_\_\_\_ \text{ Hp}$$

b. Steam Requirement

$$STEAM = 1.0 \times \underset{\text{CU, lb/day}}{\_\_\_\_\_\_\_\_\_\_} = \_\_\_\_\_\_\_\_\_\_ \text{ lb/day}$$

c. Fuel Requirement

$$FUEL = (\underset{\text{CU, lb/day}}{\_\_\_\_\_\_\_\_\_\_} \times 0.0809) = \_\_\_\_\_\_\_\_\_\_ \text{ gal/day}$$

d. Scrubber Water

$$SCRWT = \underset{\text{FUEL, gal/day}}{\_\_\_\_\_\_\_\_\_\_} \times 0.0288 = \_\_\_\_\_\_\_\_\_\_ \text{ thou gal/day}$$

e. Quench Water

$$QUNWT = \underset{\text{CU, lb/day}}{\_\_\_\_\_\_\_\_\_\_} \times 0.0012 = \_\_\_\_\_\_\_\_\_\_ \text{ thou gal/day}$$

f. Total Water

$$WATER = \underset{\text{SCRWT, thou gal/day}}{\_\_\_\_\_\_\_\_\_\_} + \underset{\text{QUNWT, thou gal/day}}{\_\_\_\_\_\_\_\_\_\_} = \_\_\_\_\_\_\_\_\_\_ \text{ thou gal/day}$$

g. Carbon Replacement

$$CR = \underset{\text{CU, lb/day}}{\_\_\_\_\_\_\_\_\_\_} \times 0.1 = \_\_\_\_\_\_\_\_\_\_ \text{ lb/day}$$

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

IV.3.1.2 CHEMICAL OXIDATION

Introduction

Chemical oxidation processes are used to chemically break down pollutants such as cyanides, sulfides, and formaldehydes which are not amenable to biological or other traditional means of treatment. Powerful oxidants such as chlorine, peroxide, or permanganates are used for chemical oxidation depending on the specific pollutant to be treated and concern over toxic chlorinated residuals. Cyanide treatment by an alkaline chlorination process is now widely used and can achieve nearly complete cyanide destruction. Chemical oxidation processes are described in more detail in Volume III of the Treatability Manual, Section III.3.1.2. Costing methodologies and cost data for this technology are presented below.

IV.3.1.2-A. Chlorine Oxidation of Cyanide

A 1. Basis of Design

This presentation is for estimating costs for oxidation of cyanide, by the alkaline chlorination process. A system of the type considered is represented in Figure IV.3.1.2-A1. The capital cost factor is the volume of the two stage reactor vessel. The principal design factors for cyanide oxidation systems are wastewater flow and influent cyanide concentration. Influent oil and grease and TSS are checked to determine if pretreatment is necessary. Chlorine is supplied to the system at a mass ratio of 15 parts chlorine to 1 part cyanide and caustic is added to control pH between 8.0 and 9.5 and to subsequently neutralize any excess chlorine. The reaction vessel is sized for 10 minutes residence time in the first stage and 30 minutes in the second.

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitation Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

- Wastewater flow L/s (mgd)
- Wastewater characteristics
  - cyanide (mg/L)
  - oil and grease (mg/L)
  - TSS (mg/L)
  - pH

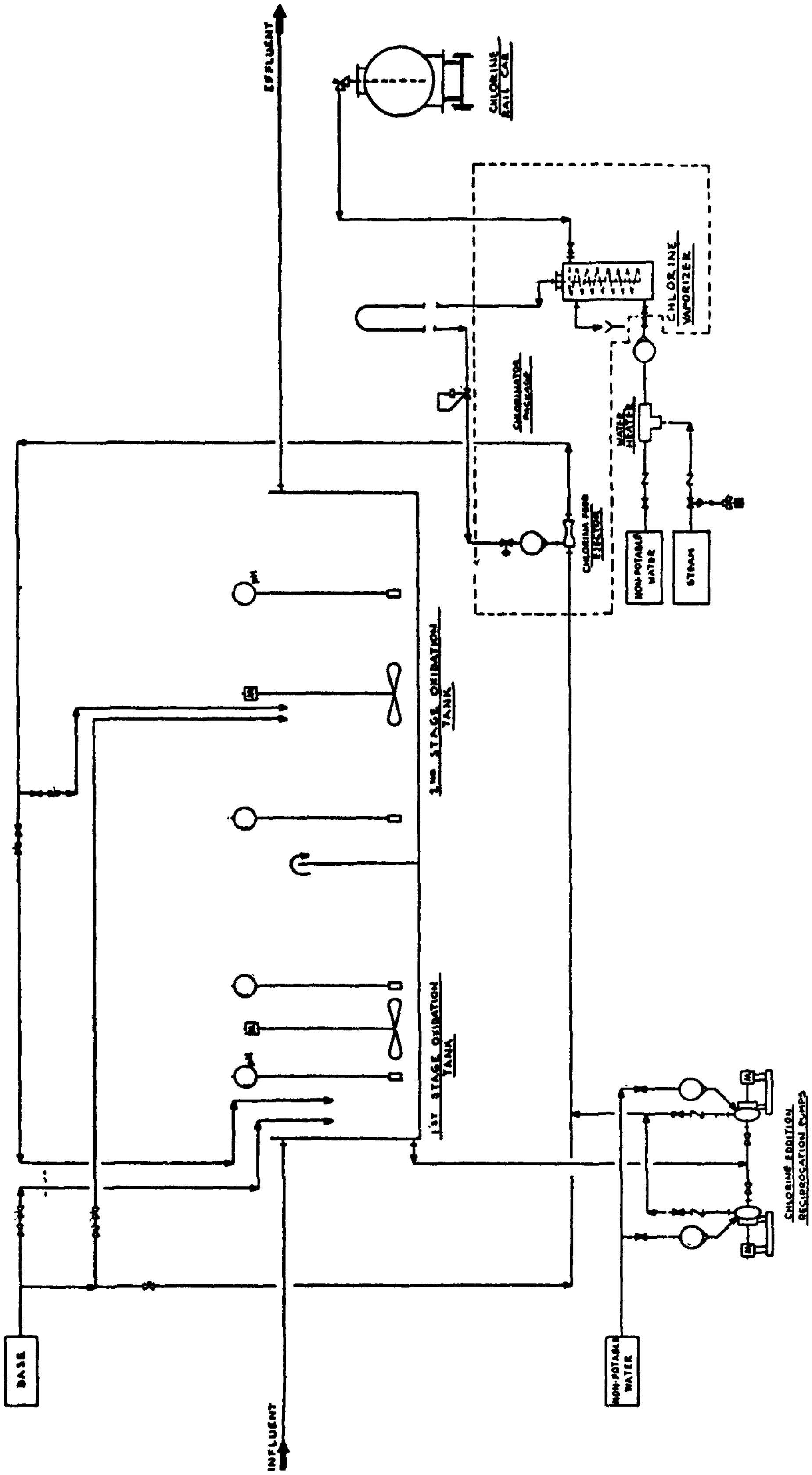


FIGURE IV.3.1.2-A1. PROCESS FLOW DIAGRAM FOR CHEMICAL OXIDATION [4-1]

c) Limitations

Chlorine oxidation is not considered applicable if cyanide is present at less than 10 mg/L.

d) Pretreatment

Pretreatment should be provided as indicated for the following conditions:

i) Equalization if necessary, due to flow variations.

ii) If influent oil and grease >50 mg/L, use oil removal process.

iii) If influent TSS >50 mg/L, use multi-media filtration.

e) Design Equation

The primary cost factor for alkaline chlorination of cyanide is the volume of the reaction vessel. The required basin volume for a chemical oxidation system is calculated based on a standard hydraulic detention time of 40 minutes (10 min. first stage and 30 min. second stage).

Metric

$$VOL = (FLOW \times 40 \times 60) \div 1000$$

where: VOL = basin volume, m^3
FLOW = average influent flow, L/s
40 = detention time, min.
60 = seconds/minute
1000 = conversion factor, L/s to m^3/s

English

$$VOL = (FLOW \times 40) \div 1.44$$

where: VOL = basin volume, thousand gallons
FLOW = average influent flow, mgd
40 = detention time, min.
1.44 = conversion factor, mgd to thousand gallons/min

f) Subsequent Treatment

None specified

g) Chlorinated Organics

Possible formation of chlorinated organics from alkaline chlorination of cyanide should be carefully considered.

A 2. Capital Costs

The volume of the two stage oxidation tank is the primary factor for estimation of capital cost using the capital cost curve (Figure IV.3.1.2-A2). Costs estimated using this curve must be adjusted to a current value using an appropriate current cost index.

a) Cost Data

Items included in the capital cost estimate for alkaline chlorination of cyanide are as follows [4-2]:

Two stage concrete reaction vessel
Agitators (2)
Chlorine feed systems
  chlorine vaporizer
  chlorinator
  circulation pumps (2)
Piping, instrumentation, electrical
Metal shed
pH control
ORP (oxidation/reduction potential) control

b) Capital Cost Curves

Curve - see Figure IV.3.1.2-A2.
- Cost (thousands of dollars) vs. basin volume (cubic meters or thousand gallons).
- Curve basis, cost estimates on four volumes: 105, 526, 1050, and 2100 m^3 (27.8, 139, 278, and 556 thousand gallons) 43.8, 219, 438, and 876 L/s (1, 5, 10, and 20 mgd) at 40 minute detention.

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. Variable operating costs include power, chlorine, and caustic. Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor. Miscellaneous plant costs and caustic costs are developed in subsequent Sections.

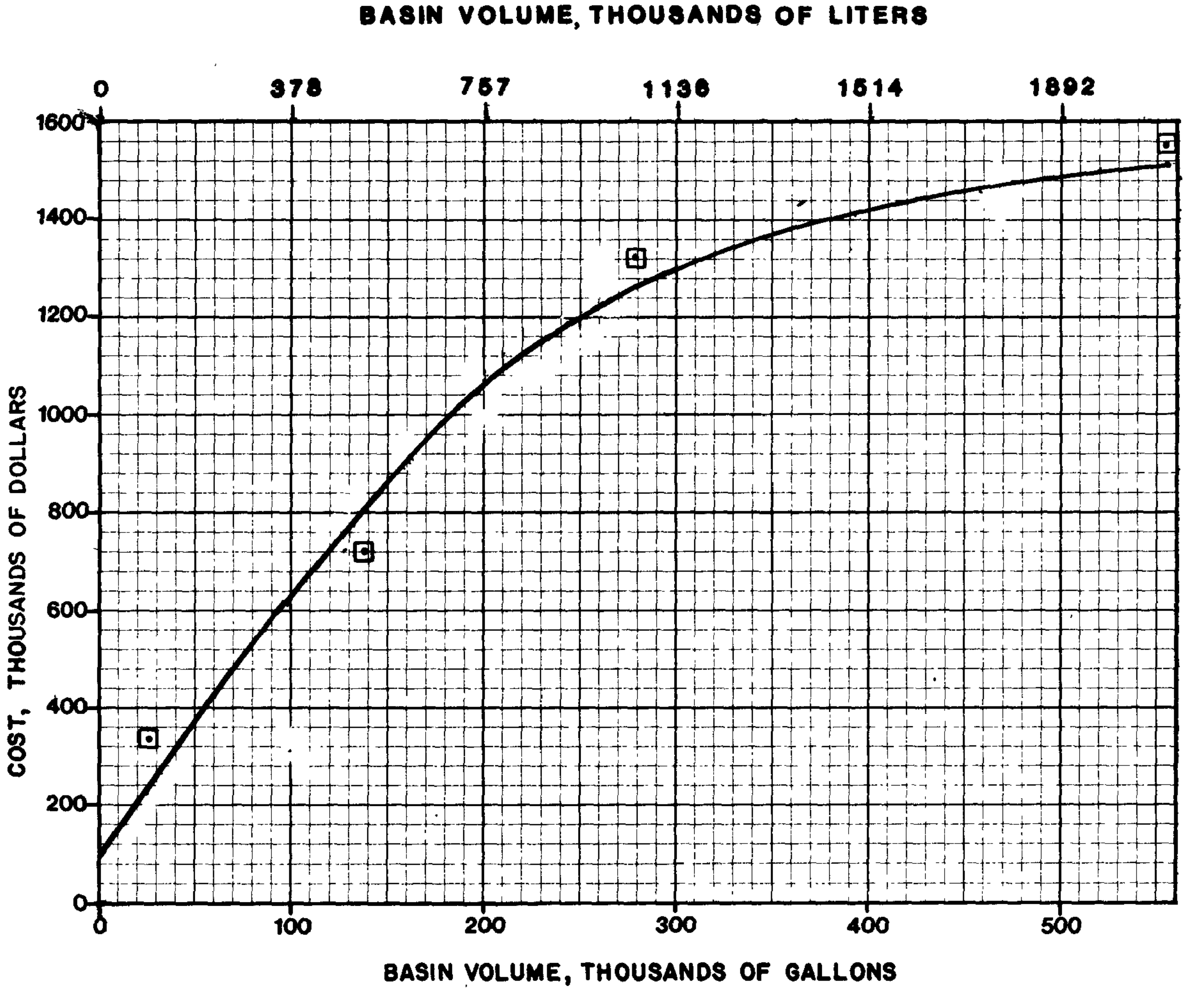


FIGURE IV.3.1.2-A2. CAPITAL COST ESTIMATE FOR CHEMICAL OXIDATION [4-10]

a) Variable Costs

i) Power Requirements - includes agitators, recirculation pumps. The following equation was developed using regression analysis procedures [4-1].

Metric

$$KW = (0.166 \times VOL) + 23.6$$

where: KW = power, kilowatts
VOL = basin volume, m^3

English

$$HP = (0.845 \times VOL) + 31.6$$

where: HP = power, Hp
VOL = basin volume, thousand gallons

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, $/day
KW = power, kilowatts
24 = hr/day
EC = electricity cost, $/Kw-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, $/day
HP = power, Hp
24 = hr/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, $/Kw-hr

iii) Chemical Requirements

- Chlorine

Metric

$$CL = FLOW \times 0.086 \times CN \times 15$$

where: CL = chlorine requirement, Kg/day
FLOW = influent flow, L/S

0.086 = conversion factor
CN = influent cyanide (as NaCN), mg/L
15 = ratio, Kg chlorine/Kg influent cyanide

English

$$CL = FLOW \times 8.34 \times CN \times 15$$

where: CL = chlorine requirement, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor
CN = influent cyanide (as NaCN), mg/L
15 = ratio, lb chlorine/lb influent cyanide

- Caustic (needed to maintain pH between 8.0 and 9.5)

- If influent pH <8.0:

Metric

$$CR = [(CN \times 17) + (8 - pH)^3 \times 15] \times 0.086 \times FLOW$$

English

$$CR = [(CN \times 17) + (8 - pH)^3 \times 15] \times 8.34 \times FLOW$$

- If influent pH ≥8.0:

Metric

$$CR = CN \times 17 \times 0.086 \times FLOW$$

where: CR = required amount of caustic, Kg/day
17 = Kg caustic/Kg CN^-

English

$$CR = CN \times 17 \times 8.34 \times FLOW$$

where: CR = required amount of caustic, lb/day
17 = lb caustic/lb CN^-

iv) Chemical Costs (except caustic):

Once the total requirements for chlorine has been established, the associated cost may be estimated as follows:

$$CC = CL \times N$$

where: CC = chlorine cost ($/day)
CL = calculated requirement for chlorine Kg/day or lb/day
N = unit cost of chlorine, $/Kg or $/lb

Capital and O & M costs for caustic addition may be calculated for individual add-on technologies or for whole plants which use a central handling and distribution system by using Section IV.3.1.13-C. For new plants or expansions involving several treatment units which use lime, a central lime/caustic unit may be considered to serve all of them. For single unit add-on's a small caustic or lime system may be considered. In either case, the total quantity of caustic or lime required should be determined and carried forward to Section IV.3.1.13-C to determine costs.

b) <u>Fixed Costs</u>

The fixed O & M components for this technology are listed in Table IV.3.1.2-A1, including values for the cost basis and the unit costs [4-11].

A 4. Miscellaneous Costs

Costs for engineering, and other common plant items such as land, piping, and buildings, are calculated after completion of costing for individual units (see Section IV.3.5).

A 5. Modifications

None.

TABLE IV.3.1.2-A1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR CHEMICAL OXIDATION [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.20 Weeks (4.80 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.48 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.15 Shifts (0.86 hrs/day)	$10.70/hr
Maintenance	3.93% Capital	NA
Services	0.04% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.075 L/s (1.72 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

CHEMICAL OXIDATION SUMMARY WORK SHEET		REFERENCE: IV.3.1.2-A
I. DESIGN FACTOR		CAPITAL
Basin Volume = ______ thousand gallons		
II. CAPITAL COST		
Cost = ______ (Cost from curve) × (______ (current index) ÷ 204.7)		$ ______
III. VARIABLE O & M	$/day	O & M
a. Power = ______ (Hp) × ______ (EC, $/Kw-hr) × 17.9	= ______	
b. Chlorine = ______ (CL, lb/day) × ______ (NCL, $/lb)	= ______	
IV. FIXED O & M		
a. Labor: ______ (hr/day) × ______ ($/hr)	= ______	
b. Supervision: ______ (hr/day) × ______ ($/hr)	= ______	
c. Overhead: ______ (Labor, $/day) × ______ (%/100)	= ______	
d. Lab Labor: ______ (hr/day) × ______ ($/hr)	= ______	
e. Maint, Service, I&T: ______ (capital, $) × ______ (%/100) ÷ 365 (day/yr)	= ______	
f. Service Water: ______ (thou gpd) × ______ ($/gal) × 1000	= ______	
V. YEARLY O & M	365 (day/yr) × ______ (sum, $/day)	= ______ $/yr
VI. UNCOSTED ITEMS		
a. Caustic = ______ lb/day		

CHEMICAL OXIDATION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ $/Kw-hr

3. NCL: Chlorine Cost = ________ $/lb

4. Labor = ________ $/hr

5. Supervision = ________ $/hr

6. Overhead = ________ % Labor ÷ 100 = ________ %/100

7. Lab Labor = ________ $/hr

8. Maintenance = ________ % Capital
   Services = ________ % Capital
   Insurance/Taxes = ________ % Capital
   Other O&M Factor Sum = ________ ÷ 100 = ________ %/100

9. Service Water = ________ $/thou gal

I. DESIGN FACTOR

Basin Volume = $\dfrac{\text{\_\_\_\_\_\_\_\_\_\_}}{\text{FLOW, mgd}}$ × 27.8 = ________ thousand gallons

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements

HP = (________________ × 0.845) + 31.6 = ________ Hp
basin volume, thou. gal.

b. Chlorine Requirement for Cyanide Oxidation

CL = ________ × ________ × 125 = ________ lb/day
FLOW, mgd CN, mg/L

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Caustic Requirement for Cyanide Oxidation

<u>If</u> influent pH <8.0

$$CR = [(\underset{\text{CN, mg/L}}{\underline{\hspace{2cm}}} \times 17) + (8 - \underset{\text{pH}}{\underline{\hspace{0.5cm}}})^3 \times 15] \times 8.34 \times \underset{\text{FLOW, mgd}}{\underline{\hspace{2cm}}}$$

$$= \underline{\hspace{2cm}} \text{ lb/day}$$

<u>If</u> influent pH ≥8.0

$$CR = \underset{\text{CN, mg/L}}{\underline{\hspace{2cm}}} \times \underset{\text{FLOW, mgd}}{\underline{\hspace{2cm}}} \times 142 = \underline{\hspace{2cm}} \text{ lb/day}$$

IV.3.1.5 PRECIPITATION AND COAGULATION/FLOCCULATION

Introduction

Chemical precipitation, coagulation, and flocculation are employed to help remove heavy metals and colloidal and dissolved solids from wastewater streams. Various coagulants such as alum, lime, ferric chloride, organic polymers, and synthetic polyelectrolytes are used in the process depending on the specific waste material to be removed. The coagulants are rapidly mixed with the wastewater and the colloidal particles are allowed to agglomerate into a floc large enough to be removed by subsequent sedimentation or filtration processes. Precipitation is a chemical process by which soluble metallic ions and certain anions are converted to an insoluble form for subsequent removal from the wastewater stream. Coagulation/Flocculation is often included to aid in the removal of the insoluble precipitates. The performance of the process is limited by chemical interactions, temperature, solubility variances, and common ion and mixing effects. This process is discussed in more detail in Volume III of the Treatability Manual, Section III.3.1.5. Costing methodologies and cost data for this technology are presented below.

IV.3.1.5-A. Precipitation and Coagulation/Flocculation

A 1. Basis of Design

This presentation is for precipitation and coagulation/flocculation of priority and conventional pollutants in wastewater streams. The basic factor for estimating the capital cost of a precipitation/coagulation/flocculation system with this method is wastewater flow. The system is designed with separate mixing and flocculation chambers having two minutes and 20 minutes detention time respectively at 120% of average daily flow. A flow diagram of such a system is presented in Figure IV.3.1.5-A1.

A standard dose of 200 mg/L of alum is assumed in all cases unless otherwise specified. If different coagulant(s) and/or different dose rate(s) are considered more appropriate by the user, they may be substituted for the standard alum dose. A dosage of one mg/L of polyelectrolyte is assumed in all cases except when the unit is used to coagulate and flocculate an activated sludge waste stream. In that case, alum is not used and only a 5 mg/L dose of polyelectrolyte is used. If precipitation of some priority pollutant(s) is desired an appropriate precipitant dose must be assumed by the user. For more information see Section III.3.1.13 of Volume III. Sludge generation from this unit process is accounted for by summing the amount of coagulants added and precipitates removed. Final conditioning and disposal of sludge as well as provisions for lime handling, if needed, are accounted for in subsequent unit processes.

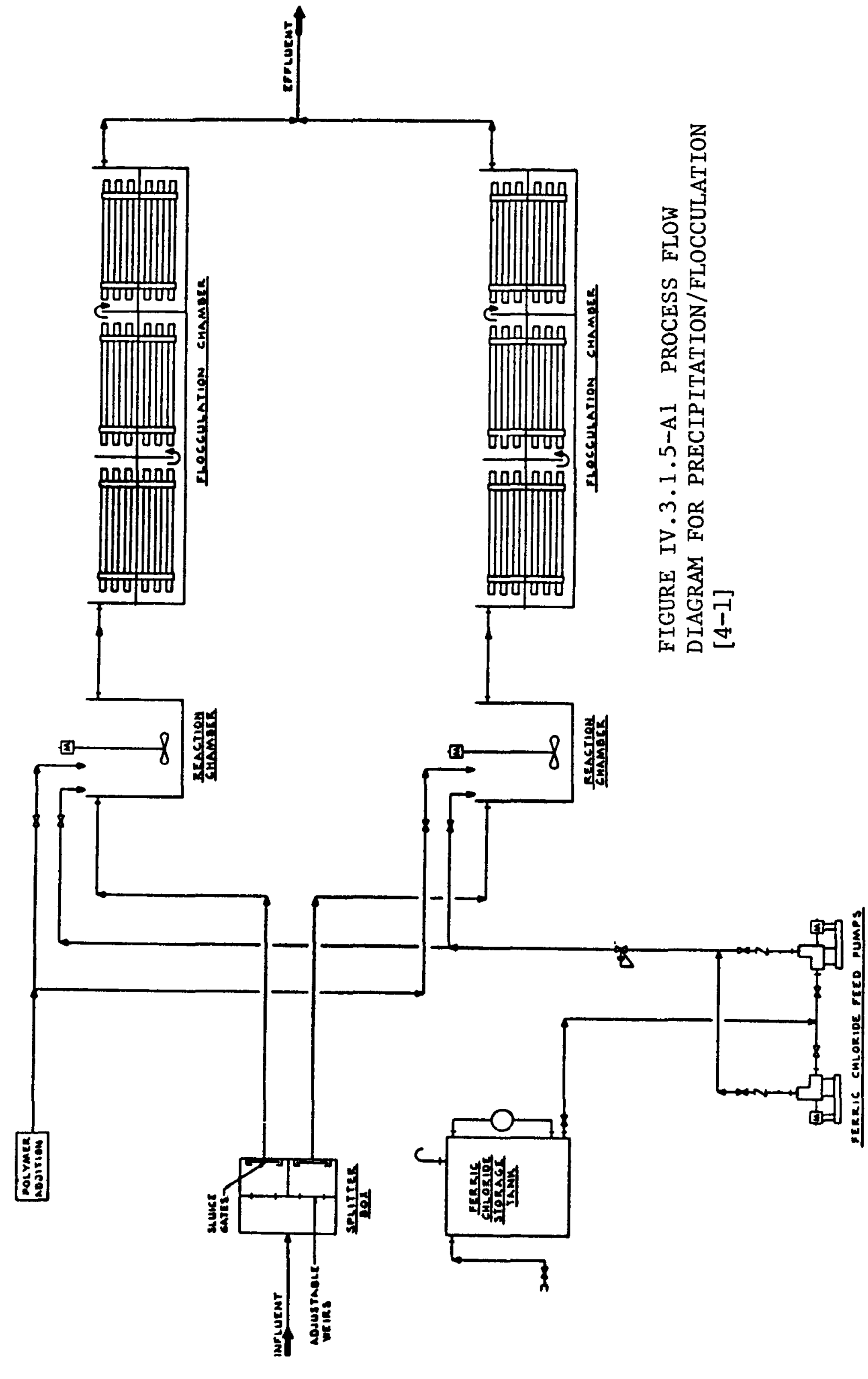


FIGURE IV.3.1.5-A1 PROCESS FLOW DIAGRAM FOR PRECIPITATION/FLOCCULATION [4-1]

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2].

b) Required Input Data

Wastewater flow L/s (mgd)
Influent TSS and precipitable pollutant concentrations (mg/L)

c) Limitations

Precipitation/coagulation/flocculation may not be suitable if:

i) Precipitable pollutants not present or present at concentrations below treatable levels.

ii) No precipitable pollutants and influent TSS <30 mg/L.

d) Pretreatment

Neutralization is required when influent pH ≤2.5 or pH ≥9.0. Depending on the coagulant used, the suitable ranges of pH may be much smaller.

e) Design Equation

Average daily wastewater flow is the primary capital cost factor for coagulation/flocculation systems. The design of the system is based on two minutes detention in the mixing chamber and twenty minutes detention in the flocculation chamber at 120% of average daily flow.

f) Subsequent Treatment

Subsequent treatment involves a solids separation process (multimedia filtration or sedimentation depending on TSS concentration and floc characteristics).

A 2. Capital Costs

Flow is the primary capital cost factor for this unit process. Capital cost can be estimated using the capital cost curve (Figure IV.3.1.5-A2). This curve is based on the addition of one coagulant chemical plus polyelectrolyte. The cost for a system which uses more than one coagulant should be adjusted as indicated in Section A 5, b. Costs estimated using this curve must be adjusted to a current value using an appropriate current cost index.

a) Cost Data

Items included in the capital cost curve estimates are as follows [4-2]:

Concrete mixing chamber (2)
Concrete flocculation chamber (2)
Polyelectrolyte addition system (1)
Coagulant holding tank (1)
Coagulant feed pumps (2)
Agitators (2)
Horizontal paddle wheel flocculators
Sluice Gates (2)

b) Capital Cost Curve

Curve - see Figure IV.3.1.5-A2.
- Cost (thousands of dollars) vs flow (liters per second or million gallons per day).
- Curve basis, cost estimates on four flow rates: 17.5, 87.6, 438, and 876 L/S (0.4, 2.0, 10.0, and 20 mgd).

Scale Factor - for more than one coagulant, see Section A 5,b

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. Variable operating costs include power, coagulants, and poly-electrolyte. Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor. Byproduct handling and miscellaneous common plant costs must be estimated separately.

a) Variable Costs

i) Power Requirements. This equation was developed using regression analysis procedures [4-1].

Metric

$$KW = (0.054 \times FLOW) + 1.79$$

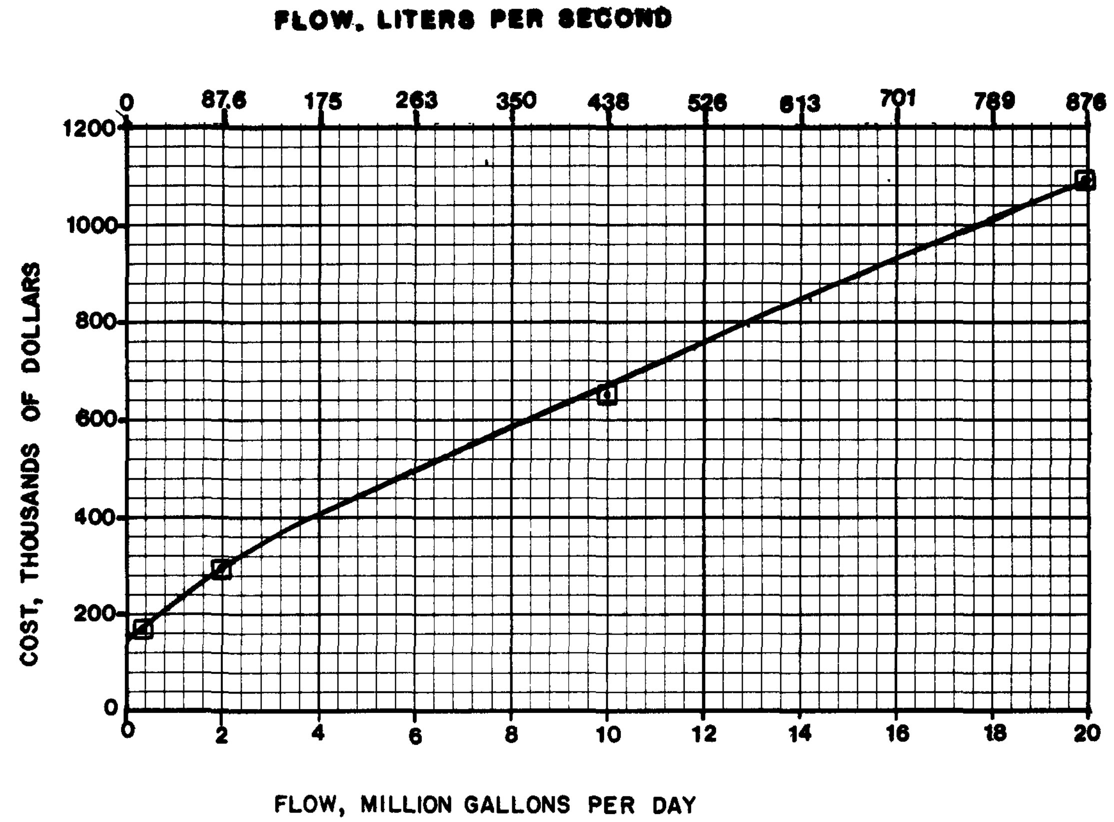


FIGURE IV.3.1.5-A2. CAPITAL COST ESTIMATE FOR PRECIPITATION AND COAGULATION/FLOCCULATION [4-10]

where: KW = power, kilowatts
$FLOW$ = influent flow, L/s

English

$$HP = (3.17 \times FLOW) + 2.40$$

where: HP = power, Hp
$FLOW$ = influent flow, mgd

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost \$/day
KW = power, kilowatts
24 = hr/day
EC = electricity cost \$/Kw-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, \$/day
24 = hr/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, \$/Kw-hr

iii) Chemical Requirements

Chemical requirements for this unit process include the coagulant and polyelectrolyte.

- Requirement for Coagulant or Precipitant

Metric

$$CHEM(n) = COGDOSE(n) \times FLOW \times 0.086$$

where: $CHEM(n)$ = amount of coagulant (n) needed, Kg/day
$COGDOSE$ = coagulant dose, mg/L
$FLOW$ = influent flow, L/S
0.086 = conversion factor

English

$$CHEM(n) = COGDOSE(n) \times FLOW \times 8.34$$

where: $CHEM(n)$ = amount of coagulant (n) needed, lb/day
$COGDOSE(n)$ = coagulant dose, mg/L (standard 200 mg/L alum dose or see Section A 5, a)
FLOW = influent flow, mgd
8.34 = conversion factor

- Requirement for Polyelectrolyte

  Polyelectrolyte is added in an amount sufficient to achieve a concentration of 1.0 mg/L.

  Metric

  $$POLY = PDOSE \times FLOW \times 0.086$$

  where: POLY = amount of polyelectrolyte required, Kg/day
  PDOSE = polyelectrolyte dose, mg/L
  FLOW = influent flow, L/S
  0.086 = conversion factor

  English

  $$POLY = FLOW \times PDOSE \times 8.34$$

  where: POLY = amount of polyelectrolyte required, lb/day
  FLOW = influent flow, mgd
  PDOSE = polyelectrolyte dose, mg/L
  8.34 = conversion factor

  If coagulation/flocculation is being used only to aid in the settling of waste activated sludge, it is assumed that a polyelectrolyte dose of 5 mg/L is required and no other chemicals are used [4-1].

iv) Chemical Cost (except lime*)

The chemical cost may be estimated as follows:

$$CC\ (n) = \Sigma\ (CHEM\ (n) \times N\ (n))$$

where: CC (n) = cost of chemical (n), $/day
CHEM (n) = requirement for chemical (n), Kg/day or lb/day
N (n) = unit cost of chemical (n), $/Kg or $/lb

*Costs for lime are based on total plant needs rather than on the needs of an individual unit. Lime is assumed to be stored and distributed through a central lime handling system. Therefore, lime requirements should be totaled for each unit process but costs for handling systems and chemicals should be estimated separately after the design of all unit processes requiring lime is completed (See Section IV.3.1.13C). If lime is required for an add-on technology, lime handling and material costs may also be estimated from information in Section IV.3.1.13C.

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.1.5-A1, including values for the cost basis and the unit costs [4-2].

A 4. Miscellaneous Costs

Costs for engineering, and common plant items such as land, yard piping, and buildings, are calculated after completion of costing for individual units (see Section IV.3.5).

Sludge handing and treatment facilties are not included in the cost estimates for this technology but should be designed and costed separately according to the individual technologies required (see Section IV.3.4). The nature and quantity of sludge generated by each wastewater treatment process should be estimated for use in the design and costing of sludge treatment processes. Sludge generation by this technology is determined from chemical use and influent pollutants removed (including solids and precipitable pollutants). A rough estimate of sludge generation may be made using the equation indicated below:

Metric

$$SLDG\ (n) = \Sigma\ [CHEM\ (n) + MPPT\ (i)]$$

where: SLDG (n) = sludge of type n, Kg/day
CHEM (n) = coagulant (n) added, Kg/day
MPPT (i) = pollutant (i) removed, Kg/day
= POL (i) × FLOW × 0.086
POL (i) = pollutant (i) removed (solids or precipitable pollutant) influent concentration, mg/L
FLOW = influent flow, L/s
0.086 = conversion factor

English

$$SLDG\ (n) = \Sigma\ [CHEM\ (n) + MPPT\ (i)]$$

TABLE IV.3.1.5-A1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR PRECIPITATION AND COAGULATION/FLOCCULATION [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.25 Weeks (6.00 hr/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.60 hr/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.20 Shifts (1.14 hr/day)	$10.70/hr
Maintenance	3.53% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.08 L/S (1.81 Thou gpd)	$0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

where: SLDG (n) = sludge of type n, lb/day
CHEM (n) = coagulant (n) added, lb/day
MPPT (i) = pollutant (i) removed, lb/day
= POL (i) × FLOW × 8.34
POL (i) = pollutant (i) removed (solids or precipitable pollutant) influent concentration, mg/L
FLOW = influent flow, mgd
8.34 = conversion factor

This is an estimate of sludge generation that could be either too high or too low. Factors that will tend to make this estimate too high include the amount of the chemical added that remains in solution, the precipitable pollutants that remain in solution, and the solids that cannot be removed (e.g., too fine). Factors that may cause this estimate to be too low include side reactions such as the precipitation of alkalinity in the wastewater. It is also helpful to identify the nature of the sludge according to coagulant (e.g., alum sludge) as this information will be used in the sizing and costing of required sludge handling systems.

A 5. Modifications

a) Coagulant Dose

If the user determines that a precipitant or coagulant and/or dose rate other than the standard 200 mg/L of alum is more appropriate, it may be substituted into the design. Chemicals such as lime, ferric chloride and sodium sulfide also have been found to be effective in precipitating many priority pollutants (see Section 3.1.5 of Volume III for representative data). The coagulant dose, or doses selected should be sufficient to precipitate the pollutant(s) of concern, coagulate the resulting precipitate, and overcome any side reactions such as hydrolysis which might compete with the desired reaction. In addition, each coagulant has an optimum pH range and pH adjustment using acid or base may be required.

b) Capital Cost Scale Factor

The capital cost curve (Figure IV.3.1.5-A2) is based on feed equipment for one coagulant and a polyelectrolyte. If more than one coagulant is used, the capital cost should be adjusted by a scale factor to account for the additional feed equipment. The scale factor used for this process is the square root of the number of coagulants and is applied to the flow prior to estimating the capital cost from the cost curve [4-1].

Scale Factor (applies to flow prior to cost estimation)

$$\text{Flow for cost purposes} = \text{FLOW} \times (n)^{0.5}$$

where: Flow = influent flow, L/s or mgd
n = number of coagulant chemicals, not including polyelectrolyte

Note that the scale factor does not change the design flow, it is only a capital cost adjustment.

COAGULATION/FLOCCULATION
SUMMARY WORK SHEET

REFERENCE: IV.3.1.5-A

I. DESIGN FACTOR — CAPITAL

a. FLOW = ________ mgd

II. CAPITAL COST

Cost = ________ (Cost from curve) × (________ (current index) ÷ 204.7) — $ ________

III. VARIABLE O & M — $/day — O & M

		$/day
a. Power	= ________ (Hp) × ________ (EC, $/Kw-hr) × 17.9	= ________
b. Chemical, Alum	= ________ (AL, lb/day) × ________ (NAL, $/lb)	= ________
c. Chemical, ________	= ________ (lb/day) × ________ ($/lb)	= ________
d. Chemical, ________	= ________ (lb/day) × ________ ($/lb)	= ________
e. Polyelectrolyte	= ________ (POLY, lb/day) × ________ (NP, $/lb)	= ________

IV. FIXED O & M

		$/day
a. Labor:	________ (hr/day) × ________ ($/hr)	= ________
b. Supervision:	________ (hr/day) × ________ ($/hr)	= ________
c. Overhead:	________ (Labor, $/day) × ________ (%/100)	= ________
d. Lab Labor:	________ (hr/day) × ________ ($/hr)	= ________
e. Maint, Service, I&T:	________ (capital, $) × ________ (%/100) ÷ 365 (day/yr)	= ________
f. Service Water:	________ (thou gpd) × ________ ($/thou gal)	= ________

V. YEARLY O & M — 365 (day/yr) × ________ (sum, $/day) = ________ $/yr

VI. UNCOSTED ITEMS

a. Lime Requirement = ________ lb/day
b. Alum Sludge = ________ lb/day
c. Chemical Sludge, ________ = ________ lb/day
d. Chemical Sludge, ________ = ________ lb/day

COAGULATION/FLOCCULATION WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index
2. EC: Electricity Cost = ________ $/Kw-hr
3. NAL: Alum Cost = ________ $/lb
4. NFC: Ferric Chloride Chemical Cost, ______ = ________ $/lb
5. NP: Polymer Cost = ________ $/lb
6. Labor = ________ $/hr
7. Supervision = ________ $/hr
8. Overhead = ________ % Labor ÷ 100 = ________ %/100
9. Lab Labor = ________ $/hr
10. Maintenance = % Capital
    Services = % Capital
    Insurance/Taxes = ________ % Capital
    Other O & M Factor Sum = ________ ÷ 100 = ________ %/100
11. Service Water = ________ $/1000 gal

I. DESIGN FACTOR

a. Standard Dose, 200 mg/L Alum

FLOW = ________ mgd

b. If more than one coagulant used, not including polyelectrolyte

$$\text{Flow for cost purposes} = \underset{\text{FLOW,mgd}}{\underline{\qquad\qquad}} \times \left(\underset{n}{\underline{\qquad\qquad}}\right)^{0.5} = \underline{\qquad\qquad} \text{ mgd}$$

n = number of coagulant chemicals not including polyelectrolyte, see III B,3

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements

HP = (3.17 × ________) + 2.40 = ________ Hp
FLOW, mgd

b. Chemical Requirements

1. Standard 200 mg/L Alum Dose

CHEM (Alum) = 1670 × ________ = lb/day
FLOW, mgd

2. Nonstandard Coagulant Dose (indicate coagulant and dose rate)

CHEM = ________ × ________ × 8.34 = ________ lb/day
COGDOSE,mg/L   FLOW,mgd

CHEM = ________ × ________ × 8.34 = ________ lb/day
COGDOSE,mg/L   FLOW,mgd

3. Number of coagulant chemicals required (n) = ________

4. Polyelectrolyte Addition
If activated sludge is not being treated (1 mg/L)
POLY = ________ × 8.34 = ________ lb/day
FLOW, mgd

If activated sludge is being treated (5 mg/L)
POLY = ________ × 41.7 = ________ lb/day
FLOW, mgd

IV. FIXED O & M

a. Sludge Generation

1. Pollutants Removed
Indicate coagulant and sum of pollutant concentrations removed by coagulant

- Pollutants removed by Coagulant 1
MPPT = ________ × ________ × 8.34 = ________ lb/day
Σ POL (i)   FLOW

- Pollutants removed by Coagulant 2
MPPT = ________ × ________ × 8.34 = ________ lb/day
Σ POL (i)   FLOW

2. For standard 200 mg/L alum dose

SLDG (Alum) = $\underline{\hspace{2cm}}_{\text{MPPT(Alum)}}$ + $\underline{\hspace{2cm}}_{\text{CHEM(Alum)}}$ = ________ lb/day

3. For nonstandard coagulant dose
Indicate coagulant, sludge type, total lb/day pollutant removed (MPPT) and total lb/day chemical coagulant added (CHEM).

SLDG = $\underline{\hspace{1.5cm}}_{\text{MPPT}}$ + $\underline{\hspace{1.5cm}}_{\text{CHEM}}$ = ________ lb/day

SLDG = $\underline{\hspace{1.5cm}}_{\text{MPPT}}$ + $\underline{\hspace{1.5cm}}_{\text{CHEM}}$ = ________ lb/day

IV.3.1.9 FILTRATION

Introduction

Granular-media filtration involves the passage of a stream containing suspended matter through a bed of granular material with a resultant capture of solids. In most common filter designs, the liquid flows downward through a static bed. Mechanisms operative within the filter bed that contribute to solids removal include: physical straining, sedimentation, inertial impaction, interception, and adhesion. Further details describing this process can be found in Volume III of the Treatability Manual, Section III.3.1.9. Costing methodologies and cost data for this technology are presented below.

IV.3.1.9-A. Multi-Media Filtration

A 1. Basis of Design

This presentation is for the multi-media filtration of wastewater, with a sludge byproduct generated. A process flow diagram for this technology is presented in Figure IV.3.1.9-A1. The principal design factors for multi-media filtration are wastewater flow, TSS concentration, and filter surface area. The filter surface area is also the principal capital cost factor for this technology. Influent TSS and oil and grease are checked to determine if pretreatment is necessary. The surface hydraulic loading rate for the filter is selected based on the influent TSS concentration, floc characteristics, run length, and bed depth. From these data and the influent flow, the required filter surface area is calculated for a run time of eight hours at a bed depth of 1.5 m (5 ft). An appropriate safety factor is applied to account for backwash time and down time for operating units [4-1].

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2].

b) Required Input Data

Wastewater flow, L/s (gpm)
Influent total suspended solids (TSS), (mg/L)

c) Limitations

Multi-media filtration is not used if influent TSS concentration <5 mg/L.

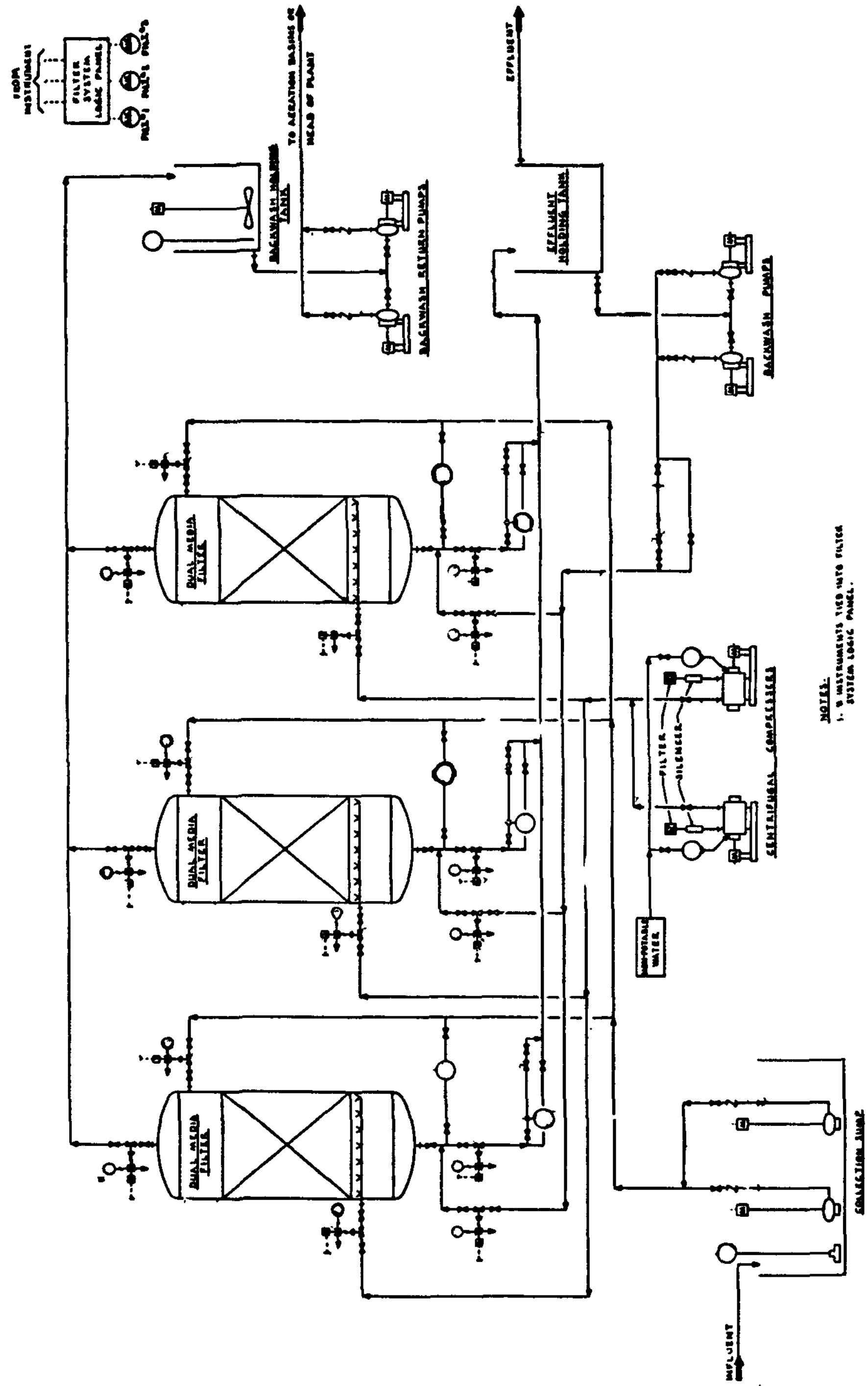


FIGURE IV.3.1.9-A1. PROCESS FLOW DIAGRAM FOR MULTI-MEDIA FILTRATION [4-1]

d) Pretreatment

Pretreatment should be provided as indicated for the following conditions:

i) If influent oil >35 mg/L, an oil removal process should be used.

ii) If influent TSS >100 mg/L, then clarification should be used.

e) Design Factor

The filter surface area is the primary factor used to estimate cost by this method. Multi-media filters are assumed to have a bed depth of 1.5 m (5 ft) and operate on an 8 hour run cycle [4-2]. The user should select an appropriate hydraulic loading rate between 1.4 and 5.4 L/s/m^2 (2 to 8 gpm/ft^2) and calculate the required filter surface area including the necessary safety margins. The surface loading rate is affected by the influent TSS concentration, the relative strength of the floc, and other factors. For further information see Volume III, Section III.3.1.9.

Metric

$$SA = FLOW \div Q$$

where: SA = surface area, m^2
FLOW = applied average influent flow, L/s
Q = surface hydraulic loading rate, L/s/m^2 (see Volume III, Section III.3.1.9 for guidance in selecting a loading rate)

English

$$SA = (FLOW \times 10^6) \div (1440 \times Q)$$

where: SA = surface area, ft^2
FLOW = applied average influent flow, mgd
Q = surface hydraulic loading rate, gpm/ft^2 (see Volume III, Section III.3.1.9 for guidance in selecting a loading rate)
10^6 = conversion factor, mgd to gpd
1440 = conversion factor, day to minute

The following safety margins are included in the final sizing of the filter surface area to account for continued operation during backwash and other downtime of filter units:

- If SA ≥58.3 m^2 (628 ft^2), add 20% for system non-service mode operation

- If SA <58.3 m^2 (628 ft^2), add 50% for system non-service mode operation

f) Subsequent Treatment

None specified.

A 2. Capital Costs

The total surface area of the multi-media filtration units is the principal factor in the capital cost estimate. Presented in Figure IV.3.1.9-A2 are installed costs for multi-media filters as a function of surface area. The filter systems represented by the curve are sized on an assumed loading rate of 3.4 L/s/m^2 (5 gpm/ft^2), for a bed depth of 1.5 m (5 ft) and a run length of 8 hours. They are assumed to use a hydraulic backwash rate of 13.6 L/s/m^2 (20 gpm/ft^2) and an air scour rate of 0.22 L/s/m^2 (5 ft^3/m/ft^2) for a period of 15 minutes. Costs estimated using these curves must be adjusted to a current value using an appropriate current cost index.

a) Cost Data

Items included in the capital cost curve estimates are as follows [4-10]:

For the 5.2, 19.5, and 65 m^2 (56, 210, and 700 ft^2) design units -
- Vertical pressure downflow sand filters, maximum individual unit size of 9.29 m^2 (100 ft^2)
- Feed pumps
- Backwash pumps
- Air compressor for air scour
- Backwash holding tank
- Piping, insulation
- Instrumentation

For the 260 m^2 (2800 ft^2) design unit -
- Four compartment horizontal filter (four units)
- Backwash pumps, air scour compressors, and backwash holding tank are not required for this equipment
- Feed pumps
- Piping, insulation
- Instrumentation

b) Capital Cost Curves

Curve - see Figure IV.3.1.9-A2.
- Cost (thousands of dollars) vs surface area (square meters or square feet).

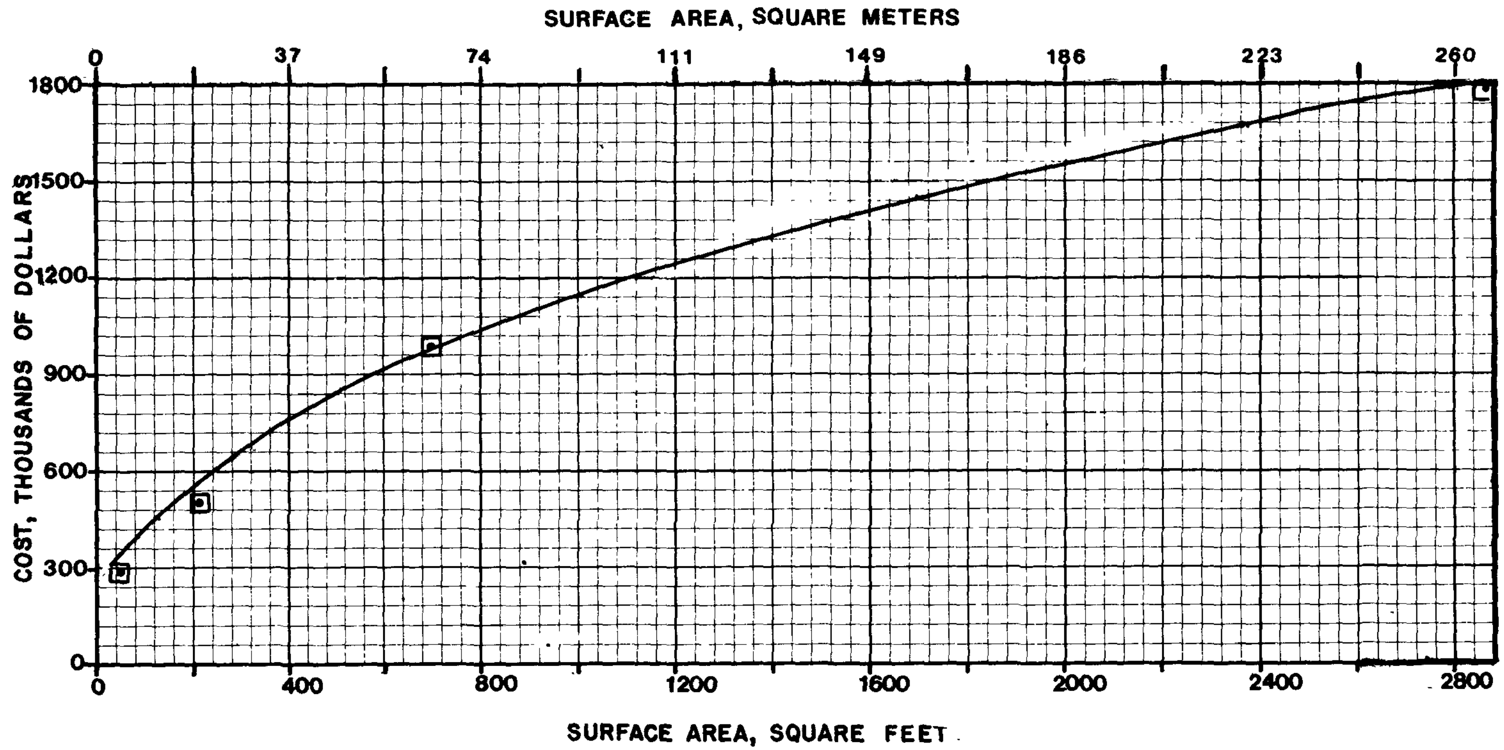


FIGURE IV.3.1.9-A2. CAPITAL COST ESTIMATE FOR MULTI-MEDIA FILTRATION [4-10]

- Curve basis, cost estimates for the filtration systems based on total filter surface areas of 5.2, 20, 65, and 260 m^2 (56, 210, 700, and 2800 ft^2) based on flows of 8.76, 43.8, 219, and 876 L/s (0.2, 1, 5, and 20 mgd).

c) Cost Index

Base Period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable component of the operating cost is the power requirement for the filtration system. Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Cost

i) Power Requirements - feed pumps, compressors, backwash pumps [4-1]. This equation was developed using regression analysis procedures.

Metric

$$KW = [71.4 \times (\log_n FLOW)] - 140$$

where: KW = power required, kilowatts
FLOW = influent flow, L/s
$\log_n$ = natural logarithm

English

$$HP = [95.8 \times (\log_n FLOW)] + 174$$

where: HP = power, Hp
FLOW = influent flow, mgd
$\log_n$ = natural logarithm

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, \$/day
24 = hours/day
EC = electricity cost, \$/Kw-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, \$/day
EC = electricity cost, \$/Kw-hr
24 = hr/day
0.746 = Kw-hr/Hp-hr

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.1.9-A1, including values for the cost basis and the unit costs [4-11].

A 4. Miscellaneous Costs

Costs for engineering, and common plant items such as piping and buildings, are calculated after completion of costing for individual units (see Section IV.3.5).

The amount of sludge accumulated by the system should be accounted for in order to facilitate cost estimates for subsequent sludge handling systems. Sludge production from filtration is based on an assumed solids removal efficiency which must be selected by the user based on conditions.

Metric

$$SP = FLOW \times 0.086 \times E \times TSS$$

where: SP = sludge production, Kg/day (dry)
$FLOW$ = applied flow, L/s
0.086 = conversion factor
E = solids removal efficiency, fraction (see Volume III, Section III.3.1.9 for guidance)
TSS = influent suspended solids, mg/L

English

$$SP = FLOW \times 8.34 \times E \times TSS$$

where: SP = sludge production, lb/day (dry)
$FLOW$ = applied flow, mgd
8.34 = conversion factor
E = solids removal efficiency, fraction (see Volume III, Secton 3.1.9 for guidance)
TSS = influent suspended solids, mg/L

TABLE IV.3.1.9-A1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR MULTI-MEDIA FILTRATION [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.15 Weeks (3.60 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.36 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.10 Shifts (0.57 hrs/day)	$10.70/hr
Maintenance	4.09% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.23 L/s	$0.13/thou L
	(5.18 Thou gpd)	($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

A 5. Modifications

The total surface area calculation is outlined in Section A 1,e, Design Factor. A minimum of two operating filters and one standby is specified for most applications with the system sized to accommodate 150% of average daily flow. For very small systems, two filters each sized to accommodate 100% of flow may be acceptable. For systems with a total filter surface area greater than 58.3 m^2 (628 ft^2), no designated spare filter is required, but the total surface area should be designed to accommodate 120% of average daily flow [4-1].

MULTI-MEDIA FILTRATION
SUMMARY WORK SHEET

REFERENCE: IV.3.1.9-A

I. DESIGN FACTOR — CAPITAL

Filtration Surface Area = SA = ________ ft^2
(including safety margin)

II. CAPITAL COST

Cost = ________ (Cost from curve) × (________ (current index) ÷ 204.7) — $ ________

III. VARIABLE O & M — $/day — O & M

a. Power = ________ (Hp) × ________ (EC, $/Kw-hr) × 17.9 = ________

IV. FIXED O & M

a. Labor: ________ (hr/day) × ________ ($/hr) = ________

b. Supervision: ________ (hr/day) × ________ ($/hr) = ________

c. Overhead: ________ (Labor, $/day) × ________ (%/100) = ________

d. Lab Labor: ________ (hr/day) × ________ ($/hr) = ________

e. Maint, Service, I&T: ________ (capital, $) × ________ (%/100) ÷ 365 (day/yr) = ________

f. Service Water: ________ (thou gpd) × ________ ($/thou gal) = ________

V. YEARLY O & M 365 (day/yr) × ________ (sum, $/day) = ________ $/yr

VI. UNCOSTED ITEMS

a. Filter Backwash Solids = ________ lb/day

MULTI-MEDIA FILTRATION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ \$/Kw-hr

3. Labor = ________ \$/day

4. Supervision = ________ \$/hr

5. Overhead = ________ % Labor ÷ 100 = ________ %/100

6. Lab Labor = ________ \$/hr

7. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O&M Factor sum = ________ ÷ 100 = ________ %/100

8. Service Water = ________ \$/thou gal

I. DESIGN FACTOR

a. Wastewater characteristics
   Influent flow = ________ mgd (FLOW)
   Influent total suspended solids = ________ mg/L (TSS)

b. Hydraulic loading rate (must be selected by user)

   Q = ________ gpm/ft^2

c. Filtration Surface Area

$$SA = \left(\underset{\text{FLOW mgd}}{\underline{\qquad\qquad}} \times 10^6\right) \div \left(\underset{Q,\ gpm/ft^2}{\underline{\qquad\qquad}} \times 1440\right) = \underline{\qquad\qquad}\ ft^2$$

d. Safety Margin

   If SA $\geq$ 628 ft^2, then: Design SA = 1.2(SA) = ________ ft^2

   If SA < 628 ft^2, then: Design SA = 1.5(SA) = ________ ft^2

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements

$$HP = \left[95.8 \times (\log_n \underset{\text{FLOW, mgd}}{\underline{\hspace{3cm}}}) \right] + 174 = \underline{\hspace{2cm}} \text{ Hp}$$

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

Filter Backwash Solids

$$SP = \underset{\text{FLOW, mgd}}{\underline{\hspace{2cm}}} \times \underset{\text{TSS, mg/L}}{\underline{\hspace{2cm}}} \times \underset{\text{E, fraction}}{\underline{\hspace{2.5cm}}} \times 8.34 = \underline{\hspace{2cm}} \text{ lb/day}$$

IV.3.1.10 FLOTATION

Flotation is used to treat wastewaters containing suspended solids, colloidal material, or oils that have a specific gravity close to that of water. Dissolved air flotation (DAF) is a process by which suspended solids, free and emulsified oils, and grease are separated from wastewater by releasing gas (air) bubbles into the wastewater to aid separation. DAF is discussed in more detail in Volume III, Section III.3.1.10 of the Treatability Manual. Costing methodologies and cost data for these technologies are presented below.

IV.3.1.10-A. Dissolved Air Flotation

A 1. Basis of Design

This presentation is for the removal of oil and solids from wastewater by the dissolved air flotation (DAF) process. This process is represented schematically in Figure IV.3.1.10-A1. The principal design factor for this technology is the influent wastewater flow.

The dissolved air flotation system is sized according to the influent flow rate and design overflow rate. The design overflow rate for this DAF unit process is 1.36 $L/s/m^2$ (2880 gpd/ft^2), based on design flow plus 50% effluent recycle. The main feed influent of the DAF unit undergoes pre-flotation flocculation using lime to aid in the separation of oils and to coagulate and stabilize the floc. The design flow rate, in all cases, is 120 percent of the average wastewater flow. A minimum of two units, each at 50% of design capacity, are provided.

Free oil is readily removed by DAF systems but further treatment is generally required to improve removal of emulsified and soluble oil. The system presented in this section includes lime flocculation of the DAF influent to aid in the separation of oils and to coagulate and stabilize floc. Oil and solids removal also may be enhanced by other chemical and physical means as well. Variations on the DAF process and information on emulsion breaking techniques are presented in Sections III.3.1.10 and III.3.1.14 of Volume III respectively.

a) <u>Source</u>

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

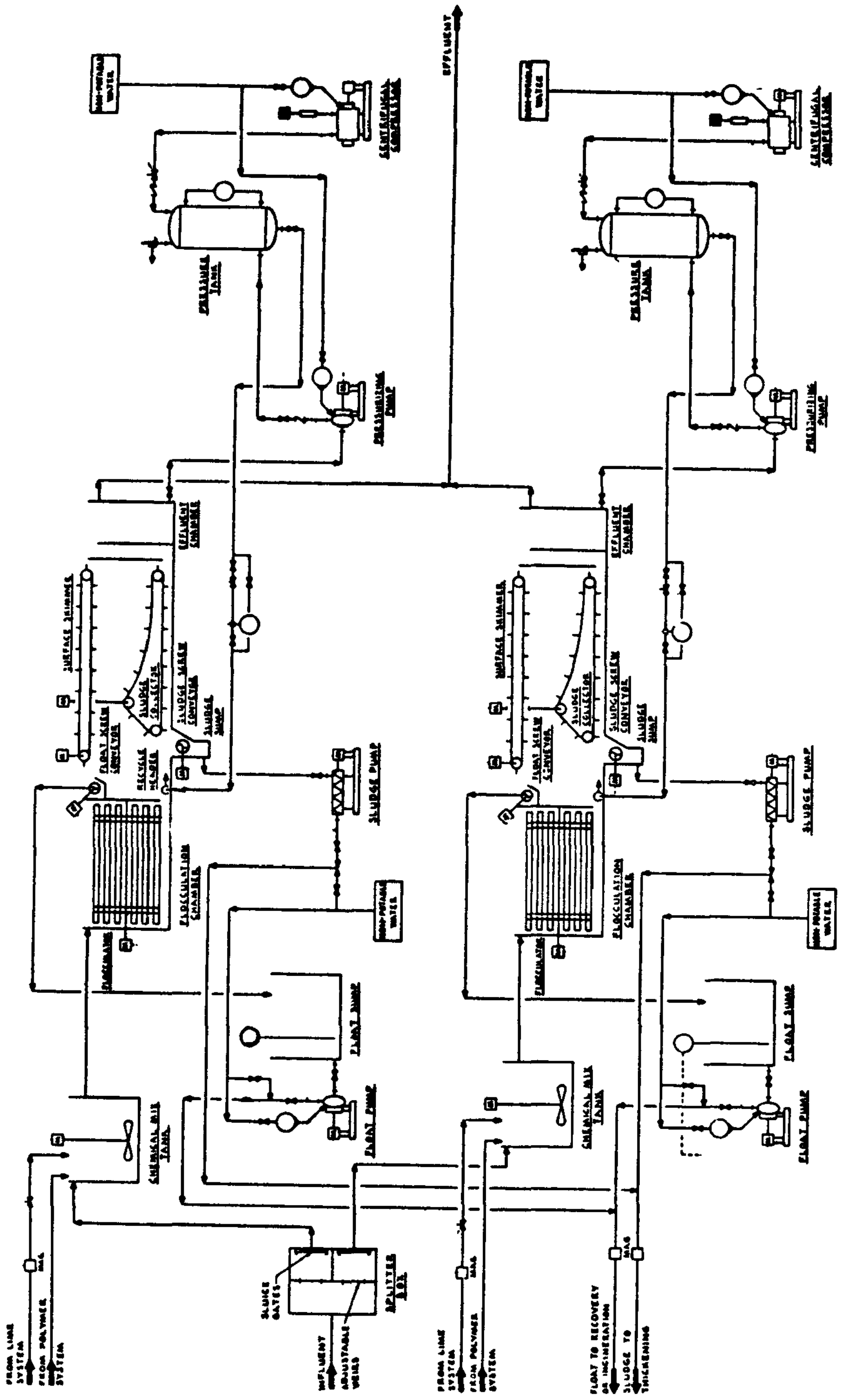


FIGURE IV.3.1.10-A1. PROCESS FLOW DIAGRAM FOR DISSOLVED AIR FLOTATION [4-1]

b) Required Input Data

Average and peak wastewater flow L/s (mgd)

Characteristics of the wastewater stream (mg/L)
- oil and grease
- TSS
- floating solids
- floating organic pollutants

c) Limitations

DAF is not considered applicable for treating influent oil concentrations of less than 10 mg/L.

d) Pretreatment

For influent oil concentrations greater than 35 mg/L DAF may be preceded by gravity oil separation.

e) Design Equation

Average influent wastewater flow rate in liters per second (million gallons per day) is the primary capital cost factor for DAF systems. The cost factor (flow) is adjusted by a scale factor (Section A 2 b) to account for peak flow prior to estimating costs.

f) Subsequent Treatment

Sludge and oil and grease removed from the wastewater stream are usually treated by thickening, stabilizing and dewatering processes before being disposed.

A 2. Capital Costs

The primary cost factor for DAF is the design influent wastewater flow rate. This parameter is the independent variable in the cost curves for the unit process (Figure IV.3.1.10-A2). For flows greater than 4.38 L/s (0.1 mgd), a scale factor is applied to adjust the flow prior to selection of a cost from the cost curve. The scale factor is used as a means of adjusting capital cost to account for peak flow capacity.

a) Cost Data

Items included in the capital cost estimates for the DAF units are as follows [4-2]:

Pre-flotation flocculation tanks (2)
Flotation clarifier, rectangular
Vertical turbine flocculators (2)

Splitter box, concrete (2)
Polymer holding tank
Polymer feed pumps (2)
Sludge pumps, progressive cavity (2)
Air compressor, centrifugal (2)
Sluice gates
Piping
Instrumentation

b) Capital Cost Curve

i) Curve - Figure IV.3.1.10-A2
- Cost (millions of dollars) vs. wastewater flow (liters per day or million gallons per day).
- Curve basis, cost estimates for system at six flow rates: 2.33, 8.39, 21, 25.2, 219, and 437 L/s (37, 133, 333, 400, 3467, and 6933 gpm).

ii) Scale factor: applies to flow prior to selection of a cost from the cost curve

- if Avg Flow <4.38 L/s (< 0.1 mgd), scale factor: SF = 1.0

- if Avg Flow >4.38 L/s (> 0.1 mgd), scale factor:

$$SF = \frac{\text{peak flow + average flow}}{2 \times \text{average flow}}$$

iii) Flow for Cost Purposes (DFLOW) = FLOW × SF

c) Cost Index

Base Period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs are comprised of both variable and fixed components. Power requirement is the only variable operating cost component. Fixed operating cost components include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Cost

i) Power Requirements, DAF - sump pumps, flocculators, DAF package, sludge pumps, polymer package feed pumps and air compressors [4-1]

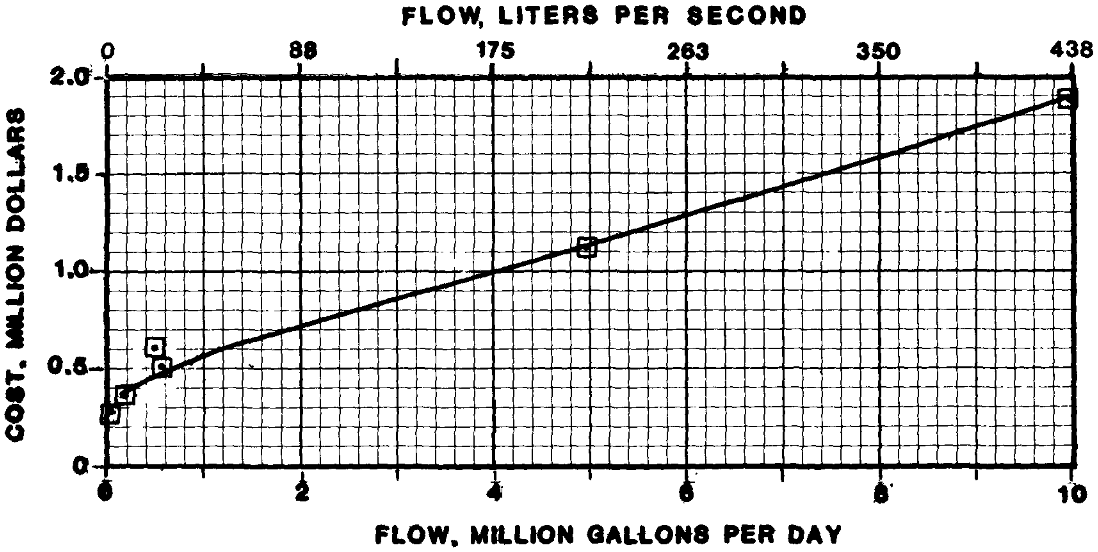


FIGURE IV.3.1.10-A2. CAPITAL COST ESTIMATE FOR DISSOLVED AIR FLOTATION [4-1]

Metric

$$KW = (0.198 \times FLOW) + 5.28$$

where: KW = power, kilowatts
FLOW = average influent flow, L/s

English

$$HP = (11.6 \times FLOW) + 7.08$$

where: HP = horsepower required, Hp
FLOW = average influent flow, mgd

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, $/day
KW = power, kilowatts
24 = hr/day
EC = electricity cost, $/KW-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, $/day
HP = horsepower required, Hp
24 = hrs/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, $/Kw-hr

iii) Lime Requirements

Lime is used in this DAF unit for preflocculation and to help reduce the solubility of some oils. The amount of lime required varies according to flow and influent conditions.

Option 1 If oil and TSS are the only pollutants present with no floating materials.

Metric

$$LIME = 1.5 \times (IOIL - EOIL) \times 0.086 \times FLOW$$

where: LIME = daily lime requirement, Kg/day
1.5 = 150% excess dose factor
IOIL = average influent oil concentration, mg/L (when DAF follows oil separation, IOIL = 35 mg/L)
EOIL = expected effluent oil, mg/L (default value 10)
0.086 = conversion factor
FLOW = average influent flow, L/s

English

$$LIME = 1.5 \times (IOIL - EOIL) \times 8.34 \times FLOW$$

where: LIME = daily lime requirement, lb/day
1.5 = 150% excess dose factor
IOIL = average influent oil concentration, mg/L (when DAF follows oil separation, IOIL assumed = 35 mg/L)
EOIL = expected effluent oil, mg/L (default value 10)
8.34 = conversion factor
FLOW = average influent flow, mgd

Option 2 If oil, TSS and floating materials are present. Two intermediate variables (A&B) are calculated and the lime requirement is equal to the larger of the two.

Metric

$$A = (IFLT - EFLT) \times 1.5 \times 0.086 \times FLOW$$

where: A = intermediate estimate of lime required for floating material, Kg/day
IFLT = average influent floating materials, mg/L
EFLT = expected effluent floating materials, mg/L (default value 30)
1.5 = 150% excess dose factor

English

$$A = (IFLT - EFLT) \times 1.5 \times 8.34 \times FLOW$$

where : A = intermediate estimate of lime required for floating material, lb/day
IFLT = average influent floating materials, mg/L
EFLT = expected effluent floating materials, mg/L (default value 30)
1.5 = 150% excess dose factor

Metric

$$B = 1.5 \times (IOIL - EOIL) \times 0.086 \times FLOW$$

where: B = intermediate estimate of lime required for oil removal, Kg/day

English

$$B = 1.5 \times (IOIL - EOIL) \times 8.34 \times FLOW$$

where: B = intermediate estimate of lime required for oil removal, lb/day

- If B > A, LIME = B, Kg/day or lb/day
- If A > B, LIME = A, Kg/day or lb/day

Option 3 If only floating materials are present in the influent

Metric

$$LIME = IFLT \times 0.086 \times 1.5 \times FLOW$$

where: LIME = daily lime requirement, Kg/day
IFLT = average influent floating materials, mg/L
1.5 = 150% excess dose factor

English

$$LIME = IFLT \times 8.34 \times 1.5 \times FLOW$$

where: LIME = daily lime requirement, lb/day
IFLT = average influent floating materials, mg/L
1.5 = 150% excess dose factor

iv) Lime Cost

Costs for lime are based on total plant needs rather than on the needs of individual unit processes. Lime requirements should be summed for all systems, but costs for lime handling systems and chemicals will be estimated after design of all unit processes requiring lime (see Section IV.3.1.13-C, Lime Handling).

b) Fixed Costs

The fixed O & M components for a DAF system are listed in Table IV.3.1.10-A1 including the cost basis and the unit costs [4-11].

TABLE IV.3.1.10-A1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR DISSOLVED AIR FLOTATION [4-11]

Dissolved Air Flotation

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.25 Weeks (6.00 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.60 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.20 Shifts (1.14 hrs/day)	$10.70/hr
Maintenance	7.53% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	4.6 L/s (105.4 Thou gpd)	$0.13/thou L ($0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

A 4. Miscellaneous Costs

Costs for engineering, and common plant items such as piping and buildings, are calculated after completion of costing for individual units (See Section IV.3.5). The required quantity of land and expected sludge generation from the unit process are calculated below to facilitate subsequent cost estimates.

a) Land

The following equation estimates the amount of land required for DAF based on the overflow rate, scale factor and cost factors.

Metric

$$LAND = SF \times FLOW \times (1.2 \div 1.36)$$

where: LAND = land requirement, m^2
SF = scale factor (see Section A2, b)
FLOW = average influent wastewater flow rate, L/s
1.2 = factor for accessories
1.36 = overflow rate, $L/s/m^2$

English

$$LAND = SF \times FLOW \times (1{,}200{,}000 \div 2{,}880)$$

where: LAND = land requirement, ft^2
SF = scale factor (see Section A2, b)
FLOW = average influent wastewater flow rate, mgd
1,200,000 = mgd × 1.2 factor for accessories, gals/day
2,880 = overflow rate, gpd/ft^2

b) Sludge and Float Production

DAF may produce waste byproducts consisting of oil, solids, or oily solids. Sludge or float production varies according to flow, the influent conditions, and whether or not the DAF unit is preceded by gravity oil separation. Two cases are considered corresponding to the influent options examined under the Lime Requirements Section (A3, a, iii). The total amount of float produced by DAF may be generally estimated as follows:

$$FLOAT = OFLOAT + SFLOAT + FFLOAT$$

where: FLOAT = total float produced, Kg/day or lb/day
OFLOAT = oil float from DAF unit, Kg/day or lb/day
SFLOAT = suspended solids float, Kg/day or lb/day
FFLOAT = floating materials float, Kg/day or lb/day

The amount of float varies according to the type of waste being treated. Three options for estimating total float production are shown below for situations in which only oil and TSS are removed, others where oil, TSS, and floating materials are removed, and last where only floating materials are removed.

i) Option 1 DAF Unit Float - if oil and TSS are the only pollutants

<u>Oil Float</u>

<u>Metric</u>

$$OFLOAT = LIME + [0.086 \times FLOW \times (IOIL - EOIL)]$$

where:
- OFLOAT = oil float from DAF unit, Kg/day
- LIME = daily lime requirement, Kg/day (see Section A3 a, iii, option 1)
- IOIL = influent insoluble oil, mg/L (assumed to be 35 mg/L)
- EOIL = expected effluent oil concentration from DAF unit, mg/L (default value 10)

<u>English</u>

$$OFLOAT = LIME + [8.34 \times FLOW \times (IOIL - EOIL)]$$

where:
- OFLOAT = oil float from DAF unit, lb/day
- LIME = daily lime requirement, lb/day (see Section A3, a, iii, Option 1)
- IOIL = influent insoluble oil, mg/L (assumed to be 35 mg/L)
- EOIL = expected effluent oil concentration from DAF unit, mg/L (default value 10)

<u>TSS Float</u>

<u>Metric</u>

$$SFLOAT = 0.086 \times FLOW \times (TSSI - TSSE)$$

where:
- SFLOAT = suspended solids float, Kg/day
- TSSI = influent TSS, mg/L
- TSSE = effluent TSS, mg/L (assumed to be 30 mg/L if DAF preceded by gravity oil separation)

<u>English</u>

$$SFLOAT = 8.34 \times FLOW \times (TSSI - TSSE)$$

where:
- SFLOAT = suspended solids float, lb/day
- TSSI = influent TSS, mg/L
- TSSE = effluent TSS, mg/L (assumed to be 30 mg/L if DAF preceded by gravity oil separation)

ii) Option 2 DAF Unit Float - if oil, TSS, and floating solids are present

If there are oil, TSS, and floating solids in the influent the following equations are used to determine the amount of float produced by the DAF unit.

Oil Float and Floating Materials

$$OFLOAT = LIME \times 1.67$$

where: OFLOAT = float from DAF unit, Kg/day or lb/day
LIME = daily lime requirement, Kg/day or lb/day (see Section A3,a, iii, Option 2)

TSS Float

Metric

$$SFLOAT = 0.086 \times FLOW \times (TSSI - TSSE)$$

where: SFLOAT = suspended solids float, Kg/day
TSSI = influent TSS, mg/L
TSSE = effluent TSS, mg/L (assumed to be 30 mg/L if DAF preceded by gravity oil separation)

Engish

$$SFLOAT = 8.34 \times FLOW \times (TSSI - TSSE)$$

where: SFLOAT = suspended solids float, lb/day
TSSI = influent TSS, mg/L
TSSE = effluent TSS, mg/L (assumed to be 30 mg/L if DAF preceded by gravity oil separation)

iii) Option 3 DAF Unit Float - if only floating solids are present

$$FFLOAT = LIME \times 1.67$$

where: FFLOAT = floating solids, Kg/day or lb/day
LIME = daily lime requirement, Kg/day or lb/day (see Section A3, a, iii, Option 3)

A 5. Modifications

DAF is often used in series with gravity oil separation to treat combination waste streams of oils, suspended solids, and colloidal materials.

DISSOLVED AIR FLOTATION
SUMMARY WORK SHEET

REFERENCE: IV.3.1.10A

I. DESIGN FACTOR — CAPITAL

a. Flow for cost purposes = ____________ mgd
DFLOW

II. CAPITAL COST

Cost = ____________ × (____________ ÷ 204.7) $ ________
Cost from curve — current index

III. VARIABLE O & M — $/day — O & M

a. Power = ________ × ________ × 17.9 = ________
Hp — EC, $/Kw-hr

IV. FIXED O & M

a. Labor: ________ × ________ = ________
hr/day — $/hr

b. Supervision: ________ × ________ = ________
hr/day — $/hr

c. Overhead: ________ × ________ = ________
Labor, $/day — %/100

d. Lab Labor: ________ × ________ = ________
hr/day — $/hr

e. Maint, Service, I&T: ________ × ________ ÷ 365 = ________
capital, $ — %/100 — day/yr

f. Service Water: ________ × ________ = ________
thou gpd — $/thou gal

V. YEARLY O & M

365 × ________ = ________
day/yr — sum, $/day — $/yr

VI. UNCOSTED ITEMS

a. Land = ________ ft^2

b. Lime = ________ lb/day

c. DAF Float = ________ lb/day

DISSOLVED AIR FLOTATION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ $/Kw-hr

3. Labor = ________ $/hr

4. Supervision = ________ $/hr

5. Overhead = ________ % Labor ÷ 100 = ________ %/100

6. Lab Labor = ________ $/hr

7. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor Sum = ________ % ÷ 100 = ________ %/100

8. Service Water = ________ $/thou gal

I. DESIGN FACTOR

a. Scale Factor for DAF:

If average wastewater flow (FLOW) < 0.1 mgd, Scale Factor = 1

If average wastewater flow (FLOW) > 0.1 mgd, Scale Factor =

$$\left(\underset{\text{Peak flow, mgd}}{\underline{\qquad\qquad}} + \underset{\text{Avg FLOW, mgd}}{\underline{\qquad\qquad}}\right) \div \left[2 \times \left(\underset{\text{Avg FLOW, mgd}}{\underline{\qquad\qquad}}\right)\right] = \underset{\text{SF}}{\underline{\qquad\qquad}}$$

b. Wastewater Flow for Costing Purposes:

$$\text{DFLOW} = \underset{\text{Avg FLOW, mgd}}{\underline{\qquad\qquad}} \times \underset{\text{Scale factor}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ mgd}$$

II. CAPITAL COST

III. VARIABLE O & M

Power Requirements (DAF)

$$\text{HP} = (11.6 \times \underset{\text{Avg FLOW, mgd}}{\underline{\qquad\qquad}}) + 7.08$$

IV. FIXED O & M
V. YEARLY O & M
VI. UNCOSTED ITEMS

a. LAND = $\underline{\qquad}_{\text{SF}}$ × $\underline{\qquad}_{\text{FLOW, mgd}}$ × 417 = ________ ft²

b. Lime Requirements for DAF

1 Option 1 (oil and TSS only pollutants, no floating material)

LIME = $\underline{\qquad}_{\text{FLOW, mgd}}$ × 12.5 × ($\underline{\qquad}_{\text{IOIL, mg/L}}$ - $\underline{\qquad}_{\text{EOIL, mg/L}}$) = ________ lb/day

2 Option 2 (oil, TSS, and floating materials present)

A = $\underline{\qquad}_{\text{FLOW, mgd}}$ × 12.5 × ($\underline{\qquad}_{\text{IFLT, mg/L}}$ - $\underline{\qquad}_{\text{EFLT, mg/L}}$) = ________

B = $\underline{\qquad}_{\text{FLOW, mgd}}$ × 12.5 × $\underline{\qquad}_{\text{IOIL, mg/L}}$ - $\underline{\qquad}_{\text{EOIL, mg/L}}$) = ________

If B > A, LIME = B = ________ lb/day

If A > B, LIME = A = ________ lb/day

3 Option 3 (Floating materials only)

LIME = $\underline{\qquad}_{\text{IFLT, mg/L}}$ × 12.5 × $\underline{\qquad}_{\text{FLOW, mgd}}$ = ________ lb/day

c. *Waste Solids from DAF Unit*

1 Option I (oil and TSS only pollutants, no floating material)

DAF Oil Float

OFLOAT = $\underline{\qquad}_{\text{LIME, lb/day}}$ + [8.34 × $\underline{\qquad}_{\text{FLOW, mgd}}$ × ($\underline{\qquad}_{\text{IOIL, mg/L}}$ - $\underline{\qquad}_{\text{EOIL, mg/L}}$)]

= ________ lb/day

DAF Suspended Solids Float

SFLOAT = 8.34 × $\underline{\qquad}_{\text{FLOW, mgd}}$ × ($\underline{\qquad}_{\text{TSSI mg/L}}$ - $\underline{\qquad}_{\text{TSSE mg/L}}$)

= ________ lb/day

Total Option I DAF Float

$$\text{FLOAT(1)} = \underset{\text{DFLOAT, lb/day}}{\underline{\hspace{6em}}} + \underset{\text{SFLOAT, lb/day}}{\underline{\hspace{6em}}} = \underline{\hspace{4em}} \text{ lb/day}$$

2 Option II (oil and floating solids present)

DAF Oil and Floating Solids Float

$$\text{OFLOAT} = 1.67 \times \underset{\text{LIME, lb/day}}{\underline{\hspace{6em}}} = \underline{\hspace{5em}} \text{ lb/day}$$

Note: for LIME see Section III,b

Suspended Solids Float from DAF

$$\text{SFLOAT} = 8.34 \times \underset{\text{FLOW, mgd}}{\underline{\hspace{5em}}} \times (\underset{\text{TSSI, mg/L}}{\underline{\hspace{5em}}} - \underset{\text{TSSE, mg/L}}{\underline{\hspace{5em}}}) = \underline{\hspace{4em}} \text{ lb/day}$$

Total Option II DAF Float

$$\text{FLOAT(1)} = \underset{\text{OFLOAT, lb/day}}{\underline{\hspace{6em}}} + \underset{\text{SFLOAT, lb/day}}{\underline{\hspace{6em}}} = \underline{\hspace{4em}} \text{ lb/day}$$

3 (Floating solids only)

$$\text{FLOAT} = \text{FFLOAT} = 1.67 \times \underset{\text{LIME, lb/day}}{\underline{\hspace{6em}}} = \underline{\hspace{4em}} \text{ lb/day}$$

IV.3.1.11 FLOW EQUALIZATION

Introduction

Flow equalization is used to reduce variations in wastewater flow, and achieve a more constant flow rate through the downstream treatment processes. A secondary objective of flow equalization is to reduce fluctuations in concentration and mass flow of wastewater constituents. Flow equalization can significantly improve the performance of wastewater treatment facilities and can reduce the required size of downstream facilities. Flow equalization is described in more detail in Volume III of the Treatability Manual, Section III.3.1.11. Costing methodologies and cost data for industrial wastewater treatment applications are presented below.

IV.3.1.11-A. Equalization

A 1. Basis of Design

Wastewater flow is the principal design factor for equalization. High, average, and low flowrate estimates are used to size the equalization basin to maintain a detention time of at least 24 hours. The surface area of the equalization basin is used as a factor in estimating the land required for diking, access roads, piping, miscellaneous associated facilities, and a spill-containment basin. A spill-containment (surge storage) basin with a detention time of 12 hours is included unless the equalization basin capacity is less than 757 m^3 (200,000 gal). A flow equalization system of the type considered is represented in Figure IV.3.1.11-A1.

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

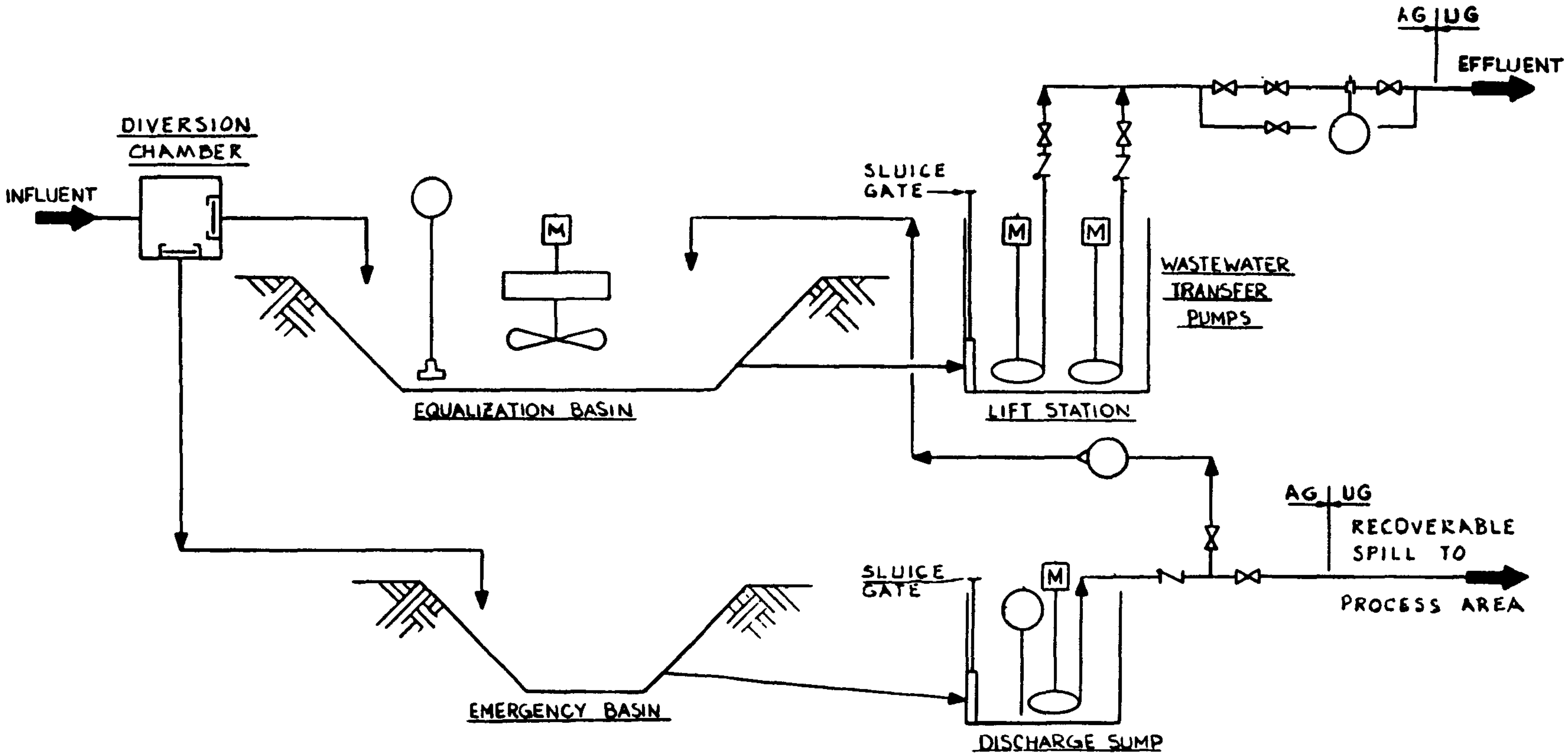
Wastewater flowrate L/s or (mgd) (high, average, low)

c) Limitations

None indicated.

d) Pretreatment

None specified; however, neutralization may precede equalization if the wastewater is excessively corrosive.



NOTE:

1. ALL ABOVE GROUND PIPING TO BE INSULATED AND ELECTRICLY TRACED.

FIGURE IV.3.1.11-A1. PROCESS FLOW DIAGRAM FOR FLOW EQUALIZATION [4-1]

e) Design Equation

The design flow is calculated based on influent high, average, and low flows:

$$FLOW = AVG \times SF$$

where: FLOW = design flow, L/s or mgd
AVG = average influent wastewater flow, L/s or mgd
SF = scale factor

The scale factor (SF) is computed in one of two ways depending on the way in which the average influent flow is determined:

If AVG is calculated as a daily average,

$$SF = [(RATIO - 2.0) + 1.0]^{0.5}$$

If AVG is calculted as a monthly average,

$$SF = [(RATIO - 1.5) + 1.0]^{0.5}$$

The flow ratio (RATIO) is the greater of the high flow to average flow ratio or the average flow to low flow ratio. The scale factor (SF) calculated from the flow ratio (RATIO) cannot be greater than 3 nor less than 1.

$$RATIOH = HIGH \div AVG$$
$$RATIOL = AVG \div LOW$$

where: RATIOH = high to average flow ratio
RATIOL = average to low flow ratio
HIGH = high flow, L/s or mgd
AVG = average flow, L/s or mgd
LOW = low flow, L/s or mgd

If RATIOH > RATIOL, set RATIO = RATIOH
If RATIOL > RATIOH, set RATIO = RATIOL

If SF > 3.0, set SF = 3.0
If SF < 1.0, set SF = 1.0

f) Subsequent Treatment

None specified.

A 2. Capital Costs

The cost factor for equalization is the wastewater flow rate. One of two different cost curves is used to estimate capital costs depending on the design volume of the equalization basin. Small equalization basins (<8.76 L/s (<0.20 mgd)) may be costed using Figure IV.3.1.11-A2 and large equalization basins (8.76 to

876 L/s (0.2 to 20 mgd)) may be costed using Figure IV.3.1.11-A3. Costs estimated using these curves must be adjusted to a current value using an appropriate current cost index.

a) Cost Data

Items included in the capital cost curve estimates are as follows [4-2]:

Low Order Equalization Basins <8.76 L/s (<0.20 mgd)
- Pumps, piping, valves
- Electrical
- Tank and pump foundations
- Carbon steel tank with liner
- Instrumentation
- Sump, sump liner
- Insulation
- Fiberglass grating

High Order Equalization Basins 8.76 to 876 L/s (0.20 to 20 mgd)
- Pumps, piping, valves
- Electrical
- Concrete diversion chamber, equalization basin, and surge storage basin
- Instrumentation
- Sluice gates
- Floating agitator
- Protective coating

b) Capital Cost Curves

Low Order Basin Curve - see Figure IV.3.1.11-A2.
- Cost (thousands of dollars) vs. design flow (liters per second or thousand gallons per day)
- Curve basis, cost estimate on design flows of 0.044, 0.219, 2.19 and 8.76 L/s (1, 5, 50, and 200 thousand gallons/day)

High Order Basin Curve - see Figure IV.3.1.11-A3.
- Cost (millions of dollars) vs. design flow (liters per second or million gallons per day)
- Curve basis, cost estimate on design flows of 8.76, 43.8, 219 and 876 L/s (0.2, 1.0, 5.0, and 20 mgd)

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

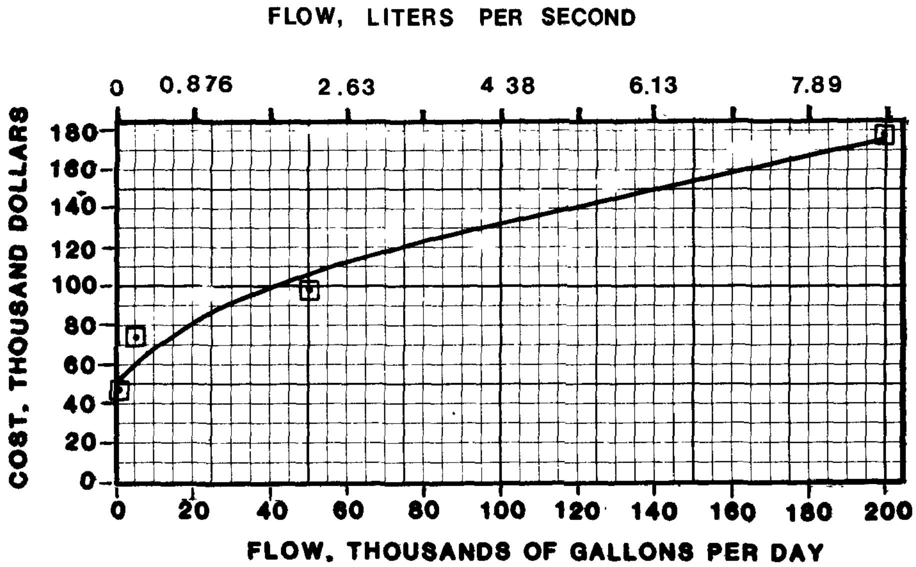


FIGURE IV.3.1.11-A2. CAPITAL COST ESTIMATE FOR FLOW EQUALIZATION (LOW ORDER) [4-10]

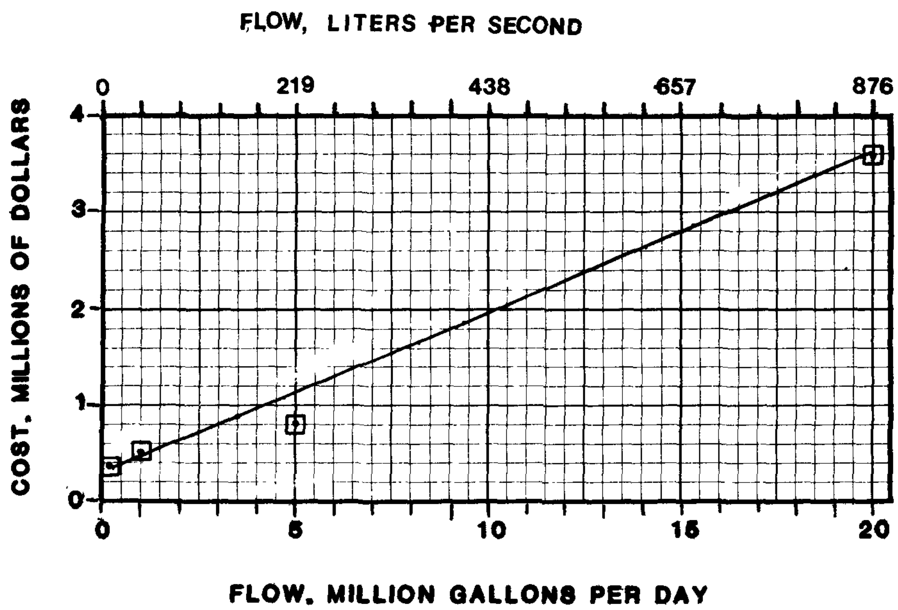


FIGURE IV.3.1.11-A3. CAPITAL COST ESTIMATE FOR FLOW EQUALIZATION (HIGH ORDER) [4-10]

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable component of operating cost for equalization is power. Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Cost

i) Power Requirements - Low Order Basins
This equation was developed using regression analysis procedures [4-1].

Metric

$$KW = (0.346 \times FLOW) + 0.71$$

where: KW = power, KW
FLOW = design flow, L/s

English

$$HP = (20.3 \times FLOW) + 0.95$$

where: HP = power, Hp
FLOW = design flow, mgd

ii) Power Requirements - High Order Basins
This equation was developed using regression analysis procedures [4-1].

Metric

$$KW = (0.553 \times FLOW) - 2.17$$

where: KW = power, KW
FLOW = design flow, L/s

English

$$HP = (32.5 \times FLOW) - 2.91$$

where: HP = power, Hp
FLOW = design flow, mgd

iii) Power Costs

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, \$/day
KW = power, kilowatts
24 = hr/day
EC = electricity cost, \$/KW-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, \$/day
HP = horsepower required, Hp
EC = electricity cost, \$/Kw-hr
24 = hr/day
0.746 = Kw-hr/Hp-hr

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.1.11-A1 including the cost basis and the unit costs [4-11].

A 4. Miscellaneous Costs

Costs for engineering, and common plant items such as yard piping and buildings, are calculated for the plant as a whole after the completion of costing for individual unit processes (see Section IV.3.5). The equalization process requirements for land are estimated separately for low and high order basins.

a) Land - Low Order Basin (<8.76 L/s or <0.20 mgd)

Metric

$$LAND = 1.2 \times AREA$$

where: $LAND$ = land requirement, m^2
1.2 = factor to account for land required for diking, access roads, piping, and miscellaneous associated facilities
$AREA$ = surface are of basin, m^2
= $(FLOW \times 86400 \times 1) \div (1000 \times 3.05)$
$FLOW$ = design flow, L/s
86400 = sec/day
1 = one day detention
1000 = liters per cubic meter
3.05 = assumed basin depth, m

English

$$LAND = 1.2 \times AREA$$

TABLE IV.3.1.11-A1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR FLOW EQUALIZATION [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.15 Weeks (3.60 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.36 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.25 Shifts (1.43 hrs/day)	$10.70/hr
Maintenance	1.34% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.0 Thou L/s	$0.13/thou L
	(0.00 Thou gpd)	($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

where: LAND = land requirement, ft^2
1.2 = factor to account for land required for diking, access roads, piping, and miscellaneous associated facilities
AREA = surface area of basin, ft^2
= $(FLOW \times 10^6) \div (7.48 \times 10) \times 1$
FLOW = design flow, mgd
10^6 = gallons/million gallons
7.48 = gallons/cubic foot
10 = assumed basin depth, ft
1 = one day detention

b) Land - High Order Basin (8.76 to 876 L/s or 0.20 to 20 mgd)

Metric

$$LAND = 1.2 \times 1.5 \times AREA$$

where: LAND = land requirement, m^2
1.2 = factor to account for land required for diking, access roads, piping and miscellaneous associated facilities
1.5 = factor to account for the land area of the spill-containment (surge storage) basin
AREA = surface area of basin, m^2
= $(FLOW \times 86400 \times 1) \div (1000 \times 3.05)$
FLOW = design flow, L/s
86400 = sec/day
1 = one day detention
1000 = liters per cubic meter
3.05 = assumed basin dept, m

English

$$LAND = 1.2 \times 1.5 \times AREA$$

where: LAND = land requirement, ft^2
1.2 = factor to account for land required for diking, access roads, piping, and miscellaneous associated facilities
1.5 = factor to account for the land area of the spill-containment (surge storage) basin
AREA = surface area of basin, ft^2
= $(FLOW \times 10^6) \div (7.48 \times 10) \times 1$
FLOW = design flow, mgd
10^6 = gallons/million gallons
7.48 = gallons/cubic foot
10 = assumed basin depth, ft
1 = one day detention

A 5. Modifications

In addition to variations in wastewater flow rate, the following adjustments are made but not addressed in detail in this presentation.

a) <u>Dampening</u>

High and low flow estimates for a wastewater treatment system may be made by summing the high and low flows for the individual waste streams entering the plant. This will indicate the potential extreme flow, but fails to take into account internal dampening effects. The effect of dampening in the equalization basin due to mixing of short-term variations is accounted for by the scale factor (Section A 1,e). The probability of second dampening (the simultaneous occurrence of high or low flows from individual sources within the plant) is taken into account by the use of several adjustments. One factor (ADJUST) is applied to all streams depending on the amount of daily flow variation and upstream dampening information. Another factor (EXTRA) is only applied when less than five streams are being equalized to account for the mismatching of high peak and extreme low flow values. In addition to flow, it is assumed that variations in pollutant concentration are equalized and dampened to the same extent [4-1].

b) <u>Temperature</u>

A heat balance is performed over the equalization basin to determine exit temperature as follows [4-1]:

Heat Gain = Heat Loss

$$QA + QB + QC = RA + RB + RC + RD$$

where: QA = influent heat, Joules/hr or BTU/hr
QB = mechanical heat, Joules/hr or BTU/hr
QC = solar radiation, Joules/hr or BTU/hr
RA = effluent heat, Joules/hr or BTU/hr
RB = evaporation loss, Joules/hr or BTU/hr
RC = surface convection loss, Joules/hr or BTU/hr
RD = sidewall conduction loss, Joules/hr or BTU/hr

EQUALIZATION
SUMMARY WORK SHEET

REFERENCE: IV.3.1.11-A

I. DESIGN FACTOR		CAPITAL
Design Flow Rate = ______ mgd (FLOW)		
II. CAPITAL COST		
Cost = ______ (Cost from curve) × (______ (current index) ÷ 204.7) =		$ ______
III. VARIABLE O & M	$/day	O & M
Power = ______ (Hp) × ______ (EC, $/Kw-hr) × 17.9	= ______	
IV. FIXED O & M		
a. Labor: ______ (hr/day) × ______ ($/hr)	= ______	
b. Supervision: ______ (hr/day) × ______ ($/hr)	= ______	
c. Overhead: ______ (Labor, $/day) × ______ (%/100)	= ______	
d. Laboratory: ______ (hr/day) × ______ ($/hr)	= ______	
e. Maint, Service, I&T: ______ (capital, $) × ______ (%/100) ÷ 365 (day/yr)	= ______	
f. Service Water: ______ (thou gpd) × ______ ($/thou gal) ×	= ______	
V. YEARLY O & M 365 (day/yr) × ______ (sum, $/day)		= ______ $/yr
VI. UNCOSTED ITEMS		
a. Land = ______ ft^2		

EQUALIZATION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Capital Cost Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ $/Kw-hr

3. Labor = ________ $/hr

4. Supervision = ________ $/hr

5. Overhead = ________ % Labor ÷ 100 = ________ %/100

6. Laboratory = ________ $/hr

7. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor = ÷ 100 = ________ %/100

8. Service Water = ________ $/thou gal

I. DESIGN FACTOR

a. Compute the following:

RATIOH = ________ ÷ ________ = ________
High Flowrate, mgd   Average Flowrate, mgd

RATIOL = ________ ÷ ________ = ________
Average Flowrate, mgd   Low Flowrate, mgd

b. Determine the value of RATIO as follows:

1. If RATIOH > RATIOL,

   set RATIO = ________
   RATIOH

2. If RATIOL > RATIOH,

   set RATIO = ________
   RATIOL

c. Determine the value for the scale factor (SF) as follows:

1. From I b above: RATIO = ________.

2. If the average flow was computed over 24 hours,

$$\text{set SF} = [(\underset{\text{RATIO}}{\underline{\qquad}} - 2.0) + 1.0]^{0.5} = \underset{\text{SF}}{\underline{\qquad}}$$

3. If the average flow was computed over 30 days,

$$\text{set SF} = [(\underset{\text{RATIO}}{\underline{\qquad}} - 1.5) + 1.0]^{0.5} = \underset{\text{SF}}{\underline{\qquad}}$$

d. If SF (from I c above) is grater than 3.0,

set SF = 3.0

e. If SF (from I c above) is less than 1.0,

set SF = 1.0

f. Determine the design flow as follows:

1. From I c, I d, or I e, SF = ____________

2. Calculate design flow (FLOW)

$$\text{Design Flowrate (FLOW)} = \underset{\text{SF}}{\underline{\qquad}} \times \underset{\text{Average Flowrate, mgd}}{\underline{\qquad\qquad}} = \underline{\qquad} \text{ mgd}$$

II. CAPITAL COST

Based on the design flow determined in I f 2, select a cost from one of the capital cost curves.

a. Low Order (FLOW <200 thousand gallons/day), use Figure IV.3.1.11-A2

b. High Order (FLOW ≥0.20 mgd), use Figure IV.3.1.11-A3

III. VARIABLE O & M

a. Power Requirements - Low Order (<0.20 mgd)

$$\text{HP} = (20.3 \times \underset{\text{FLOW}}{\underline{\qquad}}) + 0.95 = \underline{\qquad} \text{ Hp}$$

b. Power Requirement - High Order (0.20 to 20 mgd)

$$\text{HP} = (32.5 \times \underset{\text{FLOW}}{\underline{\qquad}}) + 2.91 = \underline{\qquad} \text{ Hp}$$

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Land Requirement

1. Calculate Basin Surface Area (AREA)

$$AREA = (\underset{\text{FLOW, mgd}}{\underline{\hspace{2cm}}} \times 10^6) \div (7.48 \times 10) = \underline{\hspace{1.5cm}}\ ft^2$$

2. Low Order (Flow <200 thousand gallons/day)

$$LAND = 1.2 \times \underset{\text{AREA}}{\underline{\hspace{2cm}}} = \underline{\hspace{1.5cm}}\ ft^2$$

3. High Order (FLOW ≥0.200 mgd)

$$LAND = 1.2 \times 1.5 \times \underset{\text{AREA}}{\underline{\hspace{2cm}}} = \underline{\hspace{2cm}}\ ft^2$$

IV.3.1.13 NEUTRALIZATION

Introduction

Neutralization involves adjusting the pH of a waste stream to make it suitable for subsequent treatment or disposal. Generally this means adjusting an excessively acidic or basic waste stream to an acceptable range by the addition of an appropriate base or acid. Further details about the neutralization process may be found in Volume III, Section 3.1.13 of the Treatability Manual. Costing methodologies and cost data for this technology are presented below.

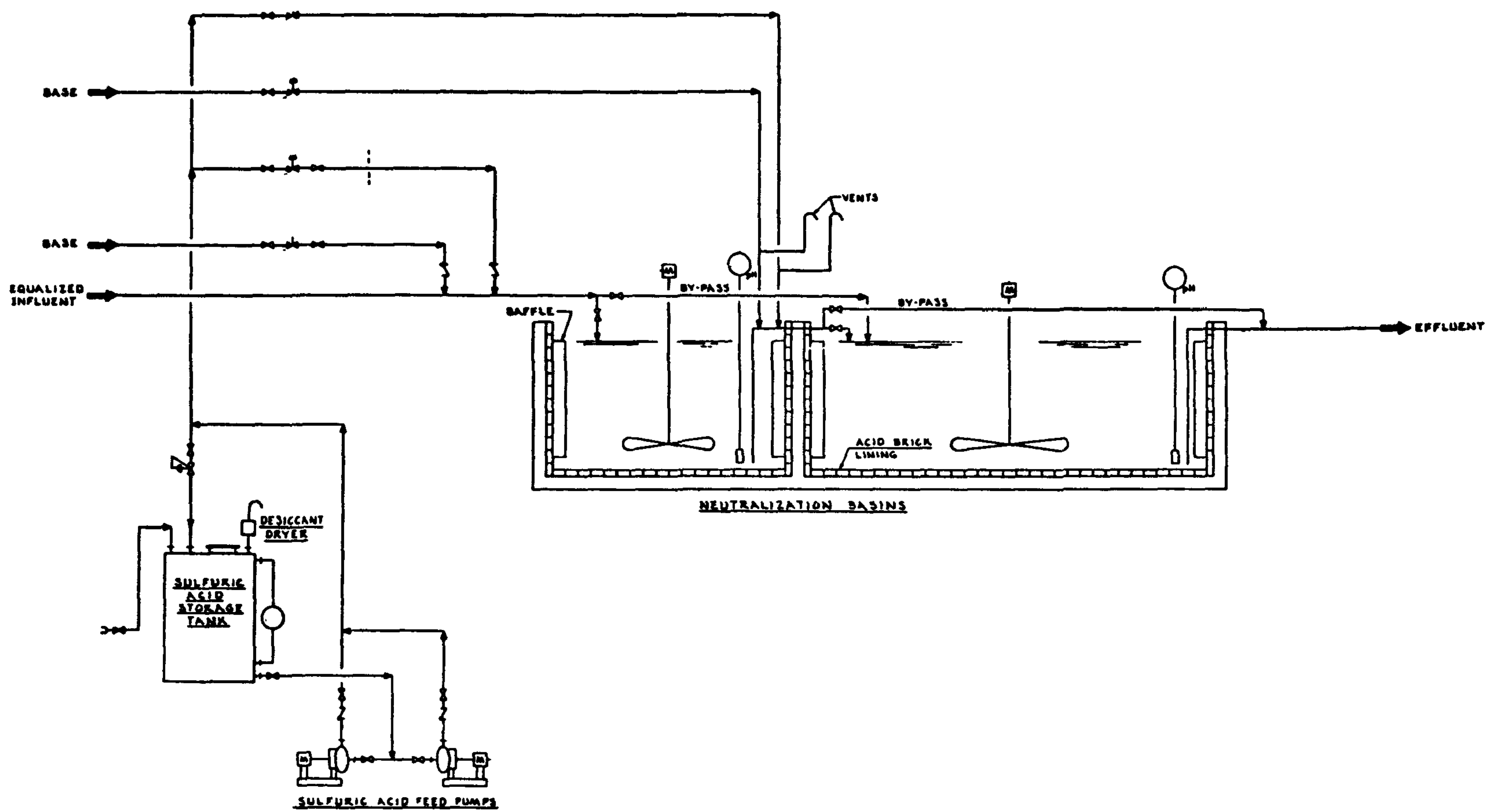
IV.3.1.13-A. Neutralization

A 1. Basis of Design

This presentation is for the neutralization of acidic or basic wastewater streams by base or acid addition. The system as represented in Figure IV.3.1.13-A1 consists of a chemical addition system and a two stage neutralization tank with a design detention time of 5 minutes in the first chamber and 20 minutes in the second. The principal design and cost factor for this technology is wastewater flow. A scale factor is used to adjust for the presence or lack of flow equalization upstream of the unit. Other important factors include influent acidity, alkalinity, pH, TDS, and TSS. Three alternative methods of estimating the neutralization chemical requirements are provided corresponding to the types of information typically available. The preferable method is to base the design dosage of sulfuric acid or base (lime or caustic) required to neutralize the wastewater stream on influent acidity or alkalinity data (in mg/L $CaCO_3$ equivalents). If these data are not available, the required reagent additions may be approximated based on pH data. For streams where no alkalinity, acidity, or pH data are available a standard chemical dose estimate may be used based on best engineering judgement. However, it should be kept in mind that use of these last two methods can introduce considerable error. The neutralization process is assumed to achieve a control to an average pH of 7.0, with a pH range of 6.5 to 8.0.

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].



FIGURES IV.3.1.13-A1. PROCESS FLOW DIAGRAM FOR NEUTRALIZATION [4-1]

b) Required Input Data

Wastewater Flow L/s (mgd)
Alkalinity, acidity (in mg/L $CaCO_3$ equivalents) pH
TDS, TSS (mg/L)

c) Limitations

None specified.

d) Pretreatment

Neutralization is usually preceded by flow equalization except when neutralization is needed first to avoid severe corrosion of downstream units.

e) Design Equation

Average daily wastewater flow in L/s (mgd) is the primary design and capital cost factor for neutralization systems. The design residence times of the reaction and attenuation chambers are five and 20 minutes, respectively, at 120% of average daily flow. A scale factor is applied to the capital cost estimate if the neutralization unit precedes flow equalization to account for sizing the units for 200% of average daily flow instead of 120%.

f) Subsequent Treatment

None specified.

A 2. Capital Costs

Influent flow is the primary capital cost factor for this unit process. Capital costs can be estimated for neutralization systems less than or equal to 8.76 L/sec (0.2 mgd) in capacity using the low order cost curve (Figure IV.3.1.13-A2) and for systems between 8.76 and 876 L/S (0.2 and 20 mgd) in capacity using the high order cost curve (Figure IV.3.1.13-A3). A scale factor of 1.67 is applied to the capital cost if the neutralization unit is not preceded by an equalization unit. Costs estimated using these curves must be adjusted to current values using an appropriate current cost index.

a) Cost Data

Items* included in the capital cost curve estimates are as follows [4-2]:

i) Low Order <8.76 L/s, (0.2 mgd)

Mixing tank, fiberglass
Attenuation tank, fiberglass

Acid storage and feed
Agitators (2)
Piping, electrical
Instrumentation

ii) High Order, 8.76 to 876 L/s (0.2 to 20 mgd)

Mixing tank, concrete, acid brick lined
Attenuation tank, acid brick lined
Acid storage and feed
Agitators (2)
Piping, electrical
Instrumentation

*Note that the lime or caustic handling and feed equipment is designed to serve the entire plant's needs and is sized and costed separately (see Lime Handling, Section IV.3.1.13-C).

b) <u>Capital Cost Curves</u>

i) Low Order Curve - See Figure IV.3.1.13-A2

- Cost (thousands of dollars) vs. flow (liters per second or million gallons per day)
- Curve basis, cost estimates on four systems with flow rates of 4.38, 8.76, 17.5, and 26.3 L/s (0.1, 0.2, 0.4, and 0.6 mgd)

ii) High Order Curve - See Figure IV.3.1.13-A3

- Cost (hundred thousand dollars) vs. flow (liters per second or million gallons per day)
- Curve basis, cost estimates on four systems with flow rates of 8.76, 43.8, 219, and 876 L/s (0.2, 1.0, 5.0, and 20.0 mgd).

iii) Scale Factor - If neutralization is not preceded by equalization, a scale factor of 1.67 is applied to standard capital cost.

c) <u>Cost Index</u>

Base Period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable components of operating cost are power and chemical costs. Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and

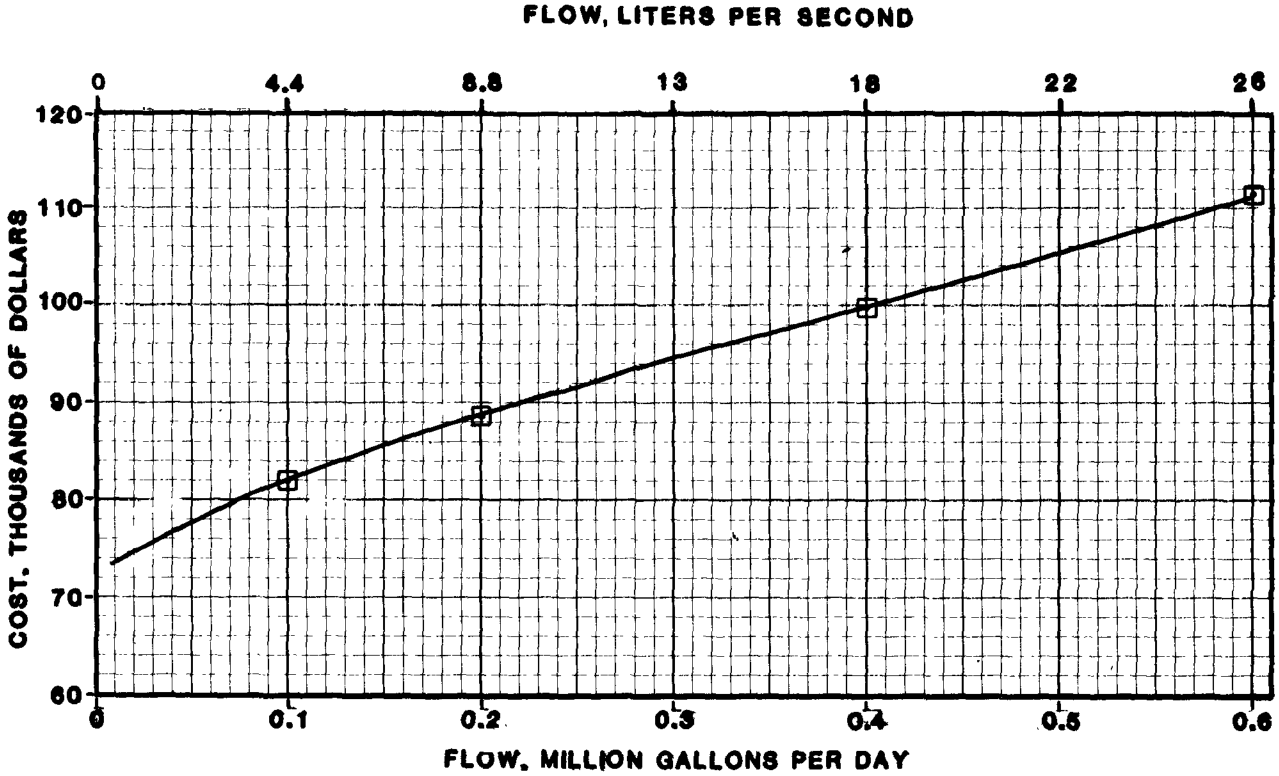


FIGURE IV.3.1.13-A2. CAPITAL COST ESTIMATE FOR NEUTRALIZATION (LOW ORDER) [4-10]

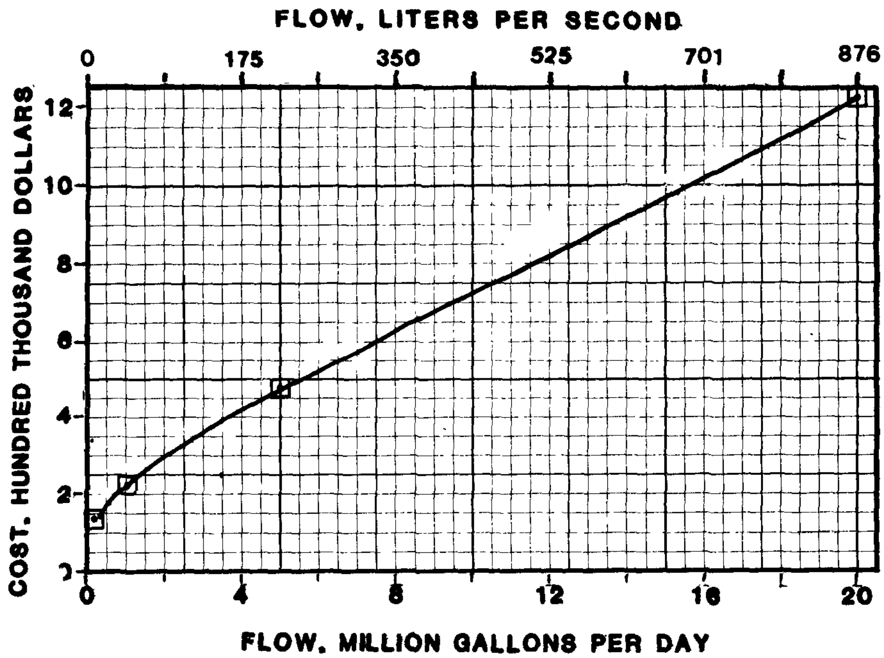


FIGURE IV.3.1.13-A3. CAPITAL COST ESTIMATE FOR NEUTRALIZATION (HIGH ORDER) [4-10] taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Costs

i) Power Requirements, Low Order (Flow <8.76 L/s (0.2 mgd)) - pumps, agitators [4-1]. These equations were developed using regression analysis procedures.

Metric

$$KW = (0.55 \times FLOW) + 0.657$$

where: KW = power requirement, kilowatts
FLOW = influent flow, L/s

English

$$HP = (32.3 \times FLOW) + 0.881$$

where: HP = power requirement, Hp
FLOW = influent flow, mgd

ii) Power Requirements, High Order (Flow 8.76 to 876 L/s (0.2 to 20 mgd)) [4-1]. These equations were developed using regression analysis procedures.

Metric

$$KW = (0.266 \times FLOW) + 6.49$$

where: KW = power requirement, kilowatts
FLOW = influent flow, L/s

English

$$HP = (15.6 \times FLOW) + 8.70$$

where: HP = power requirement, Hp
FLOW = influent flow, mgd

iii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, $/day
KW = power required, kilowatts
24 = hours/day
EC = electricity cost, $/Kw-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where:
- PC = power cost, \$/day
- HP = horsepower required, Hp
- 24 = hours/day
- 0.746 = Kw-hr/Hp-hr
- EC = electricity cost, \$/Kw-hr

iv) Chemical Requirements

The chemical requirements for neutralization may be estimated in one of three ways depending on the influent wastewater quality data available. The preferred method is to use acidity/alkalinity data (Case I), but methods using only pH data (Case II) or a standard dose (Case III) can be used.

• CASE I - Influent Acidity and Alkalinity Data Available:

- If both acidity and alkalinity are present in the influent, determine the dominant characteristic.

$$A = AP - (a \div 2)$$

where:
- A = modified dominant acidity or alkalinity, mg/L ($CaCO_3$ equivalents)
- AP = influent measured dominant acidity or alkalinity factor, mg/L
- a = influent concentration of other factor, mg/L

This modified alkalinity or acidity should be used in subsequent calculations where applicable in place of the dominant influent value.

1) Lime and topping acid requirements based on acidity.

If the influent wastewaters dominant characteristic is acidic, lime is added to neutralize the acid and topping acid is added to cover minor acidity fluctuations.

Metric

$$LIME = 0.74 \times AC \times FLOW \times 0.086$$

where:
- LIME = lime requirements, Kg/day
- 0.74 = stoichiometric ratio of $Ca(OH)_2$ to $CaCO_3$
- AC = modified influent acidity, mg/L ($CaCO_3$ equivalents)

FLOW = influent flow, L/s
0.086 = conversion factor

English

$$LIME = 0.74 \times AC \times FLOW \times 8.34$$

where: LIME = lime requirements, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor

Topping acid requirements are based on modified influent acidity as follows:

Metric

$$TA = ADOSE \times FLOW \times 0.086$$

where: TA = topping acid, Kg/day
ADOSE = acid dose, mg/L
FLOW = influent flow L/s
(ADOSE determined from the following table)

Acidity (mg/L)	Topping Acid Dose (ADOSE) (mg/L)
$AC > 150$	50
$100 < AC \leq 150$	200 - AC
$AC < 100$	100

English

$$TA = ADOSE \times FLOW \times 8.34$$

where: TA = topping acid, lb/day
ADOSE = acid dose, mg/L (from above table)
FLOW = influent flow, mgd

2) Acid and topping lime requirements based on alkalinity

If the influent wastewater is predominantly alkaline, sulfuric acid is added to neutralize the waste and topping lime is added to cover minor alkalinity fluctuations.

Metric

$$ACID = 0.98 \times ALK \times FLOW \times 0.086$$

where: ACID = acid (H_2SO_4) requirements, Kg/day
0.98 = stoichiometric ratio of H_2SO_4 to $CaCO_3$ equivalents

ALK = modified influent alkalinity, mg/L, ($CaCO_3$ equivalents)
$FLOW$ = influent flow, L/s
0.086 = conversion factor

English

$$ACID = 0.98 \times ALK \times FLOW \times 8.34$$

where: $ACID$ = acid (H_2SO_4) requirement, lb/day
$FLOW$ = influent flow, mgd
8.34 = conversion factor

Topping lime requirements are based on modified influent alkalinity as follows:

Metric

$$TL = LDOSE \times FLOW \times 0.086$$

where: TL = topping lime requirement, Kg/day
$FLOW$ = influent flow, L/s
$LDOSE$ = lime dose, mg/L (LDOSE determined from the following table)

Alkalinity (mg/L)	Topping Lime Dose(LDOSE) (mg/L)
$ALK > 150$	50
$100 < ALK \geq 150$	200 - ALK
$ALK < 100$	100

English

$$TL = LDOSE \times FLOW \times 8.34$$

where: TL = topping lime requirement, lb/day
$LDOSE$ = lime dose, mg/L (from above table)
$FLOW$ = influent flow, mgd

- CASE II - Only pH Data Available

If influent alkalinity and acidity data are not available, the lime and acid requirements for a neutralization system may be estimated based on the following influent pH ranges. Estimates derived using this method should be scrutinized for reasonableness; particularly when dealing with highly buffered wastewaters.

1) *If* (low pH) >7.0, then acid and topping lime are required:

$$ACIDC = [(\text{low pH}) - 7.0]^2 \times 20 \text{ or } 50 \text{ mg/L whichever is larger and}$$

$$TLC = 50 \text{ mg/L}$$

where: ACIDC = acid (H_2SO_4) requirement, mg/L
(low pH) = minimum influent pH value
TLC = topping lime requirement, mg/L

2) If (low pH) <7.0 and (avg pH) >7.0, then lime and topping acid are required:

$$LIMEC = [7.0 - (\text{low pH})]^3 \times 20 \text{ or } 50 \text{ mg/L whichever is larger and}$$

$$TAC = \{[((\text{avg pH}) + (\text{high pH})) \div 2] - 7\}^2 \times 20 \text{ or } 50 \text{ mg/L whichever is greater}$$

where: LIMEC = lime requirement, mg/L
(avg pH) = average influent pH value
(high pH) = highest influent pH value
TAC = topping acid requirement, mg/L

3) If (low pH) ≤7.0 and (avg pH) ≤7.0 and (high pH) ≥7.0, then lime and topping acid are required:

$$LIMEC = \{7.0 - [((\text{avg pH}) + (\text{low pH})) \div 2]\}^3 \times 20 \text{ or } 50 \text{ mg/L whichever is greater; and}$$

$$TAC = [(\text{high pH}) - 7.0]^2 \times 20 \text{ or } 50 \text{ mg/L whichever is greater}$$

4) If (low pH) ≤7.0 and (avg pH) ≤7.0 and (high pH) ≤7.0, then lime only is required:

$$LIMEC = [7.0 - (\text{avg pH})]^3 \times 20 \text{ or } 100 \text{ mg/L whichever is greater; and}$$

$$TAC = 0$$

5) To convert chemical requirements to daily weight basis;

Metric

$$ACID = ACIDC \times FLOW \times 0.086$$
$$TL = TLC \times FLOW \times 0.086$$
$$LIME = LIMEC \times FLOW \times 0.086$$
$$TA = TAC \times FLOW \times 0.086$$

where: ACID = acid required, Kg/day
TL = topping lime required, Kg/day
LIME = lime required, Kg/day
TA = topping acid required, Kg/day
FLOW = influent flow, L/s
0.086 = conversion factor

English

$$\text{ACID} = \text{ACIDC} \times \text{FLOW} \times 8.34$$
$$\text{TL} = \text{TLC} \times \text{FLOW} \times 8.34$$
$$\text{LIME} = \text{LIMEC} \times \text{FLOW} \times 8.34$$
$$\text{TA} = \text{TAC} \times \text{FLOW} \times 8.34$$

where: ACID = acid required, lb/day
TL = topping lime, lb/day
LIME = Lime required, lb/day
TA = topping and, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor

- CASE III - No Data Available

For streams where no pH, acidity, or alkalinity data are available, a standard dose of 100 mg/L of acid and 100 mg/L of lime may be assumed. These additions are considered suitable to neutralize occasional pH swings [4-1]. For streams of an essentially neutral pH, a minimum standard dose of 50 mg/L of acid and 50 mg/L of lime may be used.

Metric

$$\text{LIME} = \text{SDL} \times \text{FLOW} \times 0.086$$

where: LIME = lime required, Kg/day
SDL = standard dose of lime, mg/L (100 mg/L or 50 mg/L minimum)
FLOW = influent flow, L/s
0.086 = conversion factor

$$\text{ACID} = \text{SDA} \times \text{FLOW} \times 0.086$$

where: ACID = acid required, Kg/day
SDA = standard dose of acid, mg/L (100 mg/L or 50 mg/L minimum)

English

$$\text{LIME} = \text{SDL} \times \text{FLOW} \times 8.34$$

where: LIME = lime required, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor

$$\text{ACID} = \text{SDA} \times \text{FLOW} \times 8.34$$

where: ACID = acid required, lb/day

v) Chemical Costs (except lime*)

$$AC = ACID \times N$$

where: AC = acid cost, $/day
ACID = acid requirement, lb/day
N = unit cost of sulfuric acid, $/lb

*Cost for lime is based on total plant needs rather than on the needs of an individual unit process. Lime requirements should be accounted for but costs for handling systems and lime should be estimated separately after design of all unit processes requiring lime (see Lime Handling, Section IV.3.1.13-C).

b) Fixed Costs

The fixed O & M components of this technology are listed in Table IV.3.1.13-A1, including the cost basis and the unit costs the Model [4-11].

A 4. Miscellaneous Costs

Costs for engineering, and common plant items such as land, piping, and buildings, are calculated after completion of costing for individual units (see Section IV.3.5).

A 5. Modifications

The effluent stream may be adjusted to account for changes in total dissolved solids (TDS) and TSS which result from the neutralization process. TDS is expected to change as a result of additions of acid and lime. If both sulfate and calcium are present in the wastewater and additional amounts are added during neutralization, additional TSS may be formed as the solution reaches the solubility limit for calcium and sulfate. The formation of TSS from the wastewater is of some interest for cost considerations since it could affect the volume of sludge which would eventually be collected and disposed of in subsequent unit processes.

a) TDS Increase due to Neutralization

Metric

$$TDSE = TDSI + \{[LIME \times (40 \div 74) + ACID \times (96 \div 98)] \div (FLOW \times 0.086)\}$$

where: TDSE = average effluent TDS, mg/L
TDSI = average influent TDS, mg/L
LIME = lime added, Kg/day
$40 \div 74$ = mass ratio of Ca to $Ca(OH)_2$

TABLE IV.3.1.13-A1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR NEUTRALIZATION [4-11].

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.20 Weeks (4.80 hrs/day)	\$ 9.80/hr
Supervision (1)	10% Labor (0.48 hrs/day)	\$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.10 Shifts (0.57 hrs/day)	\$10.70/hr
Maintenance	2.50% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.00 L/s (0.00 Thou gpd)	\$ 0.13/thou L (\$ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

ACID = acid added, Kg/day
$96 \div 98$ = mass ratio of SO_4 to H_2SO_4
FLOW = influent flow, L/s
0.086 = conversion factor

English

$$TDSE = TDSI + \{ [LIME \times (40 \div 74) + ACID \times (96 \div 98)] \div (FLOW \times 8.34)\}$$

where: LIME = lime added, lb/day
ACID = acid added, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor

b) TSS Increase due to Neutralization

If calcium, sulfate, and carbonate are present in the wastewater, then additional suspended solids may be produced [4-1]. The user should check first to determine if calcium sulfate may be generated (Step 1), and then check for calcium carbonate generation (Step 2) [4-1].

i) Step 1. If calcium and sulfate are present in the influent in excess of the triggering values (1000 and 2000 mg/L respectively are used to trigger the need for this modification), the effluent TSS is calculated as follows:

Metric

$$TSSE = (CAL + SUL - 2500) + TSSI$$

where: TSSE = effluent TSS, mg/L
CAL = total calcium dissolved solids, mg/L
= $[LIME \div (FLOW \times 0.086)] \times (40 \div 74) + CALI$
LIME = lime added, Kg/day
FLOW = influent flow, L/s
0.086 = conversion factor
CALI = influent calcium dissolved solids, mg/L
$40 \div 74$ = mass ratio of Ca to $Ca(OH)_2$
SUL = total sulfate dissolved solids, mg/L
= $[ACID \div (FLOW \times 0.086)] \times (96 \div 98) + SULI$
ACID = acid requirement, Kg/day
SULI = influent sulfate dissolved solids, mg/L
$96 \div 98$ = mass ratio of SO_4 to H_2SO_4
2500 = solubility limit of calcium sulfate, mg/L
= 800 mg/L calcium plus 1700 mg/L sulfate, [4-2]

TSSI = influent TSS, mg/L
0.086 = conversion factor

English

$$TSSE = (CAL + SUL - 2500) + TSSI$$

where: CAL = total calcium dissolved solids, mg/L
= [LIME ÷ (FLOW × 8.34)] × (40 ÷ 74) + CALI
LIME = Lime added, lb/day
FLOW = influent flow, mgd
SUL = total sulfate dissolved solids, mg/L
= [ACID ÷ (FLOW × 8.34)] × (96 ÷ 98) + SULI

Note that the effluent values of calcium and sulfate may be set at their solubility limits after computing the TSS increase.

ii) Step 2. *If* calcium >200 mg/L and carbonate >200 mg/L and no sulfate:

Metric

$$TSSE = (CARI + CAL - 200) + TSSI$$

where: TSSE = effluent TSS, mg/L
CARI = influent carbonate dissolved solids, mg/L
CAL = total calcium dissolved solids, mg/L
= [LIME ÷ (FLOW × 0.086)] × (40 ÷ 74) + CALI
LIME = lime added, Kg/day
FLOW = influent flow, L/s
0.086 = conversion factor
CALI = influent calcium dissolved solids, mg/L
200 = solubility limit for calcium carbonate, mg/L
TSSI = influent TSS, mg/L

English

$$TSSE = (CARI + CAL -200) + TSSI$$

where: TSSE = effluent TSS, mg/L
CAL = total calcium dissolved solids, mg/L
= [LIME ÷ (FLOW × 8.34)] × (40 ÷ 74) + CALI
LIME = lime added, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor

NEUTRALIZATION
SUMMARY WORK SHEET   REFERENCE: IV.3.1.13-A

I. DESIGN FACTOR	CAPITAL
a. Flow = ________ mgd	
b. Scale Factor, if required = ________	
II. CAPITAL COST	
Cost = ________ (Cost from curve) × ________ (scale factor) × (________ (current index) ÷ 204.7)	$ ________

III. VARIABLE O & M	$/day	O & M
a. Power = ________ (Hp) × ________ (EC, $/Kw-hr) × 17.9	= ________	
b. ACID = ________ (lb/day) × ________ ($/lb)	= ________	
IV. FIXED O & M		
a. Labor: ________ (hr/day) × ________ ($/hr)	= ________	
b. Supervision: ________ (hr/day) × ________ ($/hr)	= ________	
c. Overhead: ________ (Labor, $/day) × ________ (%/100)	= ________	
d. Lab Labor: ________ (hr/day) × ________ ($/hr)	= ________	
e. Maint, Service, I&T: ________ (capital, $) × ________ (%/100) ÷ 365 (day/yr)	= ________	
f. Service Water: ________ (thou gpd) × ________ ($/thou gal)	= ________	
V. YEARLY O & M 365 (day/yr) × ________ (sum, $/day)		= ________ $/yr

VI. UNCOSTED ITEMS

a. LIME = ________ lb/day   b. Effluent TSS = ________ mg/L
c. Effluent TDS = ________ mg/L

NEUTRALIZATION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ $/Kw-hr

3. Sulfuric Acid = ________ $/lb

4. Labor = ________ $/hr

5. Supervision = ________ $/hr

6. Overhead = ________ % Labor ÷ 100 = ________%/100

7. Lab Labor = ________ $/hr

8. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor Sum = % ÷ 100 = ________%/100

9. Service Water = ________ $/thou gal

I. DESIGN FACTOR

a. Flow = ____________ mgd

b. Scale factor

   i) If neutralization precedes equalization, scale factor = 1.67 otherwise scale factor = 1.0

II. CAPITAL COST

Select: low order ____________ ($\leq$0.2 mgd) or high order ____________ (0.2 to 20 mgd) cost curve

III. VARIABLE O & M

a. Power Requirements, Low Order Systems (<0.2 mgd)

$$HP = (32.3 \times \underset{\text{Flow, mgd}}{\underline{\qquad\qquad}}) + 0.881 = \underline{\qquad\qquad} \text{ Hp}$$

b. Power Requirements, High Order Systems (0.2 to 20 mgd)

$$HP = (15.6 \times \underset{\text{Flow, mgd}}{\underline{\qquad\qquad}}) + 8.70 = \underline{\qquad\qquad} \text{ Hp}$$

c. Chemical Requirements Case I: Influent Acidity and Alkalinity Data Available

1. Determine dominant characteristic, alkalinity (ALK), or acidity (AC)

$$A = \underset{\text{larger of alkalinity or acidity}}{\underline{\qquad\qquad}} - (\underset{\text{smaller of alkalinity or acidity}}{\underline{\qquad\qquad}} \div 2) = \underset{\text{modified alkalinity or acidity}}{\underline{\qquad\qquad}}\ \text{mg/L}$$

2. <u>If</u> wastewater is predominantly acidic:

$$\text{LIME} = \underset{\text{AC, mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 6.17 = \underset{\text{LIME}}{\underline{\qquad\qquad}}\ \text{lb/day}$$

$$\text{TA} = \underset{\text{ADOSE, mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 8.34 = \underset{\text{Topping Acid}}{\underline{\qquad\qquad}}\ \text{lb/day}$$

3. <u>If</u> wastewater is predominantly alkaline:

$$\text{ACID} = \underset{\text{ALK, mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 8.17 = \underset{\text{ACID}}{\underline{\qquad\qquad}}\ \text{lb/day}$$

$$\text{TL} = \underset{\text{LDOSE, mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 8.34 = \underset{\text{Topping Lime}}{\underline{\qquad\qquad}}\ \text{lb/day}$$

d. Chemical Requirements Case II: Only pH Data Available (method used when data are insufficient to use method C above)

1. <u>If</u> (low pH) >7.0:

$$\text{ACIDC} = [\underset{\text{(low pH)}}{\underline{\qquad\qquad}} - 7.0]^2 \times 20 = \underline{\qquad\qquad}\ \text{mg/L}$$

<u>or</u> minimum value for ACIDC = 50 mg/L

TLC = 50 mg/L

2. <u>If</u> (low pH) <7.0 and (avg pH) >7.0:

$$\text{LIMEC} = [7.0 - \underset{\text{(Low pH)}}{\underline{\qquad\qquad}}]^3 \times 20 = \underline{\qquad\qquad}\ \text{mg/L}$$

<u>or</u> minimum value for LIMEC = 50 mg/L

$$\text{TAC} = \{[(\underset{\text{(avg pH)}}{\underline{\qquad\qquad}} + \underset{\text{(high pH)}}{\underline{\qquad\qquad}}) \div 2] - 7\}^2 \times 20 = \underline{\qquad\qquad}\ \text{mg/L}$$

<u>or</u> minimum value for TAC = 50 mg/L

3. <u>If</u> (low pH) ≤7.0 and (avg pH) ≤7.0 and (high pH) ≥7.0:

$$\text{LIMEC} = \{7.0 - [(\underset{\text{(avg pH)}}{\underline{\qquad\qquad}} + \underset{\text{(low pH)}}{\underline{\qquad\qquad}}) \div 2]\}^3 \times 20 = \underline{\qquad\qquad} \text{ mg/L}$$

<u>or</u> minimum value for LIMEC = 50 mg/L

$$\text{TAC} = (\underset{\text{(high pH)}}{\underline{\qquad\qquad}} - 7.0)^2 \times 20 = \underline{\qquad\qquad} \text{ mg/L}$$

<u>or</u> minimum value for TAC = 50 mg/L

4. <u>If</u> (low) pH ≤7.0 and (avg) pH ≤7.0 and (high) pH ≤7.0:

$$\text{LIMEC} = (7.0 - \underset{\text{(avg pH)}}{\underline{\qquad\qquad}})^3 \times 20 = \underline{\qquad\qquad} \text{ mg/L}$$

<u>or</u> minimum value for LIMEC = 100 mg/L

TAC = 0 mg/L

5. Convert to daily weight basis

<u>If</u> (low pH) >7.0 (method 1 above), then:

$$\text{ACID} = \underset{\text{ACIDC,mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 8.34 = \underline{\qquad\qquad} \text{ lb/day}$$

$$\text{LIME} = \underset{\text{TLC,mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 8.34 = \underline{\qquad\qquad} \text{ lb/day}$$

<u>If</u> method 2, 3, or 4 used above, then:

$$\text{LIME} = \underset{\text{LIMEC,mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 8.34 = \underline{\qquad\qquad} \text{ lb/day}$$

$$\text{ACID} = \underset{\text{TAC,mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 8.34 = \underline{\qquad\qquad} \text{ lb/day}$$

e. Chemical Requirements Case III: No Data Available (standard 100 mg/L doses assumed)

$$\text{LIME} = \underset{\text{SDL, mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 8.34 = \underline{\qquad\qquad} \text{ lb/day}$$

$$\text{ACID} = \underset{\text{SDA, mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 8.34 = \underline{\qquad\qquad} \text{ lb/day}$$

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Effluent TDS (TDSE) =

$$\underset{\text{TDSI,mg/L}}{\underline{\hspace{2cm}}} + [((0.54 \times \underset{\text{LIME,lb/day}}{\underline{\hspace{2.5cm}}}) + (0.98 \times \underset{\text{ACID,lb/day}}{\underline{\hspace{2.5cm}}})) \div (\underset{\text{FLOW,mgd}}{\underline{\hspace{2cm}}} \times 8.34)]$$

$$= \underline{\hspace{2cm}} \text{ mg/L}$$

b. Effluent TSS (TSSE)

1. Step 1, Calcium (CALI >1000 mg/L) and sulfate (SULI >2000 mg/L) present

$$\text{CAL} = \{[\underset{\text{LIME,lb/day}}{\underline{\hspace{2.5cm}}} \div (\underset{\text{Flow,mgd}}{\underline{\hspace{2.5cm}}} \times 8.34)] \times 0.54\} + \underset{\text{CALI,mg/L}}{\underline{\hspace{2.5cm}}}$$

$$= \underline{\hspace{2.5cm}} \text{ mg/L}$$

$$\text{SUL} = \{[\underset{\text{ACID,lb/day}}{\underline{\hspace{2.5cm}}} \div (\underset{\text{FLOW,mgd}}{\underline{\hspace{2.5cm}}} \times 8.34)] \times 0.98\} + \underset{\text{SULI,mg/L}}{\underline{\hspace{2.5cm}}}$$

$$= \underline{\hspace{2.5cm}} \text{ mg/L}$$

$$\text{TSSE} = (\underset{\text{CAL,mg/L}}{\underline{\hspace{2.5cm}}} + \underset{\text{SUL,mg/L}}{\underline{\hspace{2.5cm}}} - 2500) + \underset{\text{TSSI,mg/L}}{\underline{\hspace{2.5cm}}}$$

$$= \underline{\hspace{2.5cm}} \text{ mg/L}$$

Note - after this TSSE adjustment,
CALI = 800 mg/L
SULI = 1700 mg/L

2. Step 2, Calcium (CALI) >200 mg/L and carbonate (CARI) >200 mg/L and sulfate (SULI) <2000

$$\text{CAL} = \{[\underset{\text{LIME,lb/day}}{\underline{\hspace{2.5cm}}} \div (\underset{\text{FLOW,mgd}}{\underline{\hspace{2.5cm}}} \times 8.34)] \times 0.54\} + \underset{\text{CALI,mg/L}}{\underline{\hspace{2.5cm}}}$$

$$= \underline{\hspace{2.5cm}} \text{ mg/L}$$

$$\text{TSSE} = (\underset{\text{CARI,mg/L}}{\underline{\hspace{2.5cm}}} + \underset{\text{CAL,mg/L}}{\underline{\hspace{2.5cm}}} - 200) + \underset{\text{TSSI,mg/L}}{\underline{\hspace{2.5cm}}}$$

$$= \underline{\hspace{2.5cm}} \text{ mg/L}$$

IV.3.1.13-B. Liming to High pH

B 1. Basis of Design

This presentation is for the liming of influent wastewater streams to high pH as a pretreatment process for ammonia stripping. The principal design factors are the influent flow, alkalinity, acidity, and pH characteristics of the influent. When alkalinity and/or acidity data are known, the lime dosages for softening, dealkalizing, and neutralizing are calculated based on this information. When the influent acidity or alkalinity is not known, a generalization based on pH is used to compute the lime required. When no data are specified, the influent stream is assumed to possess negligible alkalinity or acidity, and a pH close to neutral. The minimum amount of lime added is in all cases 230 mg/L with an average target value for the effluent pH of 11.0. The mixing time for liming is 5 minutes and residence time is 20 minutes.

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

Wastewater flow L/s (mgd)
Alkalinity, acidity, mg/L (not required but preferred if known), pH
Ca, CO_3, TSS, TDS (mg/L)

c) Limitations

None specified.

d) Pretreatment

None specified

e) Design Factor

Average daily wastewater flow is the primary design and cost factor for liming to high pH. The facilities for liming to high pH are similar to neutralization systems, consisting of a two stage reaction tank and a chemical feed system. The design residence time of the reaction and attenuation chambers is 5 and 20 minutes respectively at 120% of average daily flow.

f) Subsequent Treatment

This unit process always precedes ammonia stripping and a clarifier is required to remove excess lime prior to going to the stripper.

B 2. Capital Costs

The principal cost factor for liming to high pH is the wastewater flow rate. A low flow (<26.3 L/s, 0.6 mgd) cost curve (Figure IV.3.1.13-B1) and a high flow (≥26.3 L/s, 0.6 mgd) cost curve (Figure IV.3.1.13-B2) have been developed for lime feed and monitoring systems required for liming to high pH. The quantities of lime including minimum quantity and safety factor requirements are computed using the methodologies presented in Section B 3. Costs estimated using these curves must be adjusted to a current value using an appropriate current cost index.

a) Cost Data

Items included in the capital cost curve estimates are as follows* [4-2]:

i) Low order (<26.3 L/s, 0.6 mgd)

Mixing tank, fiberglass
Attenuation tank, fiberglass
Agitators (2)
Piping, electrical
Instrumentation

ii) High order (≥26.3 L/s, 0.6 mgd)

Mixing tank, acid brick lined
Attenuation tank, acid brick lined
Agitators (2)
Piping, electrical
Instrumentation

*It should be noted that lime storage and handling facilities are not included in these estimates. Once the lime requirements for all unit processes have been determined, a central lime storage and handling facility is designed to serve the whole plant. The lime handling and storage facilities are therefore costed separately (see Lime Handling, Section IV.3.1.13-C).

b) Capital Cost Curves

i) Low Order Curve - Figure IV.3.1.13-B1
- Cost (thousands of dollars) vs. flow (liters per second or million gallons per day)

- Curve basis, cost estimates for four systems with design flows of 4.38, 8.76, 17.5, and 26.3 L/s (0.1, 0.2, 0.4, and 0.6 mgd)

ii) High Order Curve - see Figure IV.3.1.13-B2
- Cost (thousands of dollars) vs. flow (liters per second or million gallons per day)
- Curve basis, cost estimates for four systems with design flows of 8.76, 43.8, 219, and 876 L/s (0.2, 1.0, 5.0, and 20.0 mgd)

c) Cost Index

Base Period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

B 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable components of the operating cost are the lime and power requirements. Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs must be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Costs

i) Power Requirements Low Order (FLOW <26.3 L/s, 0.6 mgd) - pumps and agitators. These equations were developed using regression analysis procedures [4-1].

Metric

$$KW = (0.55 \times FLOW) + 0.286$$

where: KW = power, Kilowatts
FLOW = influent flow, L/s

English

$$HP = (32.3 \times FLOW) + 0.384$$

where: HP = power, Hp
FLOW = influent flow, mgd

ii) Power Requirements High Order (FLOW ≥26.3 L/s, 0.6 mgd) - pumps and agitators. These equations were developed using regression analysis procedures [4-1].

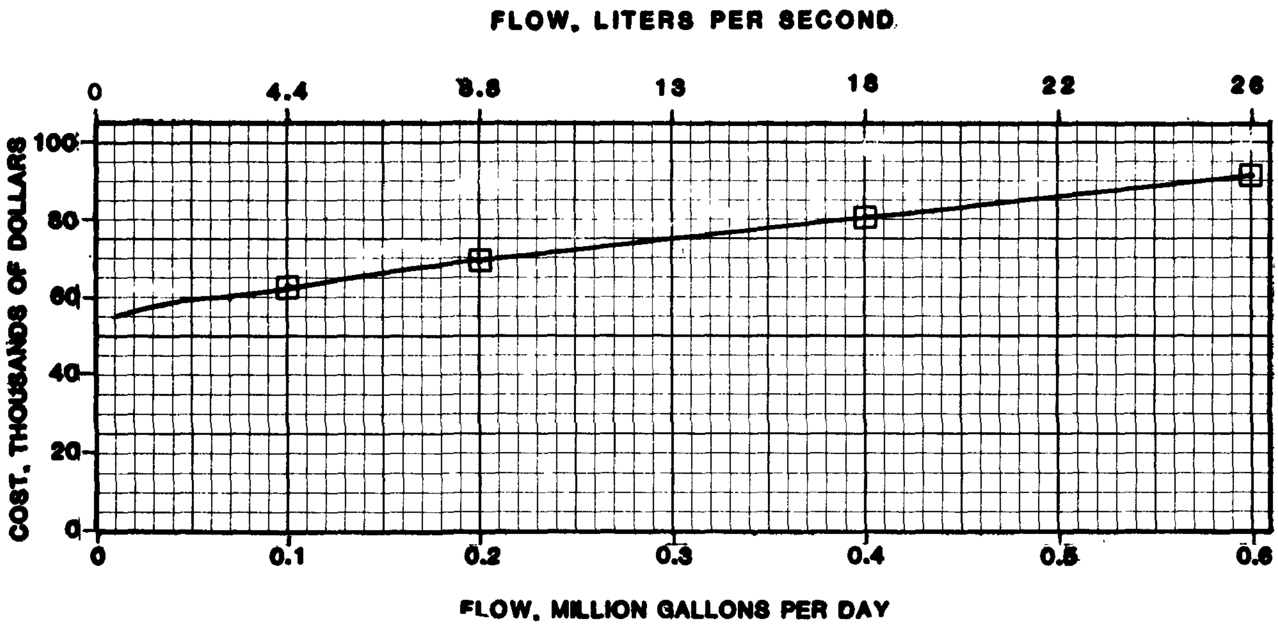


FIGURE IV.3.1.13-B1. CAPITAL COST ESTIMATE FOR LIMING TO A HIGH pH (LOW ORDER) [4-10]

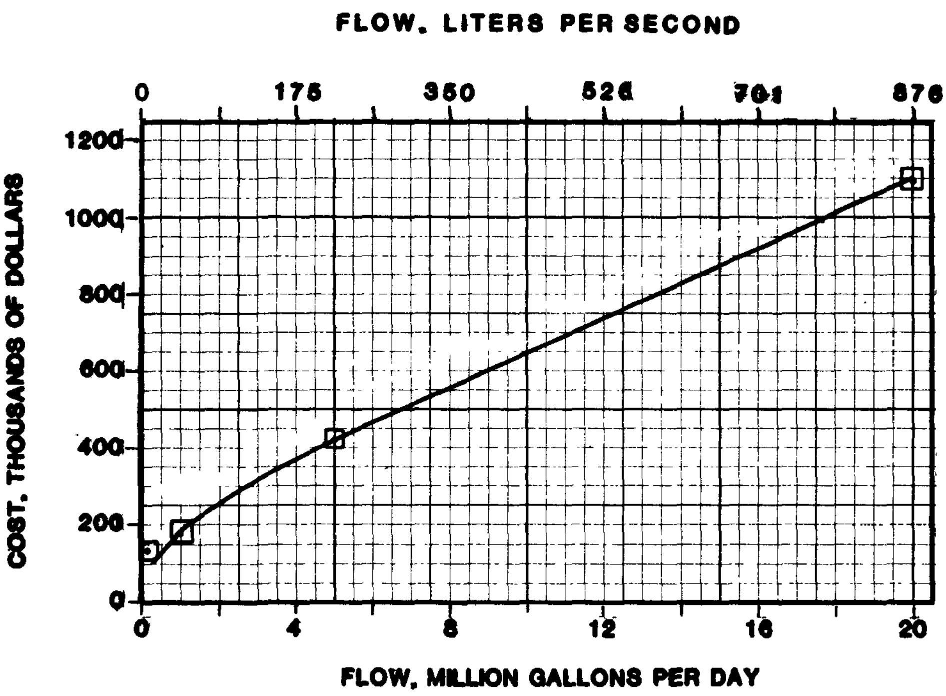


FIGURE IV.3.1.13-B2. CAPITAL COST ESTIMATE FOR LIMING TO A HIGH pH (HIGH ORDER) [4-10]

Metric

$$KW = (0.266 \times FLOW) + 6.11$$

where: KW = power, Kilowatts
FLOW = influent flow, L/s

English

$$HP = (15.6 \times FLOW) + 8.19$$

where: HP = power, Hp
FLOW = influent flow, mgd

iii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, $/day
KW = power requirement, Kilowatts
24 = hr/day
EC = electricity cost, $/Kw-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, $/day
24 = hr/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, $/Kw-hr

iv) Lime Requirements*

The lime requirements are calculated based on the information available about the influent stream characteristics (i.e., no data, alkalinity and/or acidity data, or pH data).

- CASE I: No Data.

  When no alkalinity, acidity, or pH values are specified, a soft or neutral wastewater is assumed and a minimum lime dose of 230 mg/L plus a 25% safety factor is used.

  Metric

$$LIME = 230 \times 0.086 \times FLOW \times 1.25$$

where: LIME = required lime, Kg/day
230 = minimum lime dose, mg/L
0.086 = conversion factor
FLOW = influent flow, L/s
1.25 = factor for 25% excess

English

$$LIME = 230 \times 8.34 \times FLOW \times 1.25$$

where: LIME = required lime, lb/day
8.34 = conversion factor
FLOW = influent flow, mgd

If the assumption of an essentially soft or neutral wastewater is correct, the final solution will have a pH of approximately 11.5.

- CASE II: Alkalinity and/or Acidity Data Specified.

When either alkalinity or acidity is specified, but not both, the other is assumed negligible and taken as zero. Otherwise the influent values for both are used. The amount of lime required is found using the following relationship:

Metric

$$LIME = [(0.9 \times ALK) + (0.74 \times ACD) + 230] \times 0.086 \times FLOW$$

where: LIME = required lime, Kg/day
ALK = influent alkalinity, mg/L ($CaCO_3$ equivalent)
ACD = influent acidity, mg/L ($CaCO_3$ equivalent)
230 = minimum lime dose, mg/L
0.086 = conversion factor
FLOW = influent flow, L/s

English

$$LIME = [(0.9 \times ALK) + (0.74 \times ACD) + 230] \times 8.34 \times FLOW$$

where: LIME = required lime, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor,

* CASE III: pH Data Specified.

When only pH is specified, the required lime is calculated using the following equation:

Metric

$$LIME = 20 \times [11.0 - (avg\ pH)]^3 \times 0.086 \times FLOW$$

where: LIME = required lime, Kg/day
avg pH = the average influent pH
0.086 = conversion factor
FLOW = influent flow, L/s

English

$$LIME = 20 \times [11.0 - (avg\ pH)]^3 \times 8.34 \times FLOW$$

where: LIME = required lime, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor

*Costs for lime are based on total plant needs rather than on the needs of an individual unit process. Lime requirements should be accounted for but the cost for lime and handling and storage systems are estimated separately after design of all unit processes using lime.

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.1.13-B1, including the cost basis and the unit costs [4-11].

B 4. Miscellaneous Costs

Costs for engineering, and other common plant items such as piping and buildings, are calculated after completion of costing for all unit processes (see Section IV.3.5).

B 5. Modifications

The addition of large amounts of lime affects the effluent concentrations of TDS, TSS, calcium, and carbonate. The generation of additional TSS is of particular interest since it would effect the subsequent design and handling of clarification and sludge handling facilities.

a) Effluent TSS Adjustment

$$TSS = TSSI + Q$$

TABLE IV.3.1.13-B1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR LIMING TO HIGH pH [4-11].

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.20 Weeks (4.80 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.48 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.10 Shifts (0.57 hrs/day)	$10.70/hr
Maintenance	2.50% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	1.92% Capital	NA
Service Water	0.00 L/s (0.00 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

where: TSS = average effluent TSS, mg/L
TSSI = average influent TSS, mg/L
Q = intermediate variable determined as follows:

i) Case I: If CARB >200 mg/L and [LIM × (40 ÷ 74)] >200 mg/L, then:

Metric

$$Q = LIM \times (40 \div 74) + CARB - 200$$

where: CARB = average influent CO_3, mg/L
LIM = average lime requirement, mg/L
= LIME ÷ (0.086 × FLOW)
LIME = lime requirement, Kg/day (see section B3,a,iii)
40 ÷ 74 = ratio of Ca to $Ca(OH)_2$, Kg/Kg

English

$$Q = LIM \times (40 \div 74) + CARB - 200$$

where: CARB = average influent CO_3, mg/L
LIM = average lime requirement, mg/L
= LIME ÷ (8.34 × FLOW)
LIME = lime requirement, lb/day (see Section B 3,a,iii)
40 ÷ 74 = ratio of Ca to $Ca(OH)_2$, lb/lb

ii) Case II: If CARB >200 mg/L and [LIM × (40 ÷ 74)] ≤200 mg/L, then:

$$Q = 0.2 \times LIM \times (40 \div 74)$$

iii) Case III: All other conditions.

$$Q = 0$$

b) Effluent Ca and CO_3

Following liming to high pH the following effluent concentrations of Ca and CO_3 are assumed:

Ca = 80 mg/L
CO_3 = 120 mg/L

c) Effluent TDS

Metric

$$TDS = TDSI + Y$$

where: TDS = average effluent TDS, mg/L
TDSI = average influent TDS, mg/L
Y = intermediate variable
= LIM - Q
LIM = LIME ÷ (0.086 × FLOW)
LIME = lime requirement, Kg/day
(see Section B 3,a,iii)
Q = intermediate variable
(see Section B 5,a)
0.086 = conversion factor
FLOW = influent flow, L/s

<u>English</u>

$$TDS = TDSI + Y$$

where: Y = LIM - Q
LIM = LIME ÷ (8.34 × FLOW)
8.34 = conversion factor
FLOW = influent flow, mgd

LIMING TO HIGH pH
SUMMARY WORK SHEET — REFERENCE: IV.3.1.13-B

I. DESIGN FACTOR		CAPITAL
a. Flow = ________ mgd		
II. CAPITAL COST		
Cost = ________ (Cost from curve) × (________ (current index) ÷ 204.7)		$ ________
III. VARIABLE O & M	$/day	O & M
a. Power = ________ (Hp) × ________ (EC, $/Kw-hr) × 17.9	= ________	
IV. FIXED O & M		
a. Labor: ________ (hr/day) × ________ ($/hr)	= ________	
b. Supervision: ________ (hr/day) × ________ ($/hr)	= ________	
c. Overhead: ________ (Labor, $/day) × ________ (%/100)	= ________	
d. Lab Labor: ________ (hr/day) × ________ ($/hr)	= ________	
e. Maint, Service, I&T: ________ (capital, $) × ________ (%/100) ÷ 365 (day/yr)	= ________	
f. Service Water: ________ (thou gpd) × ________ ($/thou gal)	= ________	
V. YEARLY O & M 365 (day/yr) ×	________ (sum, $/day)	= ________ ($/yr)
VI. UNCOSTED ITEMS		
a. LIME = ________ lb/day b. Effluent TSS = ________ mg/L		

LIMING TO HIGH pH
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ \$/Kw-hr

3. Labor = ________ \$/hr

4. Supervision = ________ \$/hr

5. Overhead = ________ % Labor

6. Lab Labor = ________ \$/hr

7. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor Sum = % ÷ 100 = ____ %/100

8. Service Water = ________ \$/thou gal

I. DESIGN FACTOR

a. Flow = $\underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}}$

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements, Low Order (<0.6 mgd)

$$HP = (\underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 32.3) + 0.384 = \underline{\qquad\qquad} \text{ Hp}$$

b. Power Requirements, High Order (≥0.6 mgd)

$$HP = (\underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 15.6) + 8.19 = \underline{\qquad\qquad} \text{ Hp}$$

c. Chemical Requirements, Case I - No Data Specified

$$LIME = \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 2400 = \underline{\qquad\qquad} \text{ lb/day}$$

d. Chemical Requirements, Case II - Alkalinity/Acidity Data Specified

LIME = [(0.9 × $\underset{\text{ALK,mg/L}}{\underline{\hspace{3cm}}}$) + (0.74 × $\underset{\text{ACD,mg/L}}{\underline{\hspace{3cm}}}$) + 230] × $\underset{\text{FLOW,mgd}}{\underline{\hspace{3cm}}}$

× 8.34 = ______________ lb/day

e. Chemical Requirements, Case III - pH Data Specified

LIME = (11.0 - $\underset{\text{(avg)pH}}{\underline{\hspace{3cm}}}$)^3 × $\underset{\text{FLOW,mgd}}{\underline{\hspace{3cm}}}$ × 167 = ______________ lb/day

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Effluent TSS

1. Necessary Input Data

CARB = $\underset{\text{avg influent CARB}}{\underline{\hspace{5cm}}}$ mg/L

LIM = $\underset{\textit{LIME,lb/day}}{\underline{\hspace{3.5cm}}}$ ÷ ($\underset{\textit{FLOW,mgd}}{\underline{\hspace{3.5cm}}}$ × 8.34) = ______________ mg/L

Intermediate variable = LIM × (40 ÷ 74) = __________ mg/L

2. <u>Case I</u>. <u>If</u> CARB >200 mg/L and [LIM × (40 ÷ 74)]) >200 mg/L

TSS = $\underset{\text{TSSI,mg/L}}{\underline{\hspace{3cm}}}$ + [($\underset{\text{LIM,mg/L}}{\underline{\hspace{3cm}}}$ × 0.54) + $\underset{CO_3\text{,mg/L}}{\underline{\hspace{3cm}}}$ - 200]

= ______________ mg/L

3. <u>Case II</u>. <u>If</u> CARB >200 mg/L and [LIM × (40 ÷ 74)] ≤200 mg/L

TSS = $\underset{\text{TSSI,mg/L}}{\underline{\hspace{3cm}}}$ + ($\underset{\text{LIM,mg/L}}{\underline{\hspace{3cm}}}$ × 0.11) = ______________ mg/L

4. <u>Case III</u>. All other conditions

TSS = $\underset{\text{TSSI, mg/L}}{\underline{\hspace{3cm}}}$

IV.3.1.13-C Lime Handling

C 1. Basis of Design

This presentation is for a central lime handling and distribution system designed to provide the needs of an entire industrial wastewater treatment facility. Lime or caustic may be required by such unit processes as dissolved air flotation, nitrification, ion exchange, chemical coagulation, filtration (vacuum and pressure), neutralizaton, and liming to a high pH. This system is designed after the total requirement for lime has been determined (i.e., after the unit process treatment train design is complete).

The basis for the design is the type of lime handling system and the total quantity of lime required. The type of lime handling system depends on whether neutralization is included in the treatment process and on the quantity of lime needed in the treatment process. Three handling systems are available. If neutralization is the only unit process requiring lime and if the lime requirement is less than 227 Kg/day (500 lb/day), then a liquid caustic system is installed. Where the treatment system requires 3630 Kg/day (8,000 lb/day) of lime or less, lime requirements are met using hydrated lime as illustrated in Figure IV.3.1.13-C1. For treatment systems requiring over 3630 Kg/day (8,000 lb/day) of lime, the lime requirements are met using quicklime and a slaking system as illustrated in Figure IV.3.1.13-C2.

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

Lime requirements for all individual unit processes.

c) Limitations

None specified.

d) Pretreatment

None specified.

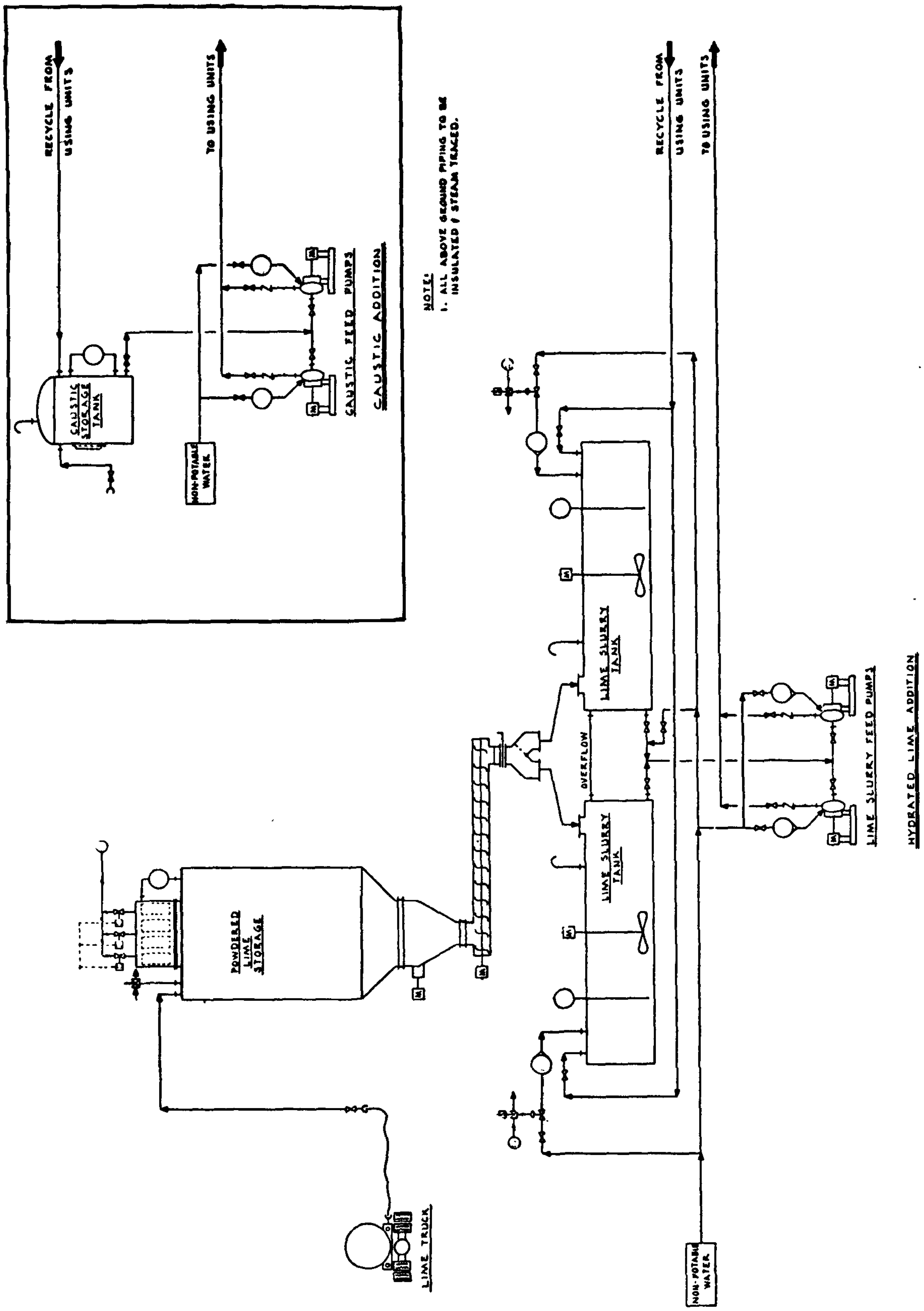


FIGURE IV.3.1.13-C1. PROCESS FLOW DIAGPAM FOR LIMING TO A HIGH pH (HYDRATED LIME ADDITION) [4-1]

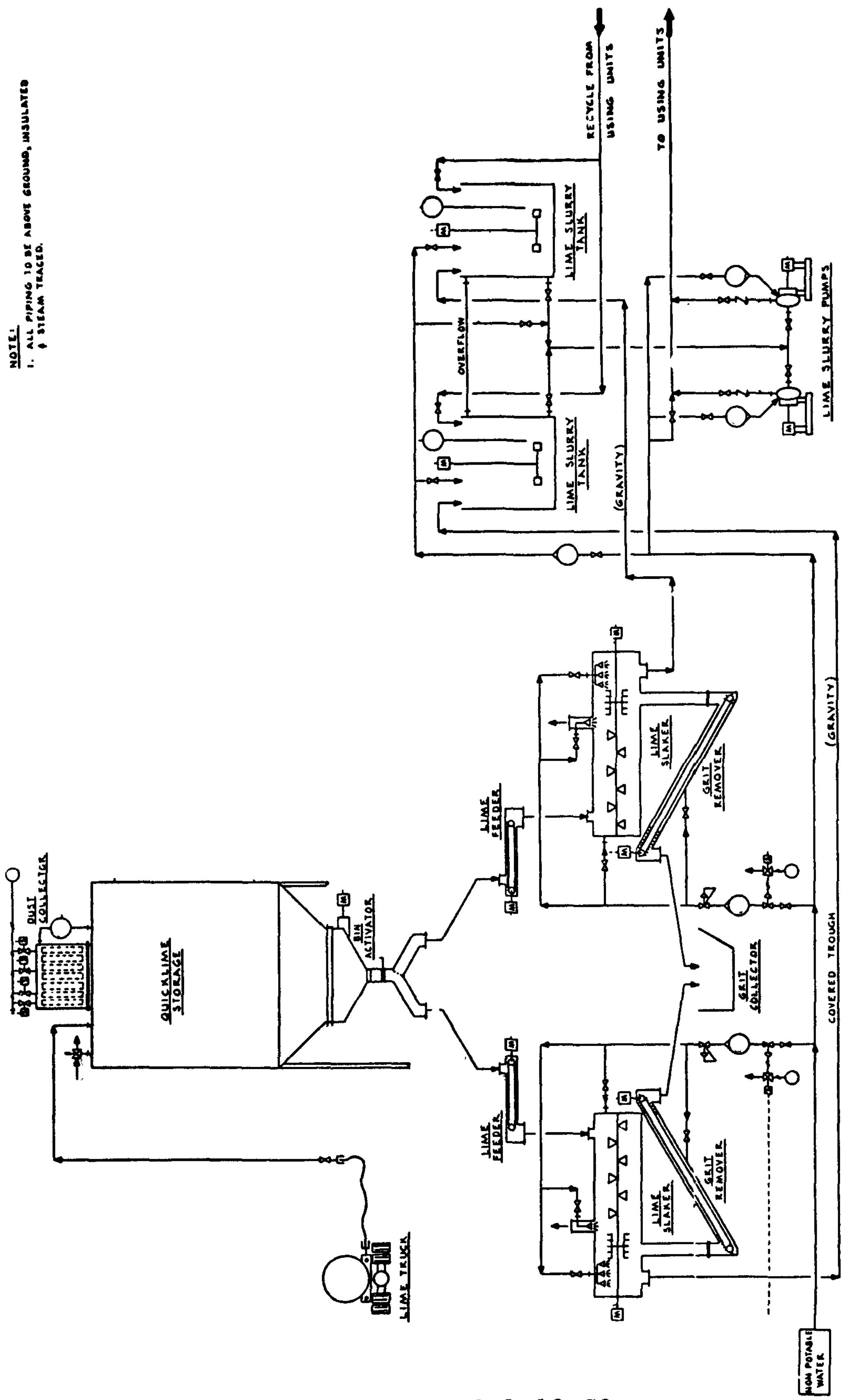


FIGURE IV.3.1.13-C2. PROCESS FLOW DIAGRAM FOR LIMING TO A HIGH pH (QUICKLIME ADDITION)[4-1]

e) <u>Design Equation</u>

The primary design and cost factor for lime handling systems is the total daily lime requirement for the plant as a whole. This is found by summing the calculated lime requirements for all unit processes as follows:

$$TOTLIME = \Sigma\ LIME(u)$$

where: TOTLIME = total lime requirement in terms of $Ca(OH)_2$, Kg/day or lb/day
LIME(u) = lime requirement for a single unit process(u) included in the treatment design in terms of $Ca(OH)_2$, Kg/day or lb/day

Based on the total lime requirement (TOTLIME), the type of lime handling system is determined as follows:

i) Liquid Caustic

If the only unit process is neutralization and if TOTLIME ≤227 Kg/day (≤500 lb/day), then a liquid caustic handling system is considered adequate to meet the wastewater treatment facility lime requirement (i.e., caustic requirement). The factor used for costing the liquid caustic system remains the equivalent lime requirement expressed in Kg $Ca(OH)_2$/day (lb $Ca(OH)_2$/day).

ii) Hydrated Lime

If unit processes other than neutralization are used alone or in combination (with or without neutralization) and if TOTLIME ≤3630 Kg/day (≤8000 lb/day), then a bagged hydrated lime handling system is considered appropriate. The factor used for costing the lime handling system remains the lime requirement expressed in Kg $Ca(OH)_2$/day (lb $Ca(OH)_2$/day).

iii) Slaking System Using Quicklime

If TOTLIME >3630 Kg/day (>8000 lb/day), then a slaking system using quicklime is considered appropriate. Because the molecular weight of quicklime (CaO) differs from the molecular weight of hydrated lime [$Ca(OH)_2$], lime requirements in terms of kilograms or pounds per day of quicklime are adjusted as follows:

$$QLIME = TOTLIME \times 28 \div 37$$

where: QLIME = the lime requirement expressed as Kg CaO/day or lb CaO/day

TOTLIME = the lime requirement expressed as Kg $Ca(OH)_2$/day or lb $Ca(OH)_2$/day

28 = equivalent weight of CaO

37 = equivalent weight of $Ca(OH)_2$

The cost factor is the lime requirement expressed in Kg CaO/day or lb CaO/day.

f) <u>Subsequent Treatment</u>

None required.

C 2. Capital Costs

The cost factor used to determine capital costs is the total lime requirement. The capital cost curve (Figure IV.3.1.13-C3) is used to cost three types of lime handling systems as follows: liquid caustic; hydrated lime; and a slaking system using quick-lime. The capital cost curve is presented in terms of dollars vs. lime requirement for systems below 3630 Kg/day (8000 lb/day), but shifts to dollars vs. quicklime requirement for systems with a lime requirement greater than 3630 Kg/day (8000 lb/day).

a) <u>Cost Data</u>

The capital cost estimates include the following items for each of the lime handling systems indicated below [4-2]:

i) Liquid Caustic

Steel storage tank
Insulation, electrical, pumps, and piping
Agitators
Instrumentation

ii) Hydrated Lime

Storage silo
Lime slurry tanks
Lime feeders
Bin activator for storage silo
Insulation, electrical, pumps, and piping
Agitators
Instrumentation

iii) Quicklime With Slaker

Storage silo

Lime slurry tank
Bin activator for storage silo
Insulation, electrical, pumps, and piping
Agitators
Instrumentation
Combination slakers
Dust filter

b) Capital Cost Curve [4-2]

Curve - see Figure IV.3.1.13-C3
- Cost (thousands of dollars) vs. lime required (thousand kilograms per day or thousand pounds per day) Kg $Ca(OH)_2$ for lime <3630 Kg/day; Kg CaO/day for lime >3630 Kg/day (lb $Ca(OH)_2$ for lime <8000 lb/day; lb CaO/day for lime >8000 lb/day)
- Curve basis, cost estimate for five systems with lime requirements of 45.4, 227, 560, 2,800, and 8,470 Kg/day (100, 500, 1235, 6170, and 18,680 lb/day)

c) Cost Index

Base period, July, 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

C 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable component includes power, while the fixed component includes labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Cost

i) Power Requirements - pumps, agitators, feeders. The following equation was developed using regression analysis procedures [4-1].

Metric

$$KW = (TOTLIME \times 1.32 \times 10^{-4}) + 1.72$$

where: KW = power, kilowatts
TOTLIME = lime required, Kg/day

English

$$HP = (TOTLIME \times 3.93 \times 10^{-4}) + 2.30$$

where: HP = power, Hp
TOTLIME = lime required, lb/day

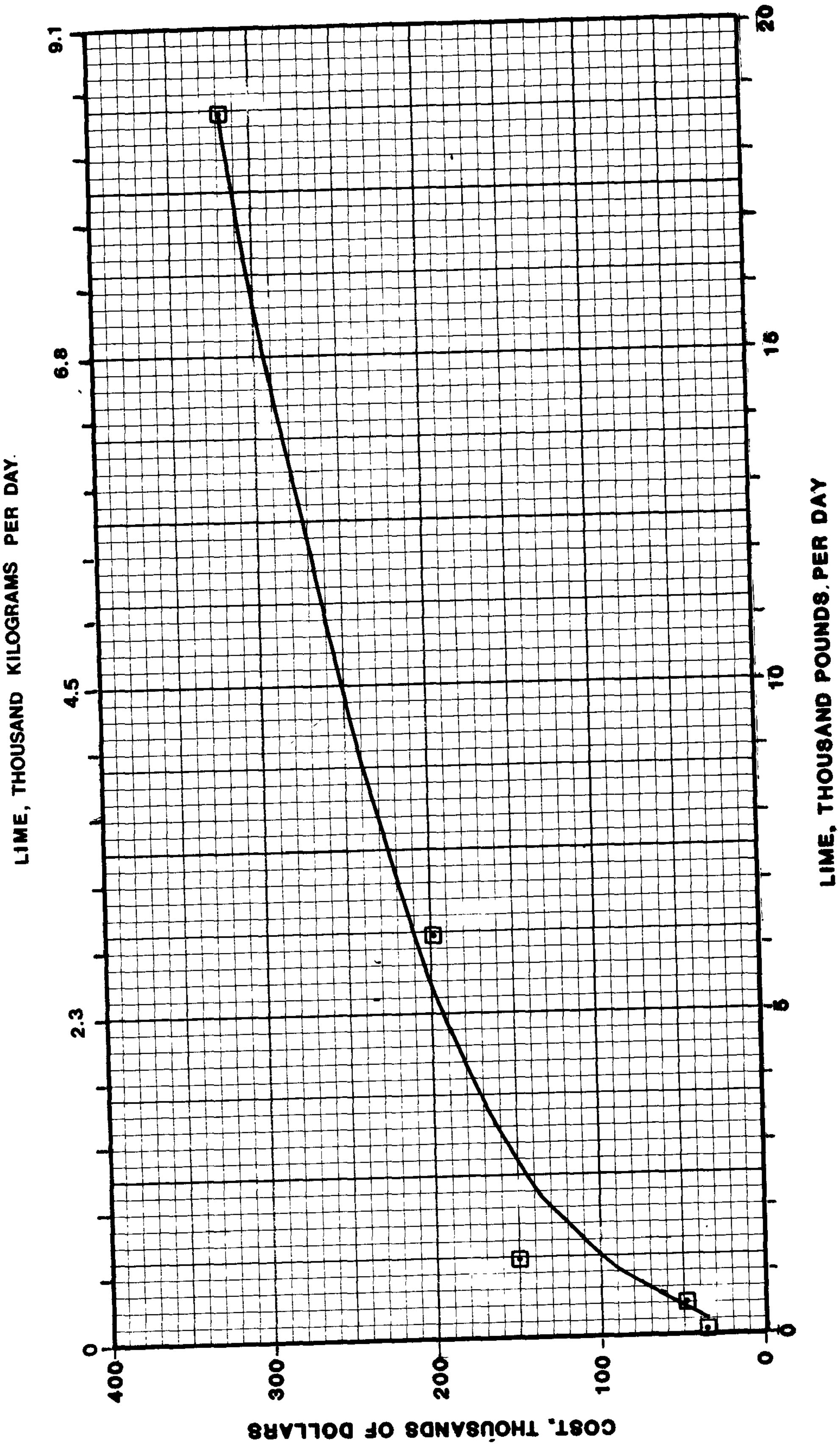


FIGURE IV.3.1.13-C3 CAPITAL COST ESTIMATE FOR LIME HANDLING [4-10]

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, \$/day
KW = power, kilowatts
24 = hr/day
EC = electricity cost, \$/KW-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, \$/day
24 = hr/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, \$/Kw-hr

iii) Process Water Requirement (TOTLIME >500 lb/day)

Metric

$$PW = TOTLIME \times 10 \div (1.0 \times 86400)$$

where: PW = process water, L/s
TOTLIME = total lime requirement, Kg/day
10 = Kg H_2O/Kg Lime
1.0 = conversion factor
86400 = s/day

English

$$PW = TOTLIME \times 10 \div 8.34 \div 1000$$

where: PW = process water, thousand gpd
TOTLIME = total lime requirement, lb/day
10 = lb water/lb lime
8.34 = conversion factor
1000 = gal/thousand gal

iv) Lime Requirement

- Liquid Caustic System

$$CAUSTIC = TOTLIME \times 40 \div 37$$

where: CAUSTIC = Kg/day or lb/day of caustic
LIME = total lime requirement as $Ca(OH)_2$, Kg/day or lb/day
40 = equivalent weight of caustic (NaOH)

37 = equivalent weight of hydrated lime $[Ca(OH)_2]$ (two equivalents per Kg-mole or lb-mole)

- Hydrated Lime System

HYDRATED LIME = TOTLIME

where: HYDRATED LIME = Kg/day or lb/day of hydrated lime
TOTLIME = total lime requirement as $Ca(OH)_2$, Kg/day or lb/day

- Quicklime with Slaker System

QUICKLIME = TOTLIME × 28 ÷ 37

where: QUICKLIME = Kg/day or lb/day of quicklime
TOTLIME = total lime requirement as $Ca(OH)_2$, Kg/day or lb/day
28 = equivalent weight of quicklime (CaO)
37 = equivalent weight of hydrated lime $[Ca(OH)_2]$

b) <u>Fixed Costs</u>

The fixed O & M components for this technology are listed in Table IV.3.1.12-C1, including the cost basis and the unit costs [4-11].

C 4. Miscellaneous Costs

Cost for engineering, and other common plant items such as piping and buildings, are calculated for the entire plant after completion of design and costing of all individual unit processes (see Section IV.3.5).

C 5. Modifications

None indicated.

TABLE IV.3.13-C1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR LIME HANDLING FACILITIES [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.20 Weeks (4.80 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.48 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.00 Shifts	$10.70/hr
Maintenance	4.19% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.41 L/s (9.26 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

LIME HANDLING
SUMMARY WORK SHEET   REFERENCE: IV.3.1.13-C

I. DESIGN FACTOR   CAPITAL

Total Lime Required = ____________ lb/day (Type = ________)

II. CAPITAL COST

Cost = ____________ × (____________ ÷ 204.7) $ ________
Cost from curve   current index

III. VARIABLE O & M $/day   O & M

a. Power = ________ × ________ × 17.9 = ________
Hp   EC, $/Kw-hr

b. Process Water = ________ × ________ = ________
thou gpd   WC, $/thou gal

c. Caustic = ________ × ________ = ________
lb/day   CC, $/lb

d. Hydrated Lime = ________ × ________ = ________
lb/day   HLC, $/lb

e. Quicklime = ________ × ________ = ________
lb/day   QLC, $/lb

IV. FIXED O & M

a. Labor: ________ × ________ = ________
hr/day $/hr

b. Supervision: ________ × ________ = ________
hr/day $/hr

c. Overhead: ________ × ________ = ________
Labor, $/day   %/100

d. Lab Labor: ________ × ________ = ________
hr/day $/hr

e. Maint, Service, I&T: ________ × ________ ÷ 365 = ________
capital, $ %/100   day/yr

V. YEARLY O & M   365 × ________ = ________
day/yr   sum, $/day $/yr

VI. UNCOSTED ITEMS

LIME HANDLING
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index
2. EC: Electricity Cost = ________ \$/Kw-hr
3. WC: Process Water Cost = ________ \$/gal
4. CC: Caustic Cost = ________ \$/lb
5. HLC: Hydrated Lime Cost = ________ \$/lb
6. QLC: Quicklime Cost = ________ \$/lb
7. Labor = ________ \$/hr
8. Supervision = ________ \$/hr
9. Overhead = ________ % Labor ÷ 100 = ________ %/100
10. Lab Labor = ________ \$/hr
11. Maintenance = % Capital
    Services = % Capital
    Insurance/Taxes = ________ % Capital
    Other O & M Factor Sum = ________ ÷ 100 = ________ %/100

I. DESIGN FACTOR

a. Determine the total lime requirement in lb/day as follows:

Complete the following table by inserting the quantity of lime required for each unit process listed.

Unit Process	Lime Required, lb/day
Neutralization	________
Dissolved Air Flotation	________
Chemical Coagulation	________
Vacuum Filtration	________
Pressure Filtration	________
Liming to High pH	________

TOTLIME = ________ lb/day

b. Determine the type of lime handling system as follows:

1. If the total lime required (TOTLIME) >8000 lb/day, the handling system is quicklime with slakers. (TYPE = QUICKLIME)

2. If the total lime required (TOTLIME) ≤500 lb/day, and if neutralization is the only unit process requiring lime, the handling system is liquid caustic. (TYPE = CAUSTIC)

3. All other lime requirements are met using the bagged hydrated lime. (TYPE = HYDRATED)

II. CAPITAL COST

a. Adjust the lime requirement for use with the cost curve as follows:

Lime Required = $\underset{\text{TOTLIME, lb/day (from I a)}}{\underline{\hspace{3cm}}}$ × $\underset{\text{Factor}}{\underline{\hspace{2cm}}}$ = ________ lb/day

1. If TYPE = QUICKLIME,

   FACTOR = 56 ÷ 74 = 0.76

2. If TYPE = HYDRATED,

   FACTOR = 1.00

3. If TYPE = CAUSTIC,

   FACTOR = 1.00

III. VARIABLE O & M

a. Power Requirements

HP = ($\underset{\text{Lime Required, lb/day}}{\underline{\hspace{4cm}}}$ × 3.93×10^{-4}) + 2.30 = ________ Hp

b. Process Water Requirements

If TOTLIME (from I a 2) >500 lb/day

PROCESS WATER = $\underset{\text{TOTLIME, lb/day (from I a 2)}}{\underline{\hspace{3cm}}}$ ÷ 834 = ________ thou gal

c. Lime Requirements

1. If TYPE (from I b) = CAUSTIC,

CAUSTIC = ______________ × (40 ÷ 37) = __________ lb/day
TOTLIME, lb/day
(from I a 2)

HYDRATED LIME = 0 lb/day

QUICKLIME = 0 lb/day

2. If TYPE (from I b) = HYDRATED,

CAUSTIC = 0 lb/day

HYDRATED LIME = __________ lb/day
TOTLIME
(from I a)

QUICKLIME = 0 lb/day

3. If TYPE (from I b) = QUICKLIME,

CAUSTIC = 0 lb/day

HYDRATED LIME = 0 lb/day

QUICKLIME = ______________ × (28 ÷ 37) = ________ lb/day
TOTLIME, lb/day
(from I a 2)

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

IV.3.1.14 OIL SEPARATION

Introduction

Oil separation involves the removal of free oils and grease from a wastewater stream. Gravity separation is designed to allow the separation to occur based only upon the differences in the specific gravities of oil and water. For further details on the gravity oil separation process, refer to Volume III, Section III.3.1.14 of the Treatability Manual. Costing methodologies and cost data for this technology are presented below.

IV.3.1.14-A. Gravity Oil Separation

A 1. Basis of Design

This presentation is for the removal of free oil from wastewater by the gravity oil separation process. This process is represented schematically in Figure IV.3.1.14-A1. The basic design and cost factor for the technology is the influent wastewater flow. Gravity oil separation tanks are sized for an overflow rate of 0.47 $L/s/m^2$ (1000 gpd/ft^2) at 120% of the average daily wastewater flow rate. A minimum of two units, each at 50% of design capacity, are provided. Horizontal velocity is limited to a maximum of 0.9 m/min (3 ft/min).

Gravity oil separation as presented in this discussion is not assumed to remove soluble or emulsified oil. Emulsions may be broken to enhance gravity oil separation by chemical or thermal means. For more information on emulsion breaking see Section III.3.1.14 of Volume III. In addition other unit processes such as dissolved air flotation (see Section IV.3.1.10-A) which are more effective in removing emulsified oils may be considered for use in combination with or instead of gravity oil separation.

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumption and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

Average and peak wastewater flow, L/s (mgd)

Characteristics of the wastewater stream (mg/L)
- oil and grease
- TSS
- floating solids
- floating organic pollutants

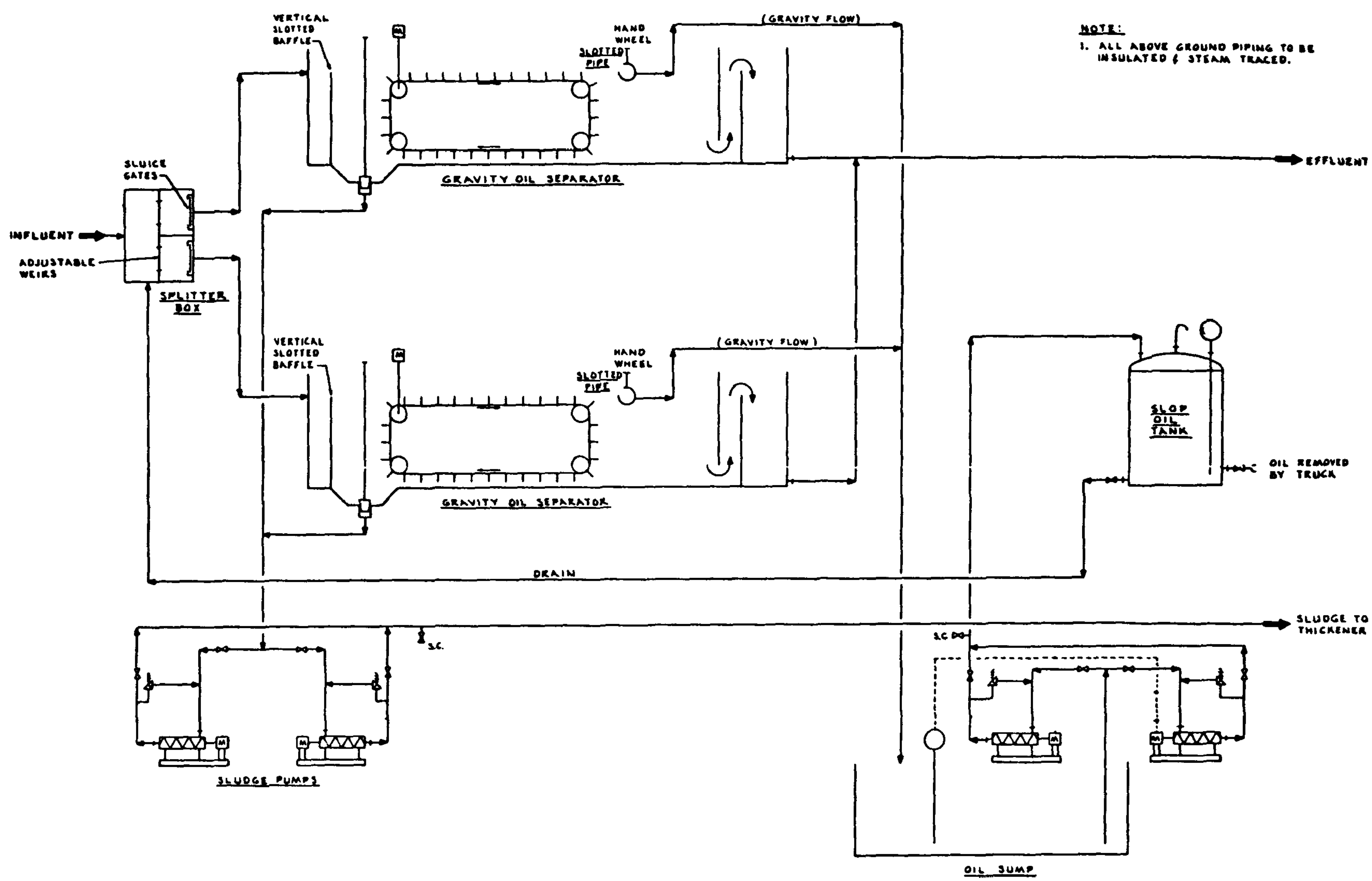


FIGURE IV.3.1.14-A1. PROCESS FLOW DIAGRAM FOR GRAVITY OIL SEPARATION [4-1]

c) Limitations

Gravity oil separation is not considered applicable for treating influent oil concentrations of less than 35 mg/L

d) Pretreatment

None specified

e) Design Equation

An adjusted influent wastewater flow rate in liters per second (million gallons per day) is the primary capital cost factor for gravity oil separation systems. The cost factor (flow) is first multiplied by a scale factor (see Section A 2) to account for peak flow prior to use for cost estimating purposes.

f) Subsequent Treatment

i) Sludge and oil and grease removed from the wastewater stream are usually treated by thickening, stabilizing and dewatering processes before being disposed.

ii) Oil separation may be used prior to solvent extraction to treat wastewater streams containing supersaturated concentrations of organic pollutants which are lighter than water.

A 2. Capital Costs

The primary cost factor for oil separation is the wastewater flow rate. This parameter is the independent variable in the capital cost curve for the unit process (Figure IV.3.1.14-A2). For flows greater than 4.38 L/s (0.1 mgd), a scale factor is applied to adjust the flow prior to selection of a cost from the cost curve. The scale factor is used as a means of adjusting capital cost to account for peak flow capacity. Costs estimated using these curves must be adjusted to a current value using an appropriate current cost index.

a) Cost Data

Items included in the capital cost estimates for the oil separation units are as follows [4-2]:

Two-chamber separation tank with baffles, concrete (2)
Slop-oil holding tank, covered, fiber reinforced plastic
Splitter box, concrete
Oil pumps, progressive cavity (2)
Sludge pumps, progressive cavity (2)

Oil skimmer mechanism (2)
Sluice gates
Piping, electrical
Instrumentation

b) Capital Cost Curve

i) Curve - Figure IV.3.1.14-A2.
- Cost (millions of dollars) vs. wastewater flow (liters per second or million gallons per day).
- Curve basis, cost estimates for system at four flow rates: 8.76, 43.8, 219, and 876 L/s (0.2, 1.0, 5.0, and 20.0 mgd).

ii) Scale factor: applies to flow prior to selection of a cost from the cost curve

- if Avg Flow <4.38 L/s (< 0.1 mgd), scale factor: SF = 1.0

- if Avg Flow ≥4.38 L/s (≥ 0.1 mgd), scale factor:

$$SF = \frac{\text{peak flow} + \text{average flow}}{2 \times \text{average flow}}$$

iii) Flow for Cost purposes = Avg Flow × SF

c) Cost Index

Base Period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs are comprised of both variable and fixed components. Power requirement is the only variable operating cost component. Fixed operating cost components include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Cost

i) Power Requirements, Oil Separation - belt skimmer, sludge pumps, flight skimmers and oil pumps [4-1].

Metric

$$KW = (0.052 \times FLOW) + 2.6$$

where: KW = power, kilowatts
FLOW = average influent flow, L/s

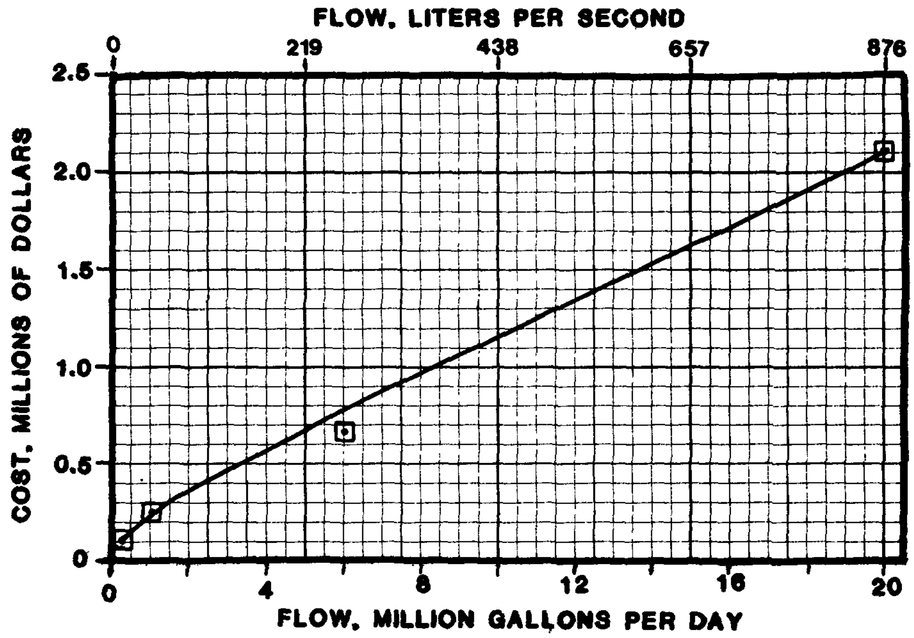


FIGURE IV.3.1.14-A2. CAPITAL COST ESTIMATE FOR GRAVITY OIL SEPARATION [4-10]

English

$$HP = (3.04 \times FLOW) + 3.45$$

where: HP = horsepower required, Hp
FLOW = average influent flow, mgd

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, $/day
KW = power required, KW
24 = hrs/day
EC = electricity cost, $/KW-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, $/day
HP = horsepower required, Hp
24 = hrs/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, $/Kw-hr

b) Fixed Costs

The fixed O & M components for gravity oil separation are listed in Table IV.3.1.14-A1 including the cost basis and the unit costs [4-11].

A 4. Miscellaneous Costs

Costs for engineering, and common plant items such as piping and buildings, are calculated after completion of costing for individual units (See Section IV.3.5). The required quantity of land and expected sludge generation from the unit process are calculated below to facilitate subsequent cost estimates.

a) Land

The following equation estimates the amount of land required for oil separation based on the overflow rate, scale factor, and cost factors.

Metric

$$LAND = SF \times FLOW \times 1.2 \div 0.47$$

TABLE IV.3.1.14-A1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR GRAVITY OIL SEPARATION [4-11]

Dissolved Air Flotation

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.25 Weeks (6.00 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.60 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.20 Shifts (1.14 hrs/day)	$10.70/hr
Maintenance	7.53% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	4.6 L/s (105.4 Thou gpd)	$0.13/thou L ($0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

where: LAND = land requirement, m^2
SF = scale factor (see Section A2,b)
FLOW = average influent flow, L/s
1.2 = factor for accessories
0.47 = overflow rate, $L/s/m^2$

English

$$LAND = SF \times FLOW \times (1{,}200{,}000 \div 1{,}000)$$

where: LAND = land requirement, ft^2
SF = scale factor (See Section A2,b)
FLOW = average influent flow, mgd
1,200,000 = mgd × 1.2 factor for accessories, gal/day
1,000 = overflow rate, gpd/ft^2

b) Sludge and Float Production

Oil separation may produce waste byproducts consisting of oil, solids, or oily solids. Sludge or float production varies according to flow and the influent conditions. In general the quantity of sludge and float produced by gravity oil separation may be estimated as follows:

$$FLOAT = PFLOAT + OFLOAT + SLDG$$

where: FLOAT = total float and sludge produced Kg/day or lb/day
PFLOAT = organic pollutant float, Kg/day or lb/day
OFLOAT = oil float from oil separation unit, Kg/day or lb/day
SLDG = suspended solids sludge, Kg/day or lb/day

Pollutant Float (PFLOAT)

This includes partially soluble pollutants that are flotable (These are normally removed by solvent extraction, but may be present at levels above their solubility limit at this point in the treatment process). This does not include oil float due to oil removal and TSS.

Metric

$$PFLOAT = 0.086 \times FLOW \times \Sigma(PC(i) - PS(i))$$

where: PFLOAT = pollutant float, Kg/day
0.086 = conversion factor
FLOW = influent flow, L/s
PC(i) = influent concentration of extractable pollutant (i), mg/L

$PS(i)$ = solubility of pollutant (i), mg/L (see Section IV.3.1.20-A, Solvent Extraction)

English

$$PFLOAT = 8.34 \times FLOW \times \Sigma(PC(i) - PS(i))$$

where:
- PFLOAT = pollutant float, lb/day
- 8.34 = conversion factor
- FLOW = influent flow, mgd
- PC(i) = influent concentration of extractable pollutant (i), mg/L
- PS(i) = solubility of pollutant (i), mg/L (see Section IV.3.1.20-A, Solvent Extraction)

Oil Float (OFLOAT)

This includes floating oil removed by the process.

Metric

$$OFLOAT = 0.086 \times FLOW \times (SEPOIL - EFOIL)$$

where:
- OFLOAT = oil float from oil separation unit, Kg/day
- FLOW = influent flow, L/s
- SEPOIL = total influent insoluble oil, mg/L
- EFOIL = expected effluent oil concentration from gravity oil separation unit, mg/L (default value 35 mg/L)

English

$$OFLOAT = 8.34 \times FLOW \times (SEPOIL - EFOIL)$$

where:
- OFLOAT = oil float from oil separation unit, lb/day
- FLOW = influent flow, mgd
- SEPOIL = total influent insoluble oil, mg/L
- EFOIL = expected effluent oil concentration from gravity oil separation unit, mg/L (default value 35 mg/L)

Sludge (SLDG)

This includes suspended solids removed by the process.

Metric

$$SLDG = 0.086 \times FLOW \times (TSSI - TSSE)$$

where: SLDG = suspended solids float, Kg/day
FLOW = influent flow, L/s
TSSI = influent TSS, mg/L
TSSE = effluent TSS, mg/L

English

$$SLDG = 8.34 \times FLOW \times (TSSI - TSSE)$$

where: SLDG = suspended solids float, lb/day
FLOW = influent flow, mgd
TSSI = influent TSS, mg/L
TSSE = effluent TSS, mg/L

A 5. Modifications

Gravity oil separation and dissolved air flotation (DAF) are often used in series to treat combination waste streams of oils, suspended solids, and colloidal materials.

OIL SEPARATION
SUMMARY WORK SHEET — REFERENCE: IV.3.1.14A

I. DESIGN FACTOR — CAPITAL

a. Flow for cost purposes = ________ mgd
(DFLOW)

II. CAPITAL COST

Cost = ________ (Cost from curve) × (________ (current index) ÷ 204.7) $ ________

III. VARIABLE O & M — $/day — O & M

a. Power = ________ (Hp) × ________ (EC, $/Kw-hr) × 17.9 = ________

IV. FIXED O & M

a. Labor: ________ (hr/day) × ________ ($/hr) = ________

b. Supervision: ________ (hr/day) × ________ ($/hr) = ________

c. Overhead: ________ (Labor, $/day) × ________ (%/100) = ________

d. Lab Labor: ________ (hr/day) × ________ ($/hr) = ________

e. Maint, Service, I&T: ________ (capital, $) × ________ (%/100) ÷ 365 (day/yr) = ________

f. Service Water: ________ (thou gpd) × ________ ($/thou gal) = ________

V. YEARLY O & M 365 (day/yr) × ________ (sum, $/day) = ________ ($/yr)

VI. UNCOSTED ITEMS

a. Land = ________ ft^2

b. Oil Separation Float = ________ lb/day

OIL SEPARATION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ $/Kw-hr

3. Labor = ________ $/hr

4. Supervision = ________ $/hr

5. Overhead = ________ % Labor ÷ 100 = ________ %/100

6. Lab Labor = ________ $/hr

7. Maintenance = ________ % Capital
   Services = ________ % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor = ________ % ÷ 100 = ________ %/100

8. Service Water = ________ $/thou gal

I. DESIGN FACTOR

a. Scale Factor for Gravity Oil Separation:

If average wastewater flow (FLOW) < 0.1 mgd, Scale Factor = 1
If average wastewater flow (FLOW) > 0.1 mgd, Scale Factor =

$$\left(\underset{\text{Peak flow, mgd}}{\underline{\qquad\qquad}} + \underset{\text{Avg FLOW, mgd}}{\underline{\qquad\qquad}}\right) \div \left[2 \times \left(\underset{\text{Avg FLOW, mgd}}{\underline{\qquad\qquad}}\right)\right] = \underset{\text{SF}}{\underline{\qquad\qquad}}$$

b. Wastewater Flow for Costing Purposes:

$$\text{DFLOW} = \underset{\text{Avg FLOW, mgd}}{\underline{\qquad\qquad}} \times \underset{\text{Scale factor}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ mgd}$$

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements (Gravity Oil Separation)

$$\text{HP} = \left(3.04 \times \underset{\text{Avg FLOW, mgd}}{\underline{\qquad\qquad}}\right) + 3.45 = \underline{\qquad\qquad} \text{ Hp}$$

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. LAND = $\underset{SF}{\underline{\hspace{2cm}}} \times \underset{\text{Avg FLOW, mgd}}{\underline{\hspace{3cm}}} \times 1200 = \underline{\hspace{2cm}}$ ft^2

b. Float from Gravity Oil Separation Unit

1. Pollutant Float (solvent extractable pollutants removed by oil separation)

$$PFLOAT = 8.34 \times \underset{\text{FLOW, mgd}}{\underline{\hspace{2cm}}} \times \Sigma(\underset{\text{PC(i), mg/L}}{\underline{\hspace{2cm}}} - \underset{\text{PS(i), mg/L}}{\underline{\hspace{2cm}}}) = \underline{\hspace{2cm}} \text{ lb/day}$$

2. Oil Float from Gravity Oil Separation

$$OFLOAT = 8.34 \times \underset{\text{FLOW, mgd}}{\underline{\hspace{2cm}}} \times (\underset{\text{SEPOIL, mg/L}}{\underline{\hspace{2cm}}} - \underset{\text{EFOIL, mg/L}}{\underline{\hspace{2cm}}}) = \underline{\hspace{2cm}} \text{ lb/day}$$

3. Suspended Solids Sludge from Gravity Oil Separation Unit

$$SLDG = 8.34 \times \underset{\text{FLOW, mgd}}{\underline{\hspace{2cm}}} \times (\underset{\text{TSSI, mg/L}}{\underline{\hspace{2cm}}} - \underset{\text{TSSE, mg/L}}{\underline{\hspace{2cm}}}) = \underline{\hspace{2cm}} \text{ lb/day}$$

4. Total Gravity Oil Separation Float Component

$$FLOAT = \underset{\text{PFLOAT, lb/day}}{\underline{\hspace{3cm}}} + \underset{\text{OFLOAT, lb/day}}{\underline{\hspace{3cm}}} + \underset{\text{SLDG, lb/day}}{\underline{\hspace{3cm}}} = \underline{\hspace{2cm}} \text{ lb/day}$$

IV.3.1.18 SEDIMENTATION

Introduction

Gravity sedimentation is the most widely used system for removing suspended solids from wastewater streams. Typical applications include separation of chemically precipitated solids and/or biological or other solids from wastewater streams. The type of process or treatment preceeding a sedimentation system (e.g., coagulation, flocculation, and activated sludge) affects the nature and settleablity of the influent wastewater solids and thereby affects the design, performance, and cost of the system. Sedimentation systems are described in more detail in Volume III of the Treatability Manual, Section III.3.1.18. Costing methodologies and cost data for this technology are presented below.

IV.3.1.18-A. Clarification

A 1. Basis of Design

This is a presentation of costs and necessary design factors for wastewater clarification using rectangular and dual circular clarifiers. The principal cost factor is the surface area of the clarifiers, and the principal design factors are influent flow and the appropriate overflow rate, given the influent suspended solids concentration and the nature of the influent solids. Design of the unit is begun by selecting an appropriate surface overflow rate from Table IV.3.1.18-A1 based on the source and type of solids entering the clarification unit. Also, depending on the type of influent solids, it is possible to select either a biological solids type clarification system (Figure IV.3.1.18-A1) or a chemical solids type clarification system (Figure IV.3.1.18-A2) This distinction will be used in the costing of the system in Section 2b. The surface area of the clarification units is calculated with a 20% safety margin based on the average influent flow and the selected overflow rate. The design is then checked to assure that the solids flux does not exceed 146 $Kg/m^2/day$ (30 $lb/ft^2/day$).

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

Wastewater flow, L/s (mgd)
Influent TSS (mg/L)
Influent oil and grease (mg/L)

TABLE IV.3.1.18-A1. DESIGN AND APPLICATION CRITERIA FOR SEDIMENTATION SYSTEMS [4-1]

Preceding Treatment or Type of Solids	Clarifier Type	Overflow Rate $L/s/m^2$	(gpd/ft^2)
1. Raw, or untreated chemical waste	Chemical	0.377	(800)
2. Activated Sludge	Biological	0.236	(500)
3. Nitrification, Denitrification	Biological	0.189	(400)
4. Chemical Coagulation			
Alum	Chemical	0.236	(500)
Sulfides	Chemical	0.236	(500)
Iron	Chemical	0.330	(700)
5. Liming (pH Adjustment) Followed by Chemical Coagulation	Chemical	0.377	(800)

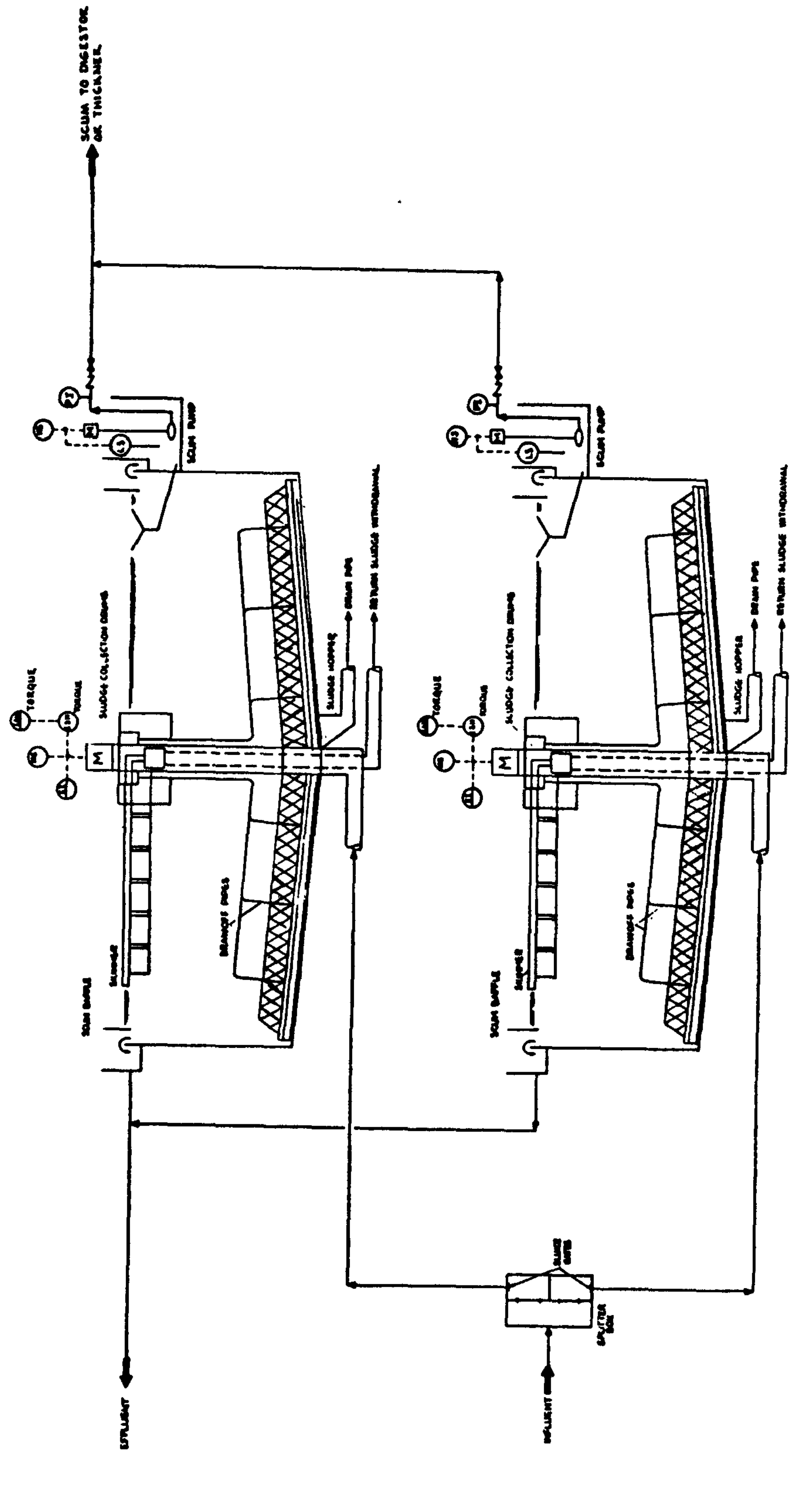


FIGURE IV.3.1.18-A1. PROCESS FLOW DIAGRAM FOR CLARIFICATION (BIOLOGICAL SOLIDS) [4-1]

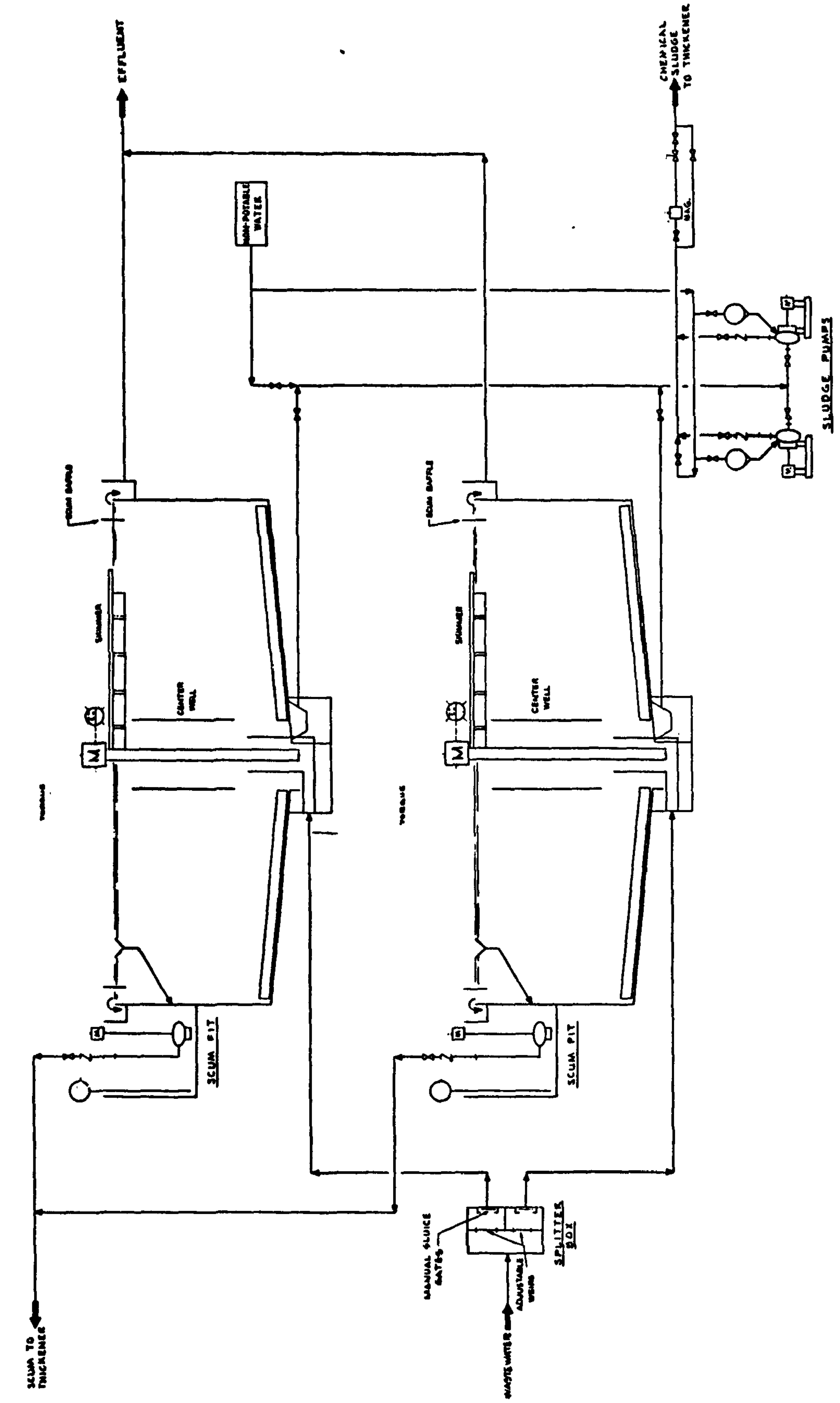


FIGURE IV.3.1.18-A2. PROCESS FLOW DIAGRAM FOR CLARIFICATION (CHEMICAL SOLIDS) [4-1]

Preceding unit process and influent solids type (see Table IV.3.1.18-A1)

c) Limitations

i) If influent TSS <50 mg/L, clarification is not required.

ii) Solids flux on the sedimentation units is limited to a maximum of 146 $Kg/m^2/day$ (30 $lb/ft^2/day$) [4-1].

d) Pretreatment

None specified.

e) Design Factor

The design surface area is initially calculated based on influent wastewater flow and the surface loading factors presented in Table IV.3.1.18-A1 corresponding to the nature of the influent solids. This design is then adjusted to a standard clarifier size based on unit diameter increments of 1.52 m (5 ft).

i) Initial estimate of Surface Area

Metric

$$SA = 1.2 \times FLOW \div OVFL$$

where:
- SA = surface area, m^2
- 1.2 = 20% safety margin for SA
- FLOW = influent flow, L/s
- OVFL = overflow rate, $L/s/m^2$ (see Table IV.3.1.18-A1)

English

$$SA = FLOW \times (1.2 \times 10^6) \div OVFL$$

where:
- SA = surface area, ft^2
- FLOW = influent flow, mgd
- OVFL = overflow rate (Table IV.3.1.18-A1), gpd/ft^2
- 1.2×10^6 = conversion factor, including 20% safety margin for SA

OVFL depends on the preceding treatment and solids type. The computed SA for a primary solids clarifier may have to be increased if the influent TSS concentration is excessively high.

ii) Clarifier Diameters

Dual circular clarifiers are considered for biological and high order (SA >20.9 m^2 (>225 ft^2)) chemical clarification systems. These units are adjusted to standard 1.52 m (5 ft) diameter increments with a maximum unit diameter of 61 m (200 ft). Low order (SA ≤20.9 m^2 (≤225 ft^2)) chemical applications call for single rectangular units and are not adjusted.

$$DM = [(4 \times SA) \div (M \times \pi)]^{0.5}$$

where: DM = individual clarifier diameter, m or ft (maximum = 61 m (200 ft))
4 = conversion factor, $radius^2$ to $diameter^2$
SA = total required surface area, m^2 or ft^2
M = number of equal sized clarifiers, (two or more)
π = 3.1417

iii) Design Surface Area

After the standard diameter and number of clarifier units has been determined the design surface area for cost purposes is computed.

$$DSA = M \times \pi \times DM^2 \div 4$$

where: DSA = design surface area, m^2 or ft^2
M = number of equal sized clarifiers
π = 3.1417
DM = individual clarifier diameter, m or ft
4 = conversion factor, $radius^2$ to $diameter^2$

f) Subsequent Treatment

None specified.

A 2. Capital Costs

The design surface area of the sedimentation units is the primary factor for the estimation of capital costs. One of three different cost curves is used to estimate capital costs depending on the relative size of the units and whether the influent solids are primarily chemical or biological in nature. Small sedimentation systems (0.46 to 20.9 m^2) (5 to 225 ft^2) for chemical or raw solids may be costed using Figure IV.3.1.18-A3 while larger systems (20.9 to 2790 m^2) (225 to 30,000 ft^2) for chemical or raw solids may be costed using Figure IV.3.1.18-A4. Systems for settling treated biological solids may be costed using Figure IV.3.1.18-A5. Costs estimated using these curves must be adjusted to a current value using an appropriate current cost index.

a) Cost Data

Items included in the capital cost curve estimates are as follows [4-2]:

i) Low order chemical, (0.46 to 20.9 m^2) (5 to 225 ft^2)
Single, concrete rectangular basin with hopper bottom
Progressive cavity pumps (two)
Piping, electrical
Instrumentation

ii) High order chemical, (20.9 to 2790 m^2) (225 to 30,000 ft^2)
Splitter influent and effluent boxes
Sluice gates (two)
Dual, concrete circular basins with hopper bottom
Horizontal centrifugal pumps (two)
Scrapers, skimmers, weirs
Piping, electrical
Instrumentation

iii) Biological
Splitter, influent, effluent, and scum boxes
Sluice gates (two)
Dual, concrete circular basins with hopper bottom sump
Rapid sludge withdrawal, skimmer, baffle, weir
Scum sump pumps (two)
Piping, electrical
Instrumentation

b) Capital Cost Curves

i) Low Order Chemical Curve - see Figure IV.3.1.18-A3.
- Cost (thousands of dollars) vs. surface area (m^2 or ft^2).
- Curve basis, cost estimate on single rectangular units of 2.32, 4.65, 9.29, and 20.9 m^2 (25, 50, 100, and 225 ft^2).

ii) High Order Chemical Curve - see Figure IV.3.1.18-A4.
- Cost (thousands of dollars) vs. total surface area (m^2 or ft^2).
- Curve basis, cost estimate on dual circular units of 32.5, 131, 730, and 2859 m^2 (350, 1,410, 7,860, and 30,770 ft^2) total surface area.

iii) Biological Curve - see Figure IV.3.1.18-A5.
- Cost (thousands of dollars) vs. total surface area (m^2 or ft^2).
- Curve basis, cost estimate on dual circular units with diameters of 4.57, 10.67, 24.4, and 48.8 m (15, 35, 80, and 160 ft).

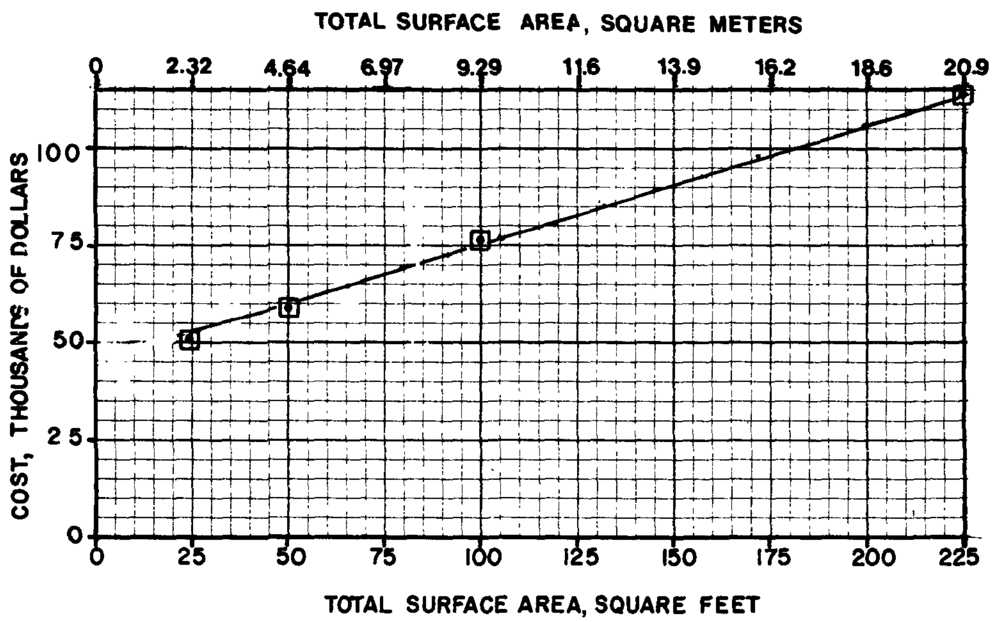


FIGURE IV.3.1.18-A3. CAPITAL COST ESTIMATE FOR CLARIFICATION OF CHEMICAL WASTE (LOW ORDER) [4-10]

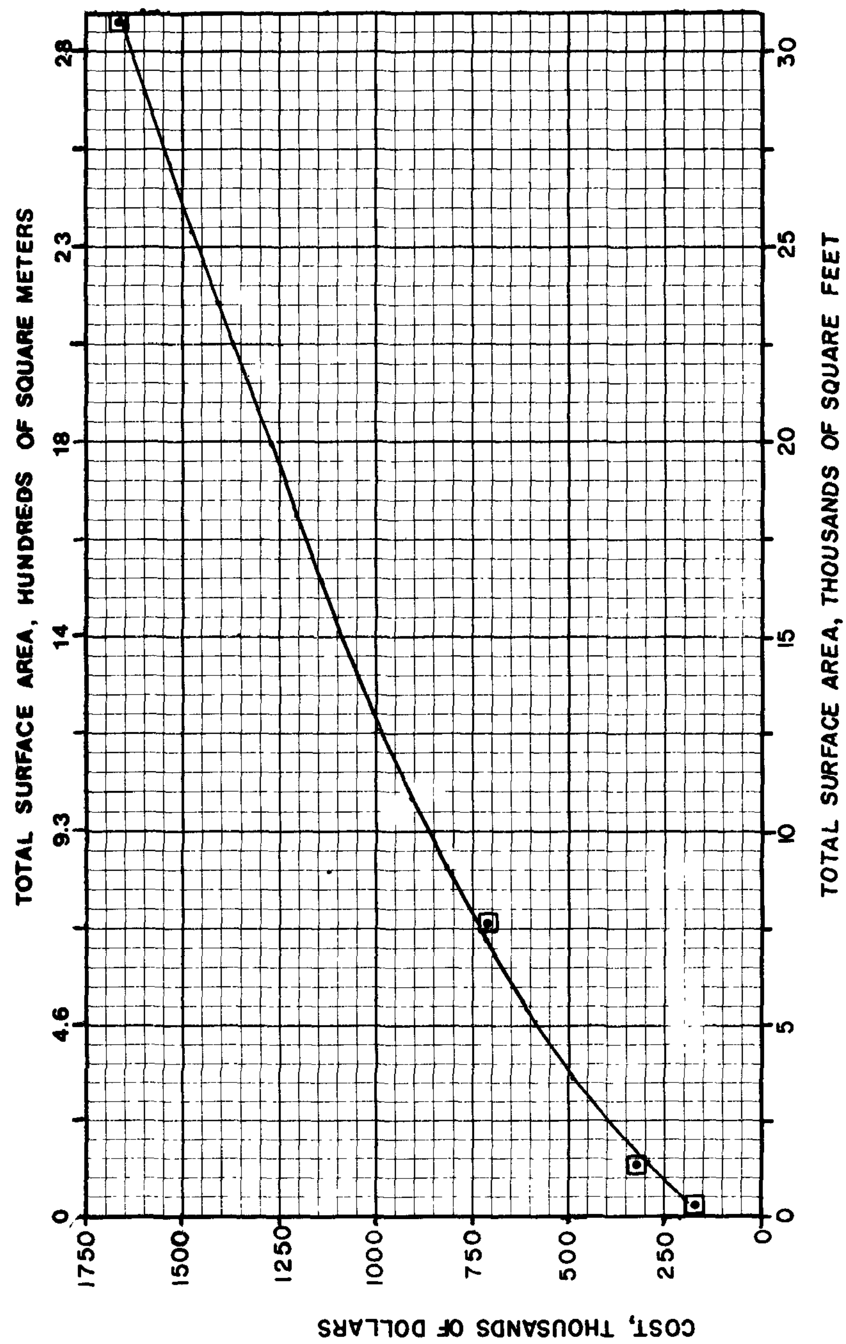


FIGURE IV.3.1.18-A4. CAPITAL COST ESTIMATE FOR CLARIFICATION OF CHEMICAL WASTE (HIGH ORDER) [4-10]

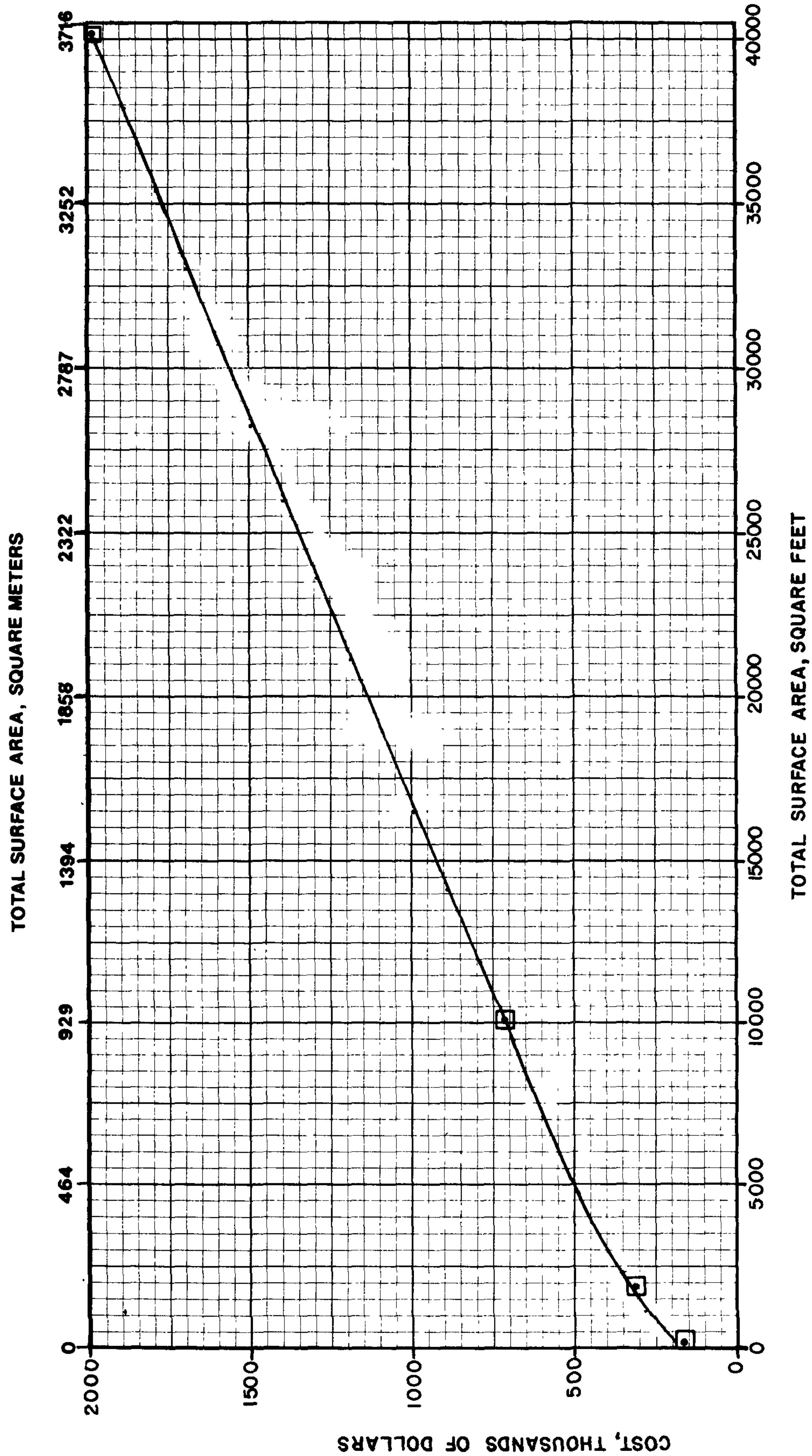


FIGURE IV.3.1.18-A5. CAPITAL COST ESTIMATE FOR CLARIFICATION (BIOLOGICAL) [4-10]

c) Cost Index

Base Period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable component of operating cost is power for clarifier mechanisms and pumps. Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor. Byproduct handling and miscellaneous plant costs are developed in subsequent routines.

a) Variable Cost

i) Power Requirements - primary and chemical sedimentation [4-1]. This equation was developed using regression analysis procedures.

Metric

$$KWC = [(1.39 \times 10^{-3}) \times SA] + 2.06$$

where: KWC = power required, kilowatts
SA = design surface area, m^2

English

$$HPC = [(1.73 \times 10^{-4}) \times SA] + 2.76$$

where: HPC = power required, Hp
SA = design surface area, ft^2

ii) Power Requirements - biological sedimentation [4-1]. This equation was developed using regression analysis procedures

Metric

$$KWB = [(1.99 \times 10^{-4}) \times SA] + 1.53$$

where: KWB = power required, kilowatts
SA = surface area, m^2

English

$$HPB = [(2.48 \times 10^{-5}) \times SA] + 2.05$$

where: HPB = power required, Hp
SA = surface area, ft^2

iii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, \$/day
KW = KWC or KWB, kilowatts
24 = hr/day
EC = electricity cost, \$/KW-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, \$/day
HP = HPC or HPB, Hp
24 = hr/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, \$/Kw-hr

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.1.18-A2, including values for the cost basis and unit costs [4-11].

A 4. Miscellaneous Costs

Costs for engineering, and common plant items such as piping and buildings, are calculated after completion of costing for individual units (see Section IV.3.5). Land requirements, and sludge collection for clarifiers are not costed here but are calculated as indicated below in order to facilitate subsequent design and cost estimates.

a) Sludge Collection

Wastewater solids collected by clarification are computed as follows.

Metric

$$SLDG = FLOW \times \Delta TSS \times 0.086$$

where: SLDG = sludge collected, Kg/day (dry)
FLOW = influent flow, L/s
ΔTSS = influent TSS - effluent TSS, mg/L
0.086 = conversion factor

English

$$SLDG = FLOW \times 8.34 \times \Delta TSS$$

TABLE IV.3.1.18-A2. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR CHEMICAL AND BIOLOGICAL CLARIFICATION SYSTEMS [4-11]

Chemical Clarification

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.10 Weeks (2.40 hr/days)	$ 9.80/hr
Supervision (1)	10% Labor (0.24 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.25 Shifts (1.43 hrs/day)	$10.70/hr
Maintenance	2.84% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.06 L/s (1.38 Thou gpd)	$0.13/thou L ($ 0.50/thou gal)

Biological Clarification

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.10 Weeks (2.40 hr/days)	$ 9.80/hr
Supervision (1)	10% Labor (0.24 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.25 Shifts (1.43 hrs/day)	$10.70/hr
Maintenance	3.52% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.02 L/s (0.51 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).
(2) One week = 7 days = 168 hours = 4.2 shifts
(3) One shift = 40 hours

where: SLDG = sludge collected, lb/day (dry)
FLOW = influent flow, mgd
8.34 = conversion factor
ΔTSS = influent TSS - effluent TSS, mg/L

The cost of sludge treatment is not presented here but is determined for all sludges generated by the treatment facility depending on the processes required.

b) Land

The clarification process requirement for land is estimated as twice the surface area of the sedimentation units.

$$LAND = 2 \times SA$$

where: LAND = land requirement, m^2 or ft^2
SA = design surface area, m^2 or ft^2

Land requirements are summed and costs estimated after completion of unit process costing.

A 5. Modifications

a) Flux Restriction

Sedimentation unit design should be checked to insure that a solids flux of 146 $Kg/m^2/day$ (30 $lb/ft^2/day$) is not exceeded

Metric

$$Flux = (\Delta TSS \times FLOW \times 0.086) \div SA$$

where: FLUX = solids flux, $Kg/m^2/day$
ΔTSS = influent TSS - effluent TSS, mg/L
FLOW = influent flow, L/s
0.086 = conversion factor
SA = design surface area, m^2

English

$$Flux = \Delta TSS \times 8.34 \times FLOW \div SA$$

where: FLUX = solids flux, $lb/ft^2/day$
ΔTSS = influent TSS - effluent TSS, mg/L
8.34 = conversion factor
FLOW = influent flow, mgd
SA = surface area, ft^2

Exceeding this flux requires that the surface area be increased.

b) Sludge Removal Adjustment for Influent TDS and MLSS

The presence of excessive levels of dissolved and suspended solids in the wastewater affects the performance and sludge accumulation of the system by changing the density gradient and settling velocity of the wastewater solids. The user should adjust performance to compensate for the presence of excessive suspended solids and for total dissolved solids. These factors should be taken into account in the reduced solids capture.

c) Supplemental Chemical Addition

If the user is considering increasing the size of clarifier units to increase solids capture, the alternative of supplemental chemical addition might also be considered. Solids capture can be enhanced by the addition of coagulant chemicals such as alum without increasing clarifier size. For additional information see Volume III, Section III.3.1.18, Sedimentation and Section III.3.1.5, Coagulation/Flocculation.

CLARIFICATION
SUMMARY WORK SHEET — REFERENCE: IV.3.1.18-A

I. DESIGN FACTOR		CAPITAL
Surface Area = ______ ft², Clarifier Type = ______		
II. CAPITAL COST		
Cost = ______ (cost from curve) × (______ (current index) ÷ 204.7) =		$ ______
III. VARIABLE O & M	$/day	O & M
Power Cost = ______ (Hp) × ______ (EC, $/Kw-hr) × 17.9	= ______	
IV. FIXED O & M		
a. Labor: ______ (hr/day) × ______ ($/hr)	= ______	
b. Supervision: ______ (hr/day) × ______ ($/hr)	= ______	
c. Overhead: ______ (Labor, $/day) × ______ (%/100)	= ______	
d. Lab Labor: ______ (hr/day) × ______ ($/hr)	= ______	
e. Maint, Service, I&T: ______ (capital, $) × ______ (%/100) ÷ 365 (day/yr)	= ______	
f. Service Water: ______ (thou gpd) × ______ ($/thou gal)	= ______	
V. YEARLY O & M 365 (day/yr) × ______ (sum $/day)		= ______ $/yr
VI. UNCOSTED ITEMS		
a. Sludge Recovery = ______ lb/day; Type ______		
b. Land = ______ ft²		

CLARIFICATION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Capital Cost Index = ________

2. EC = Electricity Cost = ________ $/Kw-hr

3. Labor = ________ $/hr

4. Supervision = ________ $/hr

5. Overhead = ________ % Labor ÷ 100 = ________ %/100

6. Lab Labor = ________ $/hr

7. Maintenance = ________ % Capital
   Services = ________ % Capital
   Insurance/Taxes = ________ % Capital
   Other O&M Factor sum = ________ ÷ 100 = ________ %/100

8. Service Water = ________ $/1000 gal

I. DESIGN FACTOR

a. Type of influent solids ____________

b. Select corresponding overflow rate, Table IV.3.1.18-A1 ________ gpd/ft²

c. Surface Area

$$SA = [\underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times (1.2 \times 10^6)] \div \underset{\text{OVFL, gpd/ft}^2}{\underline{\qquad\qquad\qquad}} = \underline{\qquad\qquad} \text{ ft}^2$$

d. Clarifier diameter

(Note: If SA ≤225 ft² and chemical solids are influent, then go to step e, since the clarifier is a rectangular unit)

1. Set M = number of clarifiers = $\underset{\text{2 or more}}{\underline{\qquad\qquad}}$

2. $$DM = \left(\underset{\text{SA ft}^2}{\underline{\qquad\qquad}} \times 1.27 \div \underset{\text{M}}{\underline{\qquad\qquad}} \right)^{0.5} = \underline{\qquad\qquad} \text{ ft}^2$$

3. If DM >200 ft, increase the number of clarifiers until DM ≤200 ft and recompute DM

   DM = ________ ft

4. Round DM up to the next larger 5 ft increment

DM = ________ ft

5. Recalculate surface ara

$$\text{Design SA} = \underset{\text{M}}{\underline{\qquad\qquad}} \times 0.785 \times (\underset{\text{DM, ft}}{\underline{\qquad\qquad}})^2 = \underline{\qquad\qquad} \text{ ft}^2$$

e. Flux Check

$$FC = (\underset{\text{Inf TSS, mg/L}}{\underline{\qquad\qquad}} - \underset{\text{Eff. TSS, mg/L}}{\underline{\qquad\qquad}}) \times 8.34 \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \div \underset{\text{SA, ft}^2}{\underline{\qquad\qquad}}$$

$$= \underline{\qquad\qquad} \text{ lb/ft}^2\text{/day}$$

If flux >30 $lb/ft^2/day$ then the surface area should be increased and the flux rechecked.

If flux ≤30 $lb/ft^2/day$, leave SA as calculated

II. CAPITAL COST

Based on the design factor SA, select a cost from one of three capital cost curves

a. Low order (25 to 225 ft^2), chemical solids
Figure IV.3.1.18-A3 ________ ft^2 $ ____________

b. High order (350 to 30,770 ft^2) chemical solids
Figure IV.3.1.18-A4 ________ ft^2 $ ____________

c. Biological solids, Figure IV.3.1.18-A5 ______ ft^2 $ ____________

III. VARIABLE O & M

a. Power Requirements - primary and chemical sedimentation

$$HPC = [(1.73 \times 10^{-4}) \times \underset{\text{SA, ft}^2}{\underline{\qquad\qquad}}] + 2.76 = \underline{\qquad\qquad} \text{ Hp}$$

b. Power Requirements - biological sedimentation

$$HBP = [(2.48 \times 10^{-5}) \times \underset{\text{SA, ft}^2}{\underline{\qquad\qquad}}] + 2.05 = \underline{\qquad\qquad} \text{ Hp}$$

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Sludge Collection

SLDG = $\underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}}$ × 8.34 × ($\underset{\text{Inf TSS, mg/L}}{\underline{\qquad\qquad}}$ - $\underset{\text{Eff TSS, mg/L}}{\underline{\qquad\qquad}}$) = ________ lb/day

b. Land

Land = 2 × $\underset{\text{SA, ft}^2}{\underline{\qquad\qquad}}$ = ________ ft^2

IV.3.1.19 STRIPPING

Introduction

Stripping is used to remove volatile materials from wastewater using either air or steam as the stripping agent. This process usually will be designed for removal of a specific constituent, such as ammonia, phenol, or sulfur compounds. This process is described in more detail in Volume III of the Treatability Manual, Section III.3.1.19. Costing methodologies and cost data for industrial wastewater treatment applications are presented below.

IV.3.1.19-A. Ammonia Stripping

A 1. Basis of Design

This presentation is for the steam stripping of ammonia from wastewater, with recovery as ammonium sulfate. Costs and design are developed for an ammonia stripping unit as shown in Figure IV.3.1.19-A1 and an ammonium sulfate recovery unit as shown in Figure IV.3.1.19-A2. The cost factor for the ammonia stripping unit is the wastewater flow rate per two column system and the cost factor for the ammonium sulfate recovery unit is the ammonia flow rate from the stripping column to the absorber. The stripping unit design is fixed at 24 trays per column and assumes that the influent wastewater is at a pH of 10.5 or greater. The process is assumed efficient up to 99 percent removal of ammonia nitrogen or a final effluent of 50 mg/L minimum. The process is not intended for an influent ammonia concentration less than 500 mg/L. Stripping steam is provided at 0.17 Kg steam/liter of wastewater (1.4 lb steam/gallon of wastewater). The overhead stream is assumed to have a 25 weight percent ammonia concentration. The recovery system uses a 10 percent sulfuric acid feed at twice the stoichiometric requirement. The ammonium sulfate is crystallized, dewatered, and dried, with a cake produced for recovery, sale, or disposal.

a) Source

This cost estimate method was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries.

b) Required Input Data

Wastewater flow L/s (gpm)
TSS (mg/L), NH_3(mg/L), pH, temperature (°C)

c) Limitations

Ammonia stripping is not used if ammonia <500 mg/L.

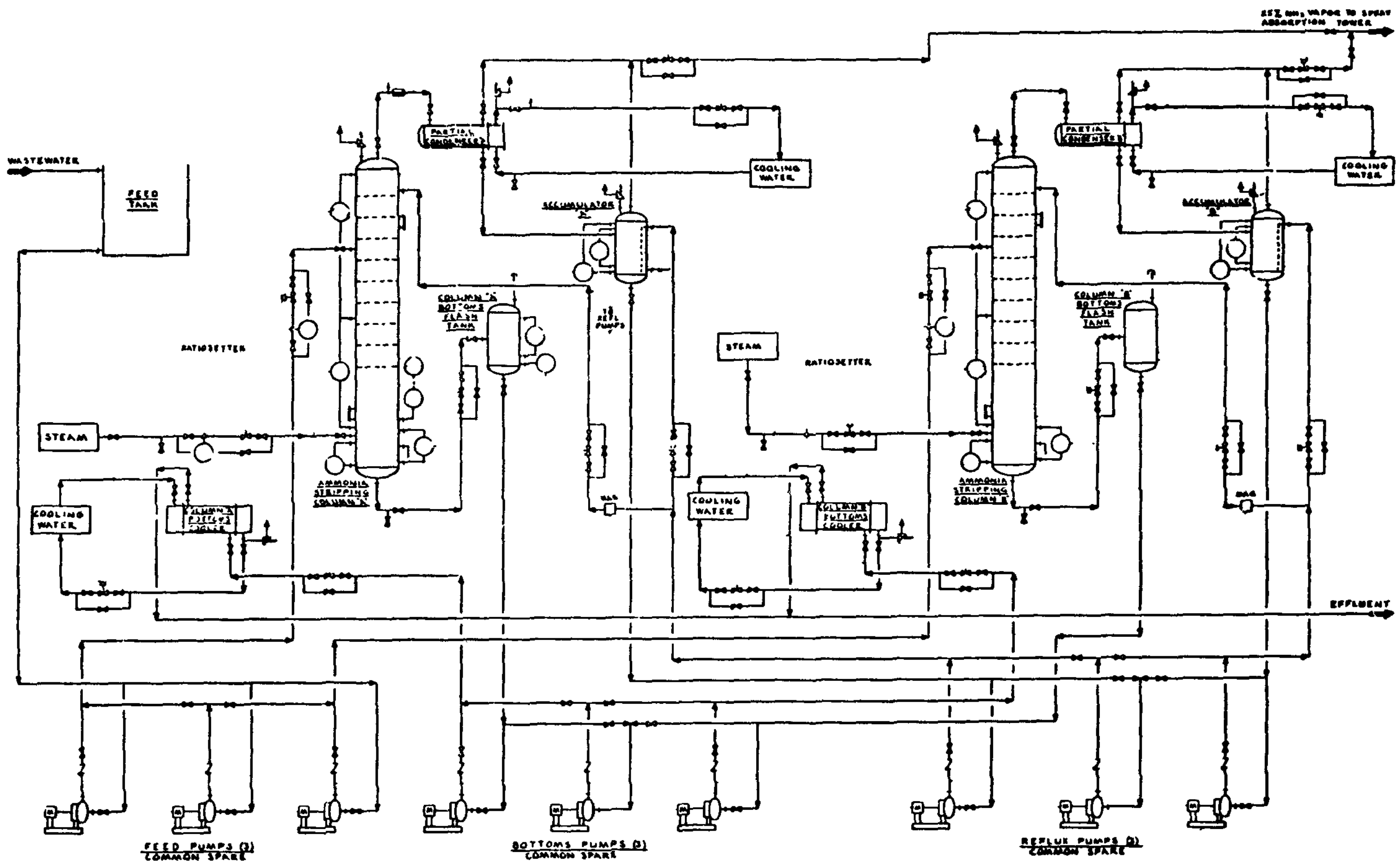


FIGURE IV.3.1.19-A1. PROCESS FLOW DIAGRAM FOR AMMONIA STRIPPING (STRIPPER AND DEPHLEGMATOR) [4-1]

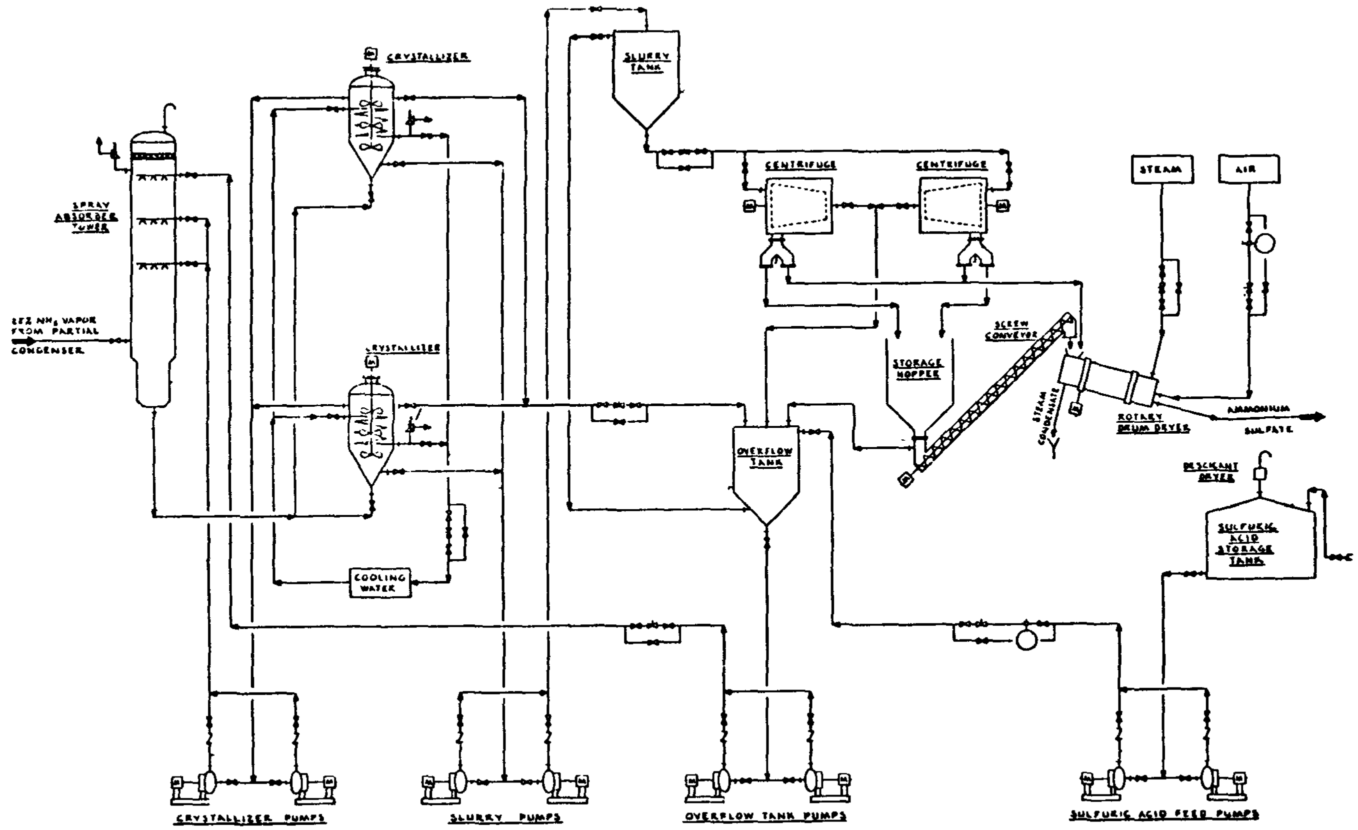


FIGURE IV.3.1.19-A2. PROCESS FLOW DIAGRAM FOR AMMONIA STRIPPING (AMMONIA SULFATE PRODUCTION) [4-1]

d) Pretreatment

Pretreatment is provided as indicated for the following conditions:

i) If influent TSS >50 mg/L, then multi media filtration is required upstream.

ii) If pH <10.5, then liming to high pH (Section IV.3.1.13-B) is required upstream.

e) Design Equation

i) Stripping Columns

The primary capital cost factor used for ammonia stripping columns is wastewater flow per two column system.

Metric

$$FPS = (FLOW \div NC) \times 2$$

where: FPS = (maximum of 12.6 L/s per column) flow per two column system, L/s
FLOW = average influent flow, L/s
NC = number of columns

English

$$FPS = (FLOW \div NC) \times 2$$

where: FPS = (maximum of 200 gpm per column) flow per two column system, gpm
FLOW = average influent flow, gpm
NC = number of columns

The number of columns must be adjusted until the flow per single column is less than 12.6 L/s (200 gpm). Each system is required to have at least two stripping columns (maximum flow of 25.2 L/s (400 gpm) for the pair). When the influent flow exceeds 25.2 L/s (400 gpm) three or more equal sized columns will be required until the flow per individual column does not exceed 12.6 L/s (200 gpm).

ii) Ammonium Sulfate Recovery

The ammonium sulfate recovery system is designed based on the ammonia feed rate to the absorber from the stripper.

Metric

NH3A = Factor × NH3I

where: NH3A = ammonia to absorber from the stripper, Kg/hr
Factor = 0.99, if influent ammonia to stripper >5000 mg/L
= (NH3 - 50) ÷ NH3, if influent <5000 mg/L
NH3 = influent ammonia to stripper, mg/L (minimum 500 mg/L)
50 = minimum effluent from stripper, mg/L
NH3I = ammonia loading to the stripper, Kg/hr
= NH3 × FLOW × 3600 × 10^{-6}
FLOW = influent flow, L/s
3600 = conversion factor, L/s to Kg/hr
10^{-6} = conversion factor mg/L to Kg/L

English

NH3A = Factor × NH3I

where: NH3A = ammonia to absorber from the stripper, lb/hr
Factor = 0.99, if influent ammonia to stripper >5000 mg/L
= (NH3 - 50) ÷ NH3, if influent <5000 mg/L
NH3 = influent ammonia to stripper, mg/L (minimum 500 mg/L)
50 = minimum effluent from stripper, mg/L
NH3I = ammonia loading to the stripper, lb/hr
= NH3 × FLOW × 500 × 10^{-6}
FLOW = influent flow, gpm
500 = conversion factor, gpm to lb/hr
10^{-6} = conversion factor mg/L to fraction

f) Subsequent Treatment

Byproduct treatment of ammonium sulfate cake is not considered directly; it is assumed that the value of the recovered material equals the cost of handling.

Residual ammonia in the wastewater stream probably requires biological treatment.

A 2. Capital Costs

The stripping column capital cost is based on the flow rate per column, with at least two columns required for each system. Where the total system flow is greater than 25.2 L/s (400 gpm), then three or more columns are required, since the maximum column size is 12.6 L/s (200 gpm). The capital cost curve in Figure IV.3.1.19-A3 for the ammonia stripping columns is based on a two column system. Therefore, when three or more columns are required (i.e., total system flow >25.2 L/s), the cost must be read as the cost per two columns. A scale factor then is used to adjust the curve cost to the appropriate system cost. (This scale factor is presented in Section A2, b). The ammonia recovery system capital cost curve in Figure IV.3.1.19-A4 is based on the flow rate of ammonia from the stripping column to the absorber. Cost estimated using these curves must be adjusted to a current value using an appropriate current cost index.

a) Cost Data

i) Items included in the capital cost estimates for the ammonia stripping columns include [4-2]:

Ammonia stripping column, 24 trays (two)
Bottoms column (two)
Dephlegmators (two)
Accumulators (two)
Bottoms flash tank (two)
Pumps, piping
Instrumentation, electrical

ii) Items included in the capital cost estimates for the ammonium sulfate recovery system include [4-2]:

Spray absorber (one)
Downcomer leg (one)
Crystallizers (two)
Slurry tank (one)
Overflow tank (one)
Acid storage tank (one)
Centrifuge (one)
Feed vibrator (one)
Rotary drum dryer (one)
Pumps, piping
Instrumentation, electrical

b) Capital Cost Curves

i) Stripper system - see Figure IV.3.1.19-A3.
- Cost (thousands of dollars) vs. flow per two column systems (liters per second or gallons per minute).
- Curve basis, cost estimate on systems at flow rates of 2.52, 6.31, 12.6, and 25.2 L/s (40, 100, 200, and 400 gpm) (individual column capacities of 1.26, 3.15, 6.31, and 12.6 L/s (20, 50, 100, and 200 gpm))

ii) Scale Factor for more than two stripping columns
- Capital Cost (two columns) = (cost from curve)
- Capital Cost (more than two columns) = (cost from curve) × (No. columns/2)$^{0.8}$

iii) Ammonium sulfate system - see Figure IV.3.1.19-A4.
- Cost (thousands of dollars) vs. ammonia to the absorber from the stripper (kilograms per hour or pounds per hour)
- Curve basis, cost estimate on four systems designed at rates of 44.9, 112, 225, and 450 kilograms (99, 248, 495, and 991 pounds) ammonia per hour

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. Variable components include chemical (sulfuric acid), utilities (steam, cooling water), and power. Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor. Byproduct handling may be required for the ammonium sulfate residue, but this is considered to be offset by the value of the byproduct.

a) Variable Costs

i) Power Requirements - Total power requirements for an ammonia stripping system consist of power for the centrifuge, dryer, and pumps [4-1]. The following power equations were developed using regression analysis procedures.

- Total Power

$$TP = CP + DP + FP + BP + AP$$

where: TP = total power required, KW or Hp
CP = power required for centrifuge, KW or Hp
DP = power required for dryer, KW or Hp
FP = power required for feed pumps, KW or Hp
BP = power required for bottoms pumps, KW or Hp
AP = power required for acid and slurry pumps, KW or Hp

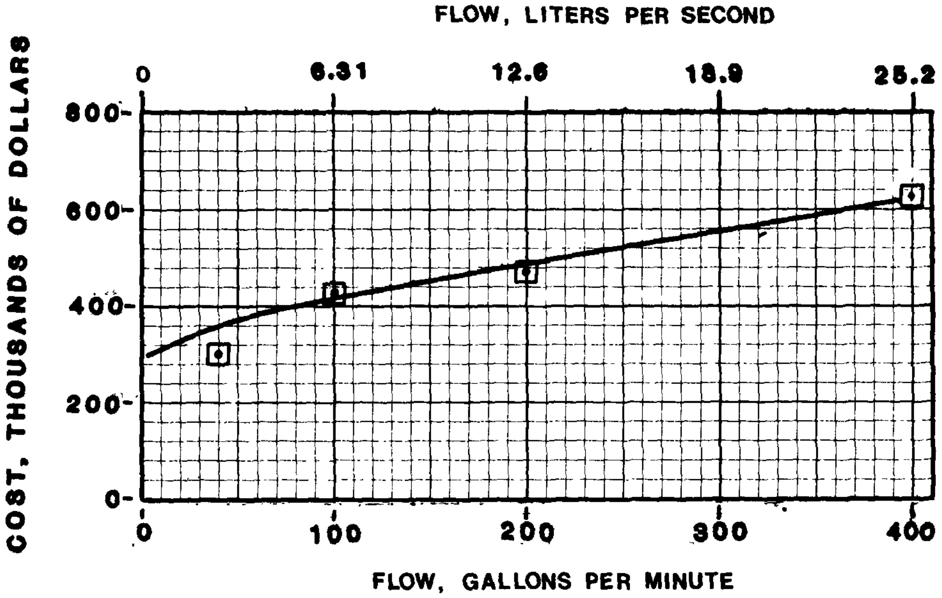


FIGURE IV.3.1.19-A3. CAPITAL COST ESTIMATE FOR AMMONIA STRIPPING [4-10]

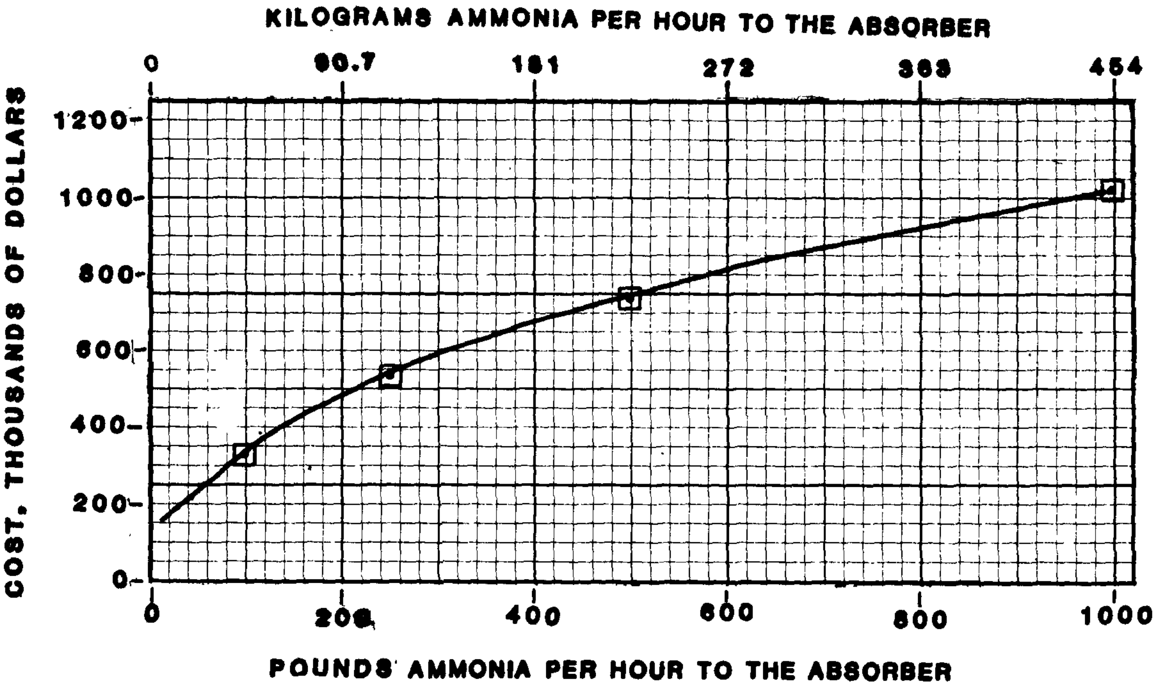


FIGURE IV.3.1.19-A4. CAPITAL COST ESTIMATE FOR AMMONIUM SULFATE REMOVAL [4-10]

- Centrifuge Power

Metric

$$CP = 0.029 \times NH3A$$

where:
- CP = centrifuge power, KW
- 0.029 = factor based on 75% dry cake and 5.08 KW-hr/metric ton dry solids, KW-hr/Kg
- NH3A = ammonia to absorber, Kg/hr

English

$$CP = 0.0173 \times NH3A$$

where:
- CP = centrifuge power, Hp
- 0.0173 = factor based on 75% dry cake and 5 Kw-hr/ton dry solids, Hp-hr/lb
- NH3A = ammonia to absorber, lb/hr

- Dryer Power

Metric

$$DP = 6.0 \times (DRYDI)^2$$

where:
- DP = dryer power, KW
- 10.8 = factor, KW/m^2
- DRYDI = dryer diameter, m
- $= 1.95 \times (ER)^{0.5}$
- 1.95 = factor
- ER = evaporation rate, Kg/hr
- $= ASP \times 2.67$
- ASP = ammonium sulfate produced, Kg/hr
- $= 3.88 \times NH3A$
- 3.88 = Kg ammonium sulfate/Kg ammonia
- 2.67 = Kg water evaporated/Kg ammonium sulfate

English

$$DP = 0.75 \times (DRYDI)^2$$

where:
- DP = dryer power, Hp
- 0.75 = factor, Hp/ft^2
- DRYDI = dryer diameter, ft
- $= 4.3 \times (ER)^{0.5}$
- 4.3 = factor
- ER = evaporation rate, lb/hr
- $= ASP \times 2.67$
- ASP = ammonium sulfate produced, lb/hr
- $= 3.88 \times NH3A$

3.88 = lb ammonium sulfate/lb ammonia
2.67 = lb water evaporated/lb ammonium sulfate

- Feed Pump Power

Metric

$$FP = 1.17 \times 10^{-4} \times 3600 \times FLOW$$

where: FP = feed pump power, KW
1.17×10^{-4} = factor relating power to mass flow, KW/Kg/hr
3600 = conversion factor L/s to Kg/hr
FLOW = wastewater flow, L/s

English

$$FP = 7.16 \times 10^{-5} \times 500 \times FLOW$$

where: FP = feed pump power, Hp
FLOW = wastewater flow, gpm
7.16×10^{-5} = factor relating power to mass flow, Hp/lb/hr
500 = conversion, gpm to lb/hr

- Bottoms Pump Power

Metric

$$BP = 6.91 \times 10^{-4} \times BTM$$

where: BP = bottoms pump power, KW
3.7×10^{-3} = factor relating power to mass flow, KW/Kg/hr
BTM = flow from bottom of column (effluent) including condensed steam and excluding overhead vapors, Kg/hr
= $(1.17 \times 3600 \times FLOW) - (NH3I \times 4)$
1.17 = allowance for effluent to include 0.168 Kg steam per liter feed
3600 = conversion L/s to Kg/hr
FLOW = wastewater flow, L/s
NH3I = ammonia loading to stripper, Kg/hr
= $NH3 \times FLOW \times 3600 \times 10^{-6}$
NH3 = influent ammonia concentration, mg/L
FLOW = wastewater flow, L/s
3600 = conversion factor, L/s to Kg/hr
10^{-6} = conversion factor, mg/L to Kg/L

English

$$BP = 4.21 \times 10^{-4} \times BTM$$

where: BP = bottoms pump power, Hp
BTM = flow from bottom of column (effluent) including condensed steam and excluding overhead vapors, lb/hr
= $(1.17 \times 500 \times FLOW) - (NH3I \times 4)$
1.17 = allowance for effluent to include 1.4 lb steam per gallon feed
500 = conversion, gpm to lb/hr
FLOW = wastewater flow, gpm
NH3I = ammonia loading to stripper, lb/hr
= $NH3 \times FLOW \times 500 \times 10^{-6}$
NH3 = influent ammonia concentration, mg/L
500 = conversion factor, gpm to lb/hr
10^{-6} = conversion factor, mg/L to fraction

- Acid and Slurry Pumps Power

Metric

$$AP = 1.8 \times 10^{-4} \times ACID$$

where: AP = acid pump power, KW
1.8×10^{-4} = factor relating power to mass flow, KW/Kg/hr
ACID = 10% sulfuric acid recirculation, Kg/hr
= $57.6 \times NH3A$
57.6 = stoichiometric factor including 2 times required acid
NH3A = ammonia to absorber, Kg/hr

English

$$AP = 1.08 \times 10^{-4} \times ACID$$

where: AP = acid pump power
1.08×10^{-4} = factor relating power to mass flow, Hp/lb/hr
ACID = 10% sulfuric acid recirculation, lb/hr
= $57.6 \times NH3A$
57.6 = stoichiometric factor including 2 times required acid
NH3A = ammonia to absorber, lb/hr

ii) Chemical Requirements - Sulfuric acid makeup is required to compensate for the reaction with the ammonia removed. This is calculated on the basis of 7% makeup for the recirculated acid feed to the absorber.

Metric

$$AMUP = 0.07 \times 57.6 \times NH3A$$

where: AMUP = acid makeup, (10% sulfuric acid) Kg/hr
0.07 = % makeup
57.6 = stoichiometric factor
NH3A = ammonia to absorber, Kg/hr

English

$$AMUP = 0.07 \times 57.6 \times NH3A$$

where: AMUP = acid makeup, (10% sulfuric acid) lb/hr
0.07 = % makeup
57.6 = factor
NH3A = ammonia to absorber, lb/hr

iii) Utilities - Steam and cooling water are required for the ammonium sulfate recovery system.

- Cooling Water

Metric

$$CWF = 7.94 \times 10^{-5} \times ACID$$

where: CWF = cooling water flow, L/s
7.94×10^{-5} = temperature change factor
ACID = 10% sulfuric acid recirculation, Kg/hr
= $57.6 \times NH3A$
57.6 = factor
NH3A = ammonia to absorber, Kg/hr

English

$$CWF = 5.71 \times 10^{-4} \times ACID$$

where: CWF = cooling water flow, gpm
5.71×10^{-4} = temperature change factor
ACID = 10% sulfuric acid recirculation, lb/hr
= $57.6 \times NH3A$
57.6 = factor
NH3A = ammonia to absorber, lb/hr

- Steam for Dryer

Metric

$$STD = 2.3 \times ASP \times 2.67$$

where: STD = steam required for dryer, Kg/hr
2.3 = factor
ASP = ammonium sulfate produced, Kg/hr
= 3.88 × NH3A
3.88 = Kg ammonia sulfate produced/Kg ammonia to absorber
NH3A = ammonia to absorber from the stripper, Kg/hr
2.67 = Kg water evaporated/Kg ammonium sulfate

English

$$STD = 2.3 \times ASP \times 2.67$$

where: STD = steam required for dryer, lb/hr
2.3 = factor
ASP = ammonium sulfate produced, lb/hr
= 3.88 × NH3A
3.88 = lb ammonia sulfate produced/lb ammonia to absorber
NH3A = ammonia to absorber from the stripper, lb/hr
2.67 = lb water evaporated/lb ammonium sulfate

- Steam for Stripping Column

Metric

$$STC = 0.168 \times FLOW \times 3600$$

where: STC = steam required for column, Kg/hr
0.168 = Kg steam/liter flow
FLOW = influent flow, L/s
3600 = s/hr

English

$$STC = 1.4 \times FLOW \times 60$$

where: STC = steam required for column, lb/hr
1.4 = lb steam/gallon flow
FLOW = influent flow, gpm
60 = min/hr

iv) Cost for variable components includes:

- Chemical Cost (Sulfuric Acid)

Metric

$$SAC = AMUP \times 0.1 \times 24 \times SAP$$

where: SAC = cost for sulfuric acid, \$/day
AMUP = acid makeup (10% sulfuric acid), Kg/hr
24 = hr/day
SAP = price for concentrated (100% sulfuric acid), \$/Kg acid
0.1 = conversion factor for 10% acid

English

$$SAC = AMUP \times 0.1 \times 24 \times SAP$$

where: SAC = cost for sulfuric acid, \$/day
AMUP = acid makeup (10% sulfuric acid), lb/hr
24 = hr/day
SAP = price for concentrated (100% sulfuric acid), \$/lb acid
0.1 = conversion factor for 10% acid

- Power Cost

Metric

$$PC = TP \times 24 \times EC$$

where: PC = power cost, \$/day
TP = total power, KW
24 = hr/day
EC = electricity cost, \$/KW

English

$$PC = TP \times 0.746 \times 24 \times EC$$

where: PC = total power cost, \$/day
TP = total power, Hp
0.746 = Kw-hr/Hp-hr
24 = hr/day
EC = electricity cost, \$/Kw-hr

- Cooling Water

Metric

$$WC = CWF \times 86400 \times CPG$$

where: WC = water cost, \$/day
CWF = cooling water flow, L/s
86400 = s/day
CPG = cost of water per liter, \$/L

English

$$WC = CWF \times 1440 \times CPG$$

where:
WC = water cost, \$/day
CWF = cooling water flow, gpm
1440 = min/day
CPG = cost of water per gallon, \$/gallon

- Steam Cost

Metric

$$TSC = (STD + STC) \times 24 \times CPP$$

where:
TSC = total steam cost, \$/day
STD = steam for dryer, Kg/hr
STC = steam for stripping column, Kg/hr
24 = hr/day
CPP = cost per Kg of steam, \$/Kg

English

$$TSC = (STD + STC) \times 24 \times CPP$$

where:
TSC = total steam cost, \$/day
STD = steam for dryer, lb/hr
STC = steam for stripping column, lb/hr
24 = hr/day
CPP = cost per lb of steam, \$/lb

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.1.19-A1, including values for the cost basis and the unit costs.

A 4. Miscellaneous Costs

Costs for engineering, and common plant items such as land, piping, and buildings, are calculated after completion of costing for individual units (see Section IV.3.5).

A 5. Modifications

Additional information on the design of the various components of the ammonia stripping columns and ammonium sulfate recovery systems may be found in Reference [4-1].

TABLE IV.3.1.19-A1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR AMMONIA STRIPPING AND AMMONIUM SULFATE RECOVERY [4-11]

Ammonia Stripping

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.25 Weeks (6.00 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.60 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.10 Shifts (0.57 hrs/day)	$10.70/hr
Maintenance	5.25% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.22 L/s (5.18 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

Ammonium Sulfate Recovery

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.00 Weeks	$ 9.80/hr
Supervision (1)	10% Labor	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.00 Shifts	$10.70/hr
Maintenance	7.45% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.15 L/s (3.46 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable
(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).
(2) One week = 7 days = 168 hours = 4.2 shifts
(3) One shift = 40 hours

AMMONIA STRIPPING
SUMMARY WORK SHEET — REFERENCE: IV.3.1.19-A

I. DESIGN FACTOR	CAPITAL
a. Stripping Columns: flow per 2-column system = ________ gpm	
b. Ammonium Sulfate System: = ________ lb/hr	
II. CAPITAL COST	
a. Stripping Columns: Cost = ________ (cost from curve) × (________ scale factor) × (________ current index ÷ 204.7)	$ ________
b. Ammonium Sulfate Recovery: Cost = ________ (cost from curve) × (________ current index ÷ 204.7)	$ ________

III. VARIABLE O & M				$/day	O & M
a. Power =	________ Hp	× ________ EC, $/Kw-hr	× 17.9	= ________	
b. Acid =	________ acid, lb/hr	× ________ SAP, $/lb	× 2.4	= ________	
c. Cooling water cost =	________ water, gpm	× ________ WC, $/gal	× 1440	= ________	
d. Steam =	________ steam, lb/hr	× ________ CPP, $/lb	× 24	= ________	
IV. FIXED O & M	STRIPPING		RECOVERY		
a. Labor:	________ $/day	+	________ $/day	= ________	
b. Supervision:	________ $/day	+	________ $/day	= ________	
c. Overhead:	________ $/day	+	________ $/day	= ________	
d. Lab Labor:	________ $/day	+	________ $/day	= ________	
e. Maint., Service, I&T:	________ $/day	+	________ $/day	= ________	
f. Service Water:	________ $/day	+	________ $/day	= ________	
V. YEARLY O & M		365 day/yr	×	________ sum $/day	= ________ $/yr
VI. UNCOSTED ITEMS					

AMMONIA STRIPPING
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Capital Cost Index = ________

		AMMONIA STRIPPING	AMMONIUM SULFATE RECOVERY	
2.	EC: electricity cost =	________	________	\$/Kw-hr
3.	SAP: sulfuric acid price =	________	________	\$/lb
4.	WC: water cost =	________	________	\$/gal
5.	CPP: steam cost =	________	________	\$/lb
6.	Labor =	________	________	\$/hr
7.	Supervision =	________	________	\$/hr
8.	Overhead# =	________	________	% Labor#
9.	Lab Labor =	________	________	\$/hr
10.	Maintenance =			% Capital
	Services =			% Capital
	Insurance/Taxes =	________	________	% Capital
	Other O & M Factor Sum# =			
11.	Service Water =	________	________	\$/thou gal

#Note - these must be divided by 100 for use in Part IV of the Work Sheet.

I. DESIGN FACTORS

a. Stripping Columns

Flow per column = ________ ÷ ________ = ________ gpm*
FLOW, gpm   no. columns

* minimum of 2 columns, maximum 200 gpm per column

FLOW per 2-column system = 2 × ________ = ________ gpm**
gpm/column

** Note - this is used to develop cost from Figure IV.3.1.19-A3.

b. Ammonia Feed Rate To Absorber (NH3A)

1. Factor Check

a. If influent ammonia (NH3) to the stripping column >5000 mg/L, then FACTOR = 0.99

b. If influent ammonia (NH3) to the stripping column = between 50 and 5000 mg/L, then

FACTOR = (______ - 50) ÷ ______ = ______
NH3, mg/L NH3, mg/L

2. Ammonia Feed Rate (NH3A)

NH3A = ______ × ______ × ______ ÷ 2000 = ______ lb/hr
NH3, mg/L FACTOR FLOW, gpm

II. CAPITAL COST

Stripping Columns scale factor = $(\underline{\hspace{2cm}}_{\text{\# columns}} \div 2)^{0.8}$ = ______

III. VARIABLE O & M

a. Total Power = ______ + ______ + ______ + ______ + ______ = ______ Hp
CP, Hp DP, Hp FP, Hp BP, Hp AP, Hp

1. CP = 0.0173 × ______ = ______ Hp
NH3A, lb/hr

2. DP = 143 × ______ = ______ Hp
NH3A, lb/hr

3. FP = 0.0358 × ______ = ______ Hp
FLOW, gpm

4. BP = (0.246 × ______) - (8.42×10^{-7} × ______ × ______)
FLOW, gpm NH3, mg/L FLOW, gpm

= ______ Hp

5. AP = 6.22×10^{-3} × ______ = ______ Hp
NH3A, lb/hr

b. Acid makeup = ______ × 4.032 = ______ lb/hr
NH3A, lb/hr

c. Cooling Water = ______ × 0.0329 = ______ gpm
NH3A, lb/hr

d. Steam = (23.827 × ______) + (84 × ______) = ______ lb/hr
NH3A, lb/hr FLOW, gpm

IV. FIXED O & M

a. AMMONIA STRIPPING

Labor: ________ hr/day × ________ $/hr = ________ $/day

Supervision: ________ hr/day × ________ $/hr = ________ $/day

Overhead: ________ Labor,$/day × ________ % Labor/100 = ________ $/day

Laboratory: ________ hr/day × ________ $/hr = ________ $/day

Maint., Serv. I&T: ________ Capital × ________ %/100 ÷ 365 = ________ $/day

Water Service: ________ 1000 gal/day × ________ $/1000 gal = ________ $/day

b. AMMONIUM SULFATE RECOVERY

Labor: ________ hr/day × ________ $/hr = ________ $/day

Supervision: ________ hr/day × ________ $/hr = ________ $/day

Overhead: ________ Labor,$/day × ________ % Labor/100 = ________ $/day

Laboratory: ________ hr/day × ________ $/hr = ________ $/day

Maint., Serv. I&T: ________ Capital × ________ %/100 ÷ 365 = ________ $/day

Water Service: ________ 1000 gal/day × ________ $/1000 gal = ________ $/day

V. YEARLY O & M

VI. UNCOSTED ITEMS

IV.3.2.1 ACTIVATED SLUDGE

Introduction

Activated sludge processes are designed for the removal of dissolved and colloidal organic materials from the wastewater stream by physical and biological mechanisms. There are numerous variations of the process in use, but general practice has found that certain conditions result in stable and economical operating conditions. The key aspect of activated sludge processes is that they involve the recycle of active biological sludge solids from the process discharge back to the aeration basin. The activated sludge process is discussed in more detail in Volume III of the Treatability Manual, Section III.3.2.1. Costing methodologies and cost data for this technology are presented below.

IV.3.2.1-A. Activated Sludge

A 1. Basis of Design

This section presents a cost estimating method for activated sludge basins and appurtenances not including aeration or nutrient addition. Aeration and nutrient addition costs are addressed in Sections IV.3.2.1-B and IV.3.2.1-C, respectively. A schematic flow diagram of an activated sludge system of the type considered is presented in Figure IV.3.2.1-A1.

The primary cost factor for this technology is basin volume, but cost curves are also presented in terms of flow and influent BOD concentration for certain standardized conditions. The principal design factors considered in this method are flow, wastewater characteristics, and detention time. The basic design approach involves calculation of detention time based on the influent BOD concentration, a set of appropriate assumptions regarding the mixed liquor volatile suspended solids (MLVSS) concentration, and the food to microorganism (F/M) ratio in the basin. Basin volume is then calculated as the product of the average daily flow and the detention time. A cost curve based on basin volume is provided for estimating capital costs. A simplified cost estimating procedure is also presented for the users convenience which relates capital costs to flow for a set of standard influent and operating conditions.

Neither of these methods addresses the performance of the activated sludge system. However, the user may find it necessary to make independent estimates of performance in order to estimate sludge generation and to size and cost the aerator and nutrient addition systems in later sections.

a) Source

The unit cost information in this section was derived from the

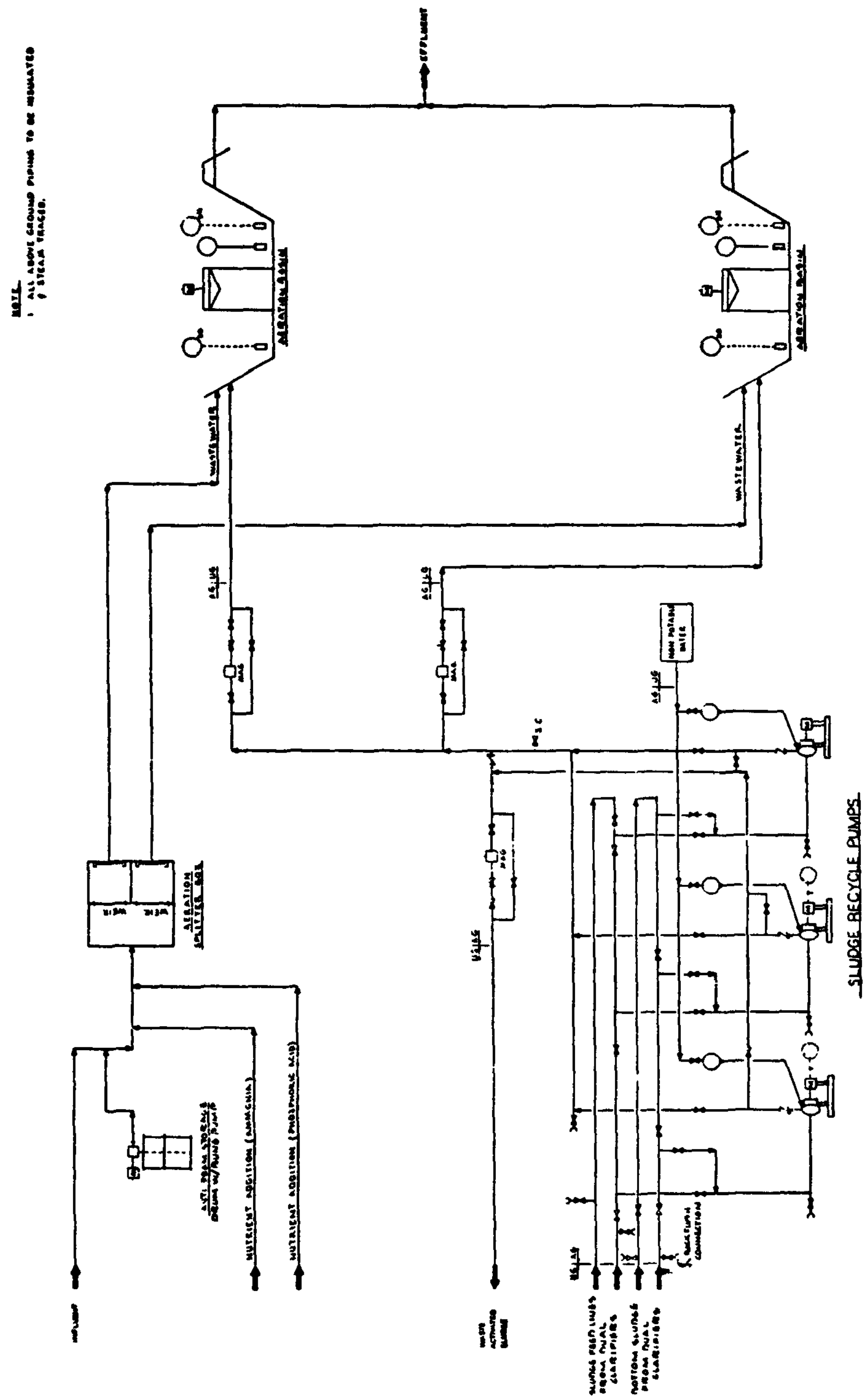


FIGURE IV.3.2.1-A1. PROCESS FLOW DIAGRAM FOR ACTIVATED SLUDGE [4-1]

BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/ Plastics and Synthetic Fibers Industries [4-2].

b) Required Input Data

Wastewater flow, L/s (mgd)
Temperature (°C), pH
BOD (mg/L)
Oil and grease, ammonia, phosphorus, TSS, TDS, phenol (mg/L)
Heavy metals and other priority pollutants (µg/L)

c) Limitations

i) Activated sludge is not considered applicable if influent BOD < 10 mg/L.

d) Pretreatment

Pretreatment should be provided as indicated for the following conditions [4-1]:

i) Oil >35 mg/L requires oil separation.

ii) pH >9 or pH <6 requires neutralization.

iii) Ammonia >500 mg/L requires stripping (unless ammonia is less than 5% of the influent BOD).

iv) TSS >150 mg/L requires solids separation process.

v) Heavy metals greater than the following values require precipitation (lead = 1.5 mg/L; copper = 0.5 mg/L; total chromium = 1.5 mg/L; zinc = 1.5 mg/L; nickel = 0.5 mg/L; trivalent chromium = 10 mg/L).

vi) Cyanide >3 mg/L requires oxidation.

vii) Phenol >300 mg/L requires solvent extraction.

viii) Phenol >100 mg/L with high value divided by average value >1.2 requires equalization.

ix) Solvent extraction will be required if the maximum phenol concentration <100 mg/L, the average concentration is >50 mg/L, the ratio of maximum to average is >1.5, and flow equalization is included in the treatment system.

x) Total dissolved solids >10,000 mg/L requires ion exchange.

e) Design Factor

The user may select either of two methods for estimating the cost of an activated sludge system. The first requires that the user determine the required basin volume and the second utilizes only influent wastewater flow. These two methods are addressed below:

i) Basin Volume Method

This method requires that the user calculate the basin volume from the hydraulic detention time. Detention time may be estimated for a particular influent BOD concentration as follows by using combinations of MLVSS and F/M ratios that correspond to standard operating modes:

$$t = \frac{So}{(Xv) \times (F/M)}$$

where: t = detention time, days
So = influent BOD, mg/L
Xv = MLVSS, mg/L
F/M = food to microorganism ratio

Typical ranges for the key operating parameters under standard operating modes (conventional activated sludge, extended aeration) are presented in Table IV.3.2.1-A1. Note that performance is not considered. For further information see Section A 5,a.

Basin volume is calculated as follows:

Metric

$$BV = FLOW \times t \times 86400$$

where: BV = basin volume, L
FLOW = influent flow, L/s
t = detention time, days
86400 = conversion factor, sec/day

English

$$BV = FLOW \times t$$

where: BV = basin volume, million gallons
FLOW = influent flow, mgd
t = detention time, days

TABLE IV.3.2.1-A1. TYPICAL OPERATING RANGES FOR KEY DESIGN PARAMETERS OF ACTIVATED SLUDGE SYSTEMS [4-1]

Mode	Influent BOD Range (mg/L)	MLVSS (mg/L): (Range)	F/M Range	BOD Removal (%)
Conventional Activated Sludge	>200	(500 - 4000)	0.25 - 0.6	80 - 99
Extended Aeration	>200	(500 - 4000)	0.05 - 0.15	80 - 99

ii) Simplified Method

Flow is the principal design factor for this method. The design equations shown above were solved for F/M ratios of 0.1 and 0.3, appropriate MLVSS concentrations, and various influent BOD concentrations. The user must select either the set of curves for F/M = 0.1 (typical extended aeration) or the set of curves for F/M = 0.3 (typical activated sludge) and estimate the cost from the curve most closely corresponding to the influent BOD concentration. Note that performance is not considered. For further information see Section A 5,a.

iii) Associated Factors

Requirements for aeration, land, nutrient addition, and waste sludge handling for activated sludge must be calculated separately. These are discussed in Section A 4, Miscellaneous Costs. Clarification systems are discussed in Section IV.3.1.18-A.

f) Subsequent Treatment

Subsequent treatment requires a solids separation process, usually clarification.

A 2. Capital Costs

Two capital cost estimating procedures are presented in this section for activated sludge basins without aeration. The first involves estimation of capital cost based on the estimated basin volume of the activated sludge system. The capital cost of the system as a function of basin volume is presented in Figure IV.3.2.1-A2. Capital costs for two standard types of activated sludge systems at various influent BOD concentrations are presented in Figures IV.3.2.1-A3 and -A4 as a function of wastewater flow rate. The user should select the set of operating conditions presented in the curves that most nearly match the situation at hand.

a) Cost Data

The items included in the capital cost estimates are as follows [4-2]:

Dual aeration basins (3.05 m (10 ft) depth assumed)
- $<2,080$ m^3 (550,000 gal) - all concrete
- $\geq 2,080$ m^3 (550,000 gal) - earthen basins with membrane liners and concrete abrasion pads under aerators

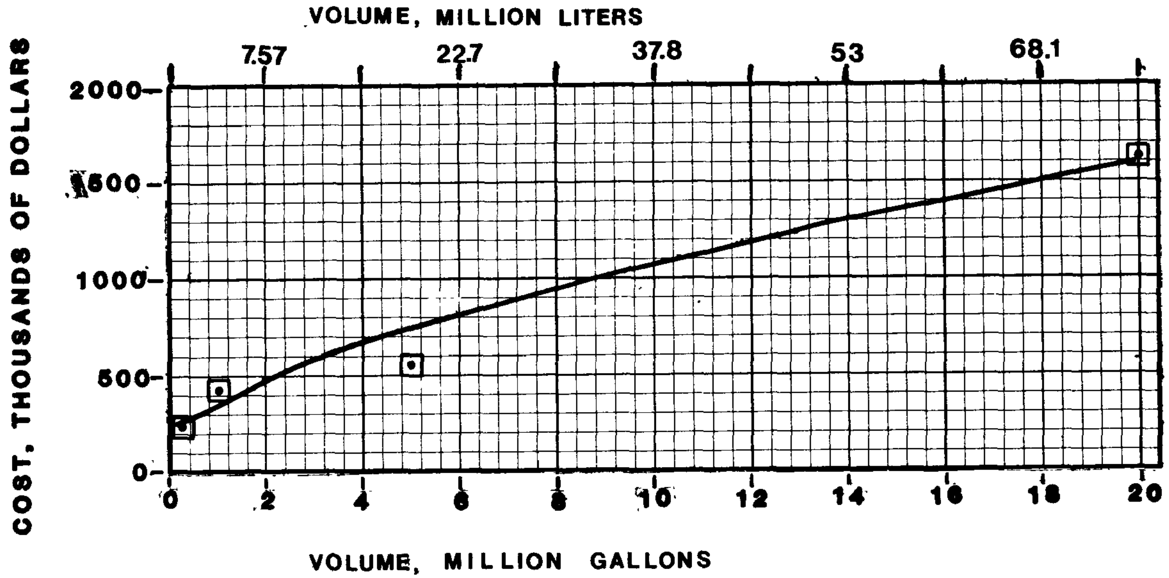


FIGURE IV.3.2.1-A2. CAPITAL COST ESTIMATE FOR ACTIVATED SLUDGE [4-10]

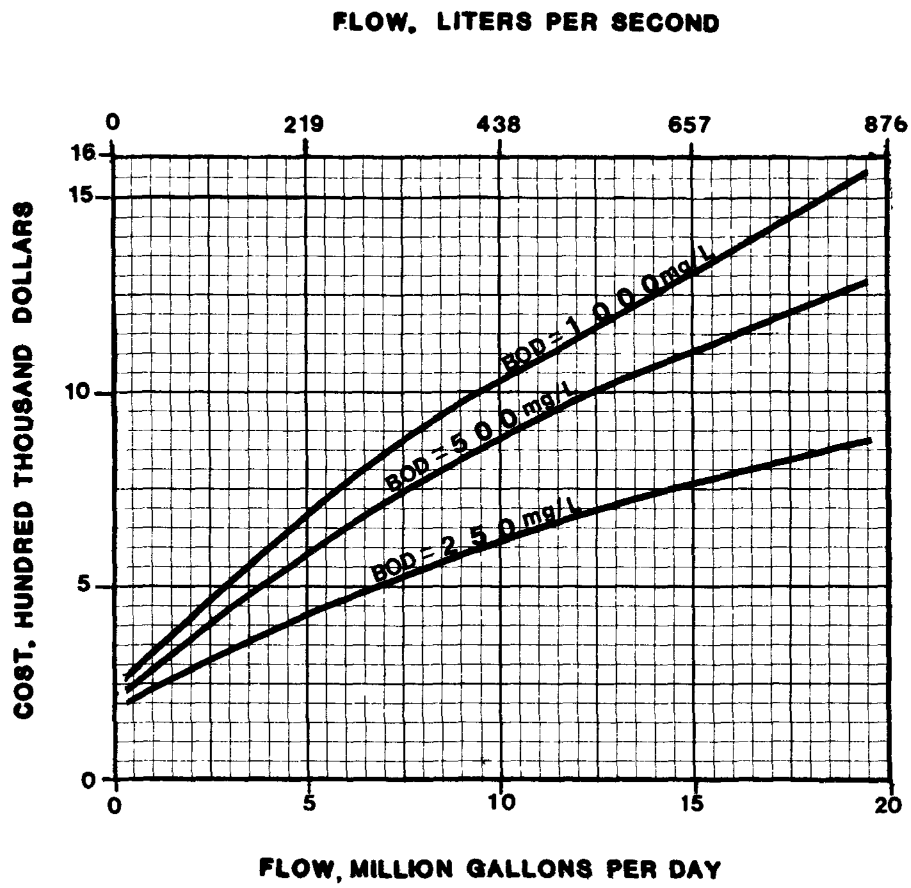


FIGURE IV.3.2.1-A3. CAPITAL COST VS FLOW AT VARIOUS INFLUENT BOD CONCENTRATIONS FOR ACTIVATED SLUDGE SYSTEMS OPERATING AT F/M = 0.3 AND MLVSS = 2500. [4-10]

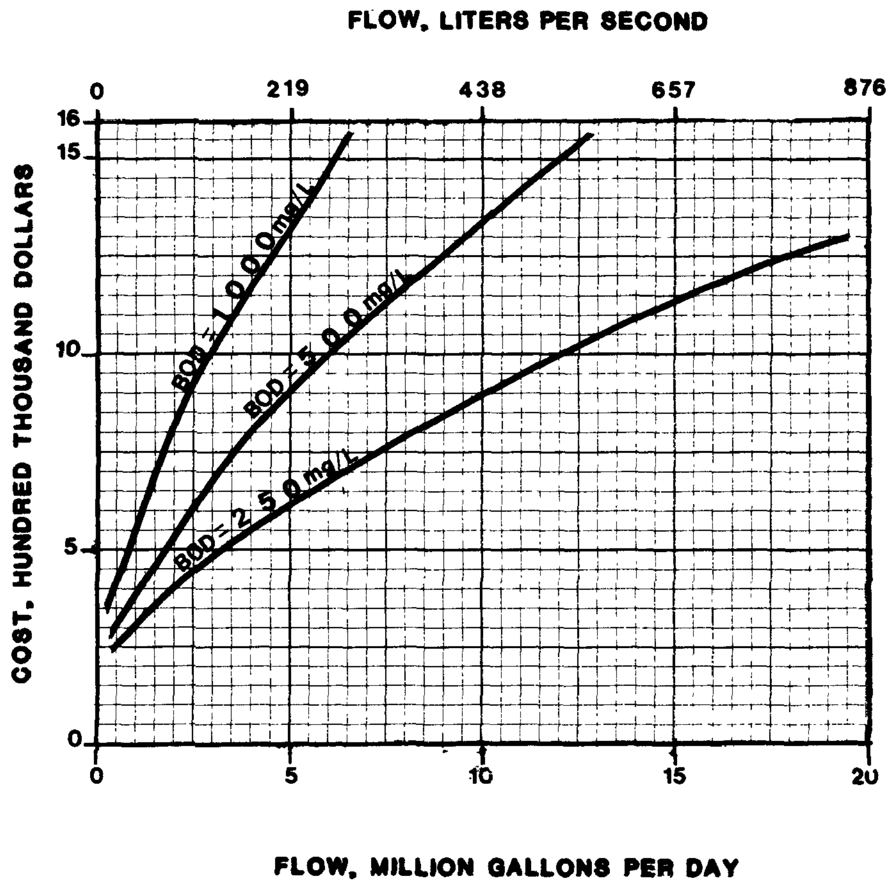


FIGURE IV.3.2.1-A4. CAPITAL COST VS FLOW AT VARIOUS INFLUENT BOD CONCENTRATIONS FOR ACTIVATED SLUDGE SYSTEMS OPERATING AT F/M = 0.1 AND MLVSS = 3500. [4-10]

Splitter box with two sluice gates
Sludge recycle pumps (two to three)
Piping
Instrumentation:
    Sludge wasting control
    Sludge recycle control
    Dissolved oxygen monitor
    Temperature monitor
    pH monitor and control
Defoamer storage and feed

b) Capital Cost Curves

i) Basin Volume Method

Curve - see Figure IV.3.2.1-A2.
- Cost (thousands of dollars) vs. basin volume (million liters or million gallons)
- Curve basis, cost estimates for systems at four flow rates: 8.76, 43.8, 219, and 876 L/s (0.2, 1.0, 5.0, and 20.0 mgd) and a detention time of 24 hours.

ii) Simplified Method

1. F/M ratio = 0.3 (activated sludge)
Curve - see Figure IV.3.2.1-A3
Cost (hundred thousand dollars) vs. flow (liters per second or million gallons per day)
- Curve basis, cost estimates for systems at three influent BOD levels: 250,500, and 1,000 mg/L, and a detention time based on the F/M ratio.

2. F/M ratio = 0.1 (extended aeration)
Curve - see Figure IV.3.2.1-A4
- Cost (hundred thousand dollars) vs. flow (liters per second or million gallons per day)
- Curve basis, cost estimates for systems at three influent BOD levels: 250,500, and 1,000 mg/L, and a detention time based on the F/M ratio.

c) Cost Index

Base Period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components.

Variable operating costs include power and defoaming agent. In addition, accounts of the need for nutrients, aeration requirements, and sludge generation should be kept for use in costing ancillary parts of the system. Fixed operating costs include labor, supervision, overhead, maintenance, laboratory labor, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Costs

i) Power Requirement (does not include aeration power) [4-1]. These equations were developed using regression analysis procedures.

Metric

$$KW = (0.127 \times FLOW) + 0.843$$

where: KW = power requirement, kilowatts
FLOW = influent flow, L/s

English

$$HP = (7.46 \times FLOW) + 1.13$$

where: HP = power requirement, Hp
FLOW = influent flow, mgd

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, $/day
24 = hours/day
EC = electricity cost, $/Kw-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, $/day
EC = electricity cost, $/Kw-hr
24 = hr/day
0.746 = Kw-hr/Hp-hr

iii) Defoamer Requirement, based on maintaining 0.5 mg/L in system

Metric

$$DF = (0.5 \times 10^{-6}) \times FLOW \times 86400$$

where: DF = defoamer requirement, Kg/day
0.5×10^{-6} = concentration of defoamer, Kg/L
FLOW = influent flow, L/s
86400 = seconds/day

English

$$DF = 0.5 \times FLOW \times 8.34$$

where: DF = defoamer requirement, lb/day
0.5 = concentration of defoamer, 0.5 mg/L
FLOW = influent flow, mgd
8.34 = conversion factor

iv) Defoamer Cost

$$DC = DF \times N$$

where: DC = defoamer cost, \$/day
N = price of defoaming agent, \$/Kg or \$/lb

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.2.1-A2, including values for the cost basis and the unit costs [4-11].

A 4. Miscellaneous Costs

Costs for engineering, and common plant items such as piping and buildings, are calculated after design and costing for all unit processes are completed (see Section IV.3.5). The aeration, nutrient addition, and land requirements, as well as the expected waste sludge generated are calculated during the activated sludge design in order to facilitate cost estimates for subsequent systems. Methods for computing these quantities are described below [4-1].

a) Aeration Oxygen Requirements

This is determined as the oxygen transfer in Kg/hr (lb/hr) required to maintain the level of biological activity in the system as designed (i.e., BOD removal, basin solids). The oxygen transfer should satisfy both the oxidation and endogenous uptake requirements.

TABLE IV.3.2.1-A2. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR ACTIVATED SLUDGE SYSTEMS [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.40 Weeks (9.60 hrs/day)	\$ 9.80/hr
Supervision (1)	10% Labor (0.96 hrs/day)	\$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.20 Shifts	\$10.70/hr
Maintenance	1.03% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.08 L/s (1.72 Thou gpd)	\$ 0.13/thou L (\$ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

Because performance is not addressed in the design equation presented in Section A 1,e, the user is responsible for making an independent estimate of BOD removal based on their understanding of the relative biodegradability of the waste. To aid the user in making this estimate, additional information on biological kinetics is presented in Section A 5,a. The reader is also referenced to Volume III Section III.3.2.1 for further information. Two methods for estimating aeration requirements are presented below. Use of the first method requires input generated in the basin volume capital cost estimating method while the second method requires no such special input.

i) Basin Volume Method

Metric

$$OR = (AP \times BODR) + (BP \times ENDOG)$$

where:
- OR = total oxygen requirement, Kg O_2/hr
- AP = oxygen required for BOD oxidation = 0.7 Kg O_2/Kg BOD (default value)
- BODR = BOD removed, Kg/hr = $(So - Se) \times FLOW \times 0.0036$
- So = influent BOD, mg/L
- Se = effluent soluble BOD, mg/L
- FLOW = influent flow, L/s
- 0.0036 = conversion, mg/s to Kg/hr
- BP = oxygen required for MLVSS oxidation, Kg O_2/hr/Kg MLVSS = $0.014 - (0.004 \times t)$, $BP \geq 0$
- t = detention time, days
- ENDOG = active biomass under aeration, Kg = $Xv \times BV \times 10^{-6}$
- Xv = MLVSS, mg/L
- BV = basin volume, L = $FLOW \times t$
- 10^{-6} = mg/Kg

English

$$OR = (AP \times BODR) + (BP \times ENDOG)$$

where:
- OR = oxygen requirement, lb O_2/hr
- AP = oxygen required for BOD oxidation = 0.7 lb O_2/lb BOD (default value)
- BODR = BOD removed, lb/hr = $(So - Se) \times FLOW \times 8.34 \div 24$
- So = influent BOD, mg/L
- Se = effluent soluble BOD, mg/L
- FLOW = design influent flow to system, mgd
- 8.34 = conversion factor
- 24 = hours/day

BP = oxygen required for MLVSS oxidation, lb O_2/hr/lb MLVSS,
= $0.014 - (0.004 \times t)$, $BP \geq 0$

t = detention time, days

ENDOG = the active biomass under aeration, lb
= $Xv \times BV \times 8.34$

Xv = mixed liquor volatile suspended solids, MLVSS, mg/L

BV = basin volume, million gallons
= $FLOW \times t$

The oxygen uptake rate is checked to assure that it is less than 100 mg/L/hr.

Metric

$$UT = OR \times 10^6 \div BV$$

where:
UT = oxygen uptake rate, mg/L/hr
OR = oxygen requirement, Kg/hr
BV = basin volume, L
10^6 = mg/Kg

English

$$UT = OR \div (BV \times 8.34)$$

where:
UT = oxygen uptake rate, mg/L/hr
OR = oxygen requirement, lb/hr
BV = basin volume, million gallons
8.34 = conversion factor

If the calculated uptake rate is greater than 100 mg/L/hr, then the basin volume is increased and another design investigated (e.g., Xv, t, or Se varied).

ii) Simplified Method

Oxygen requirements may also be estimated by the use of empirical oxygen requirement values from the literature. Some typical values are presented in Table IV.3.2.1-A3.

Metric

$$OR = O2RATE \times (So - Se) \times FLOW \times 0.0036$$

TABLE IV.3.2.1-A3. COMMON DESIGN AND OPERATING PARAMETERS OF SINGLE STAGE ACTIVATED SLUDGE SYSTEMS [4-12]

Process Type	BOD Loading @ 3000 mg/L MLSS mg BOD/day-L (lb BOD/day-1000 cu.ft.)	O_2 Required Kg O_2/Kg BOD removed or lb O_2/lb BOD removed	Waste Sludge Kg Sludge/Kg BOD removed or lb Sludge/lb BOD removed
Extended Aeration	780 - 1170 (10-15)	1.4 - 1.6	0.15 - 0.3
Conventional Activated Sludge	1560 - 4670 (20 - 60)	0.8 - 1.1	0.4 - 0.6
High Rate Activated Sludge	5450 - 14000 (70 - 180)	0.7 - 0.9	0.5 - 0.7
Single Stage Nitrification	780 - 2340 (10 - 30)	1.1 - 1.5	0.15 - 0.3

where: OR = total oxygen requirement, Kg/hr
O2RATE = required oxygen transfer, Kg O_2/Kg BOD removed.
So = influent BOD, mg/L
Se = effluent soluble BOD, mg/L
FLOW = influent flow, L/s
0.0036 = conversion, mg/s to Kg/hr

English

$$OR = O2RATE \times (So - Se) \times FLOW \times 8.34 \div 24$$

where: OR = total oxygen requirement, lb/hr
O2RATE = required oxygen transfer, lb O_2/lb BOD removed
So = influent BOD, mg/L
Se = effluent soluble BOD, mg/L
FLOW = influent flow, mgd
8.34 = conversion
24 = hours/day

b) Nutrients

Nutrient requirements may be estimated based on a BOD to nitrogen to phosphorus ratio of 100:5:1. If a deficiency is found, it is noted for subsequent use in designing the nutrient addition system (Section IV.3.2.1-C).

i) Nitrogen Required. This is determined by first calculating the effluent ammonia concentration from the activated sludge process.

$$EA = NH3 - (0.05 \times BOD)$$

where: EA = effluent ammonia concentration, mg/L
NH3 = average influent ammonia, mg/L
BOD = average influent BOD concentration, mg/L

- If EA ≥ 0, then no ammonia addition is required.
- If EA < 0, then ammonia addition is required.

Metric

$$AR = AD \times FLOW \times 0.086$$

where: AR = ammonia required, Kg/day
AD = ammonia deficit, mg/L
= -EA
= (0.05 × BOD) - NH3
FLOW = influent flow, L/s
0.086 = conversion factor

English

$$AR = AD \times FLOW \times 8.34$$

where: AR = ammonia required, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor

ii) Phosphorus Required. This is determined by first calculating the effluent phosphorus concentration from the activated sludge process.

$$EP = PO4 - (0.01 \times BOD)$$

where: EP = effluent phosphate concentration, mg/L
PO4 = average influent phosphate, mg/L
BOD = average influent BOD, mg/L

The phosphate requirement is checked at both the high and low ends of the BOD concentration range. If $EP < 0$, the additional phosphate required is calculated:

Metric

$$PR = PD \times FLOW \times 0.086$$

where: PR = phosphate required, Kg/day
PD = phosphate deficit, mg/L
= -EP
= (0.01 × BOD) - PO4
FLOW = influent flow, L/s
0.086 = conversion factor

English

$$PR = PD \times FLOW \times 8.34$$

where: PR = phosphate required, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor

c) Land

An activated sludge system is estimated to require land equal to 120% of the surface area of the aeration basin.

Metric

$$Land = BV \times 1.2 \times 0.001 \div DEPTH$$

where: Land = land required for activated sludge basin, m^2
BV = basin volume, liters
1.2 = factor for 20% additional land
0.001 = m^3/L
DEPTH = basin depth, m

English

$$\text{Land} = BV \times (1.2 \times 10^6) \div (7.48 \times \text{DEPTH})$$

where: Land = land required for activated sludge basin, ft^2
BV = basin volume, million gallons
1.2×10^6 = conversion factor including 20% allowance, million gallon to gallons
7.48 = conversion factor, gallon/ft^3
DEPTH = basin depth, ft

d) Sludge Generation

The amount of waste sludge generated by the process may be estimated either from empirical values such as those shown in Table IV.3.2.1-A3 or from estimated process conditions.

i) For conventional activated sludge system (detention $\leq$24 hours), the sludge generated is calculated as follows:

$$WS = (So - Se) \times 0.3 \times 1.18$$

where: WS = waste activated sludge, mg/L
So = influent BOD, mg/L
Se = effluent soluble BOD, mg/L
0.3 = net sludge produced per mg/L BOD removed
1.18 = ratio of MLSS to MLVSS (~ 85% volatile)

ii) For extended aeration (detention >24 hours), a reduced sludge generation is made.

$$NS = WS \times (1 - RSG)$$

where: NS = net sludge production, mg/L
WS = waste sludge computed for conventional activated sludge, as computed above, mg/L
RSG = reduced sludge generation factor
= $(t - 1) \times 24 \times 0.01$
t = hydraulic detenton, days
24 = hour/day
0.01 = adjustment factor representing 1% per hour reduction for detention time >24 hr.

iii) Sludge produced

Metric

$$SLUDGE = (NS \text{ or } WS) \times FLOW \times 0.086$$

where: SLUDGE = waste sludge produced, Kg/day
NS or WS = as defined above, mg/L
FLOW = influent flow, L/s
0.086 = conversion factor

English

$$SLUDGE = (NS \text{ or } WS) \times 8.34 \times FLOW$$

where: SLUDGE = waste sludge produced, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor

iv) For use of the simplified design procedures, estimates such as those in IV.3.2.1-A3 or other sources may be used to estimate sludge production.

Metric

$$SLUDGE = WSR \times (So - Se) \times FLOW \times 0.086$$

where: SLUDGE = waste sludge produced, Kg/day
WSR = waste sludge production rate, Kg sludge/Kg BOD removed
SO = influent BOD, mg/L
SE = effluent soluble BOD, mg/L

English

$$SLUDGE = WSR \times (So - Se) \times FLOW \times 8.34$$

where: SLUDGE = waste sludge produced, lb/day
WSR = waste sludge production rate, lb sludge/lb BOD removed

A 5. Modifications

a) Additional Design Considerations

In developing estimates for aeration requirements, sludge generation, and designs for subsequent treatment processes it is necessary that some estimate of the treatment efficiency of the activated sludge system be developed. Such an estimate may be as simple as an educated guess or as complicated as extensive experimentation and pilot plant operation. Many mathematical models have also been developed to simulate the activated sludge process. One such model, the modified Eckenfelder equation is briefly discussed below [4-1]:

i) Design Equation

This approach requires that the influent BOD be known, the biological kinetics rate constant (K factor) be known, and that a basin mixed liquor volatile solids (MLVSS) be known or assumed. It is also required that the conditions selected for the MLVSS be consistent with the detention time selected (or computed) and with the organic loading, using the food to microorganism (F/M) ratio [$F/M = So/(Xv \times t)$]. Another factor that is significant in the design is the temperature of the system. This will affect both the reaction kinetics and the oxygen transfer requirements.

One basic form of the modified Eckenfelder equation is:

$$t = (So^2 - So \times Se) \div (KT \times Xv \times Se)$$

where:
- t = detention time, day
- So = influent BOD, mg/L
- Se = effluent soluble BOD, mg/L
- Xv = mixed liquor volatile suspended solids, mg/L
- KT = (Eckenfelder) treatability factor, day^{-1} at temperature T (Note: this is a waste specific factor)

The waste conditions normally determine So and KT and the values of t, Xv, and Se are varied as necessary to maintain the system within one of the standard operational modes (e.g., activated sludge, extended aeration). Typical conditions for several of the standard operating modes are shown in Table IV.3.2.1-A1.

ii) Temperature Correction

The reaction rate, KT, is dependent upon the biodegradability characteristics of the waste and the temperature. The KT rate of BOD may be adjusted for the operating temperature of the basin as follows:

$$KT = K20 \times (1.07)^{(T - 20)}$$

where:
- KT = rate at operating temperature, day^{-1}
- K20 = rate at 20°C, day^{-1}
- T = operating temperature, °C

iii) Solids Check

When the influent TSS to the activated sludge basin is between 50 to 150 mg/L, there may be the need to provide pretreatment to avoid diluting the MLVSS with the influent solids. The maximum allowable influent solids is based on the MLVSS computed for the system [4-1].

$$ATSS = 25 + 0.05 \times Xv$$

where: ATSS = allowable influent TSS, mg/L
Xv = mixed liquor volatile suspended solids, mg/L

If the influent TSS > ATSS, then pretreatment to remove solids is recommended.

iv) Treatment Efficiency

The modified Eckenfelder equation may be rearranged in order to show treatment efficiency in terms of soluble BOD removal. Insoluble BOD removed is not considered in this equation.

$$\text{Efficiency} = 1 - (Se \div So)$$

$$= 1 - [(So - Se) \div (KT \times Xv \times t)]$$

If the other design variables are fixed, and Se is allowed to float, efficiency can be expressed as a function of the KT rate. Since KT rates are not available for most types of wastes and must be determined experimentally, it is often difficult to estimate designs and treatment efficiencies in the early stages of a project. If no KT rate is available for the waste of interest the following information may assist the user in understanding the relationship between KT rates and treatment efficiency:

1) The relative biodegradability of wastes in terms of modified Eckenfelder K rates may be broadly classified as follows:

Highly degradable	K20 = 20
Easily degradable	K20 = 10
Moderately degradable	K20 = 2
Slowly degradable	K20 = 0.5
Biostatic or toxic	K20 = 0

2) Figures IV.3.2.1-A5 and A6 represent the BOD removal efficiency of activated sludge units as a function of KT rates for the two sets of operating conditions used in the simplified design approach in Part A1,e,ii. Figure IV.3.2.1-A5 represents the BOD removal efficiency vs. KT

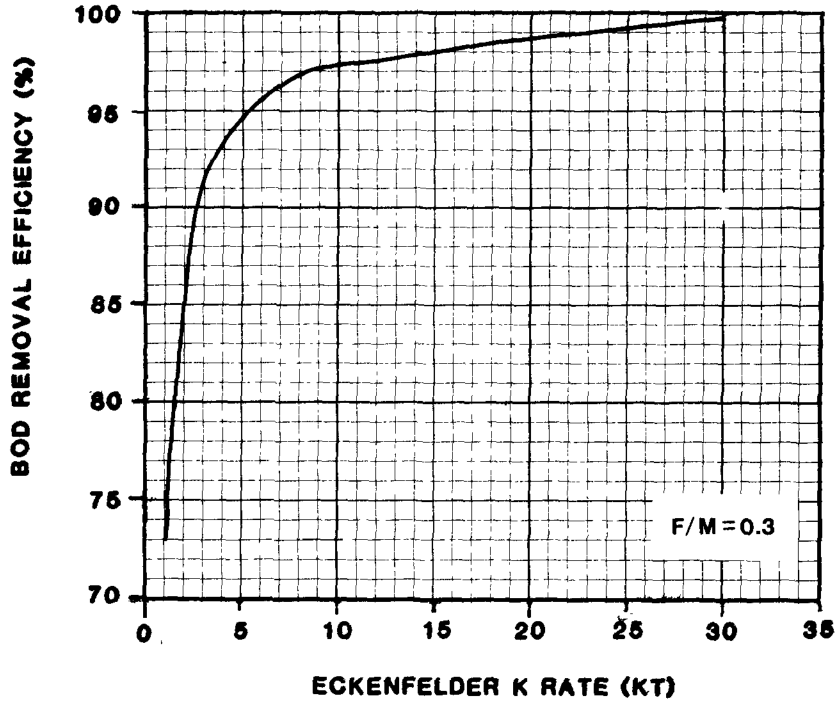


FIGURE IV.3.2.1-A5. BOD REMOVAL EFFICIENCY VERSUS MODIFIED ECKENFELDER K-RATE FOR F/M RATIO OF 0.3

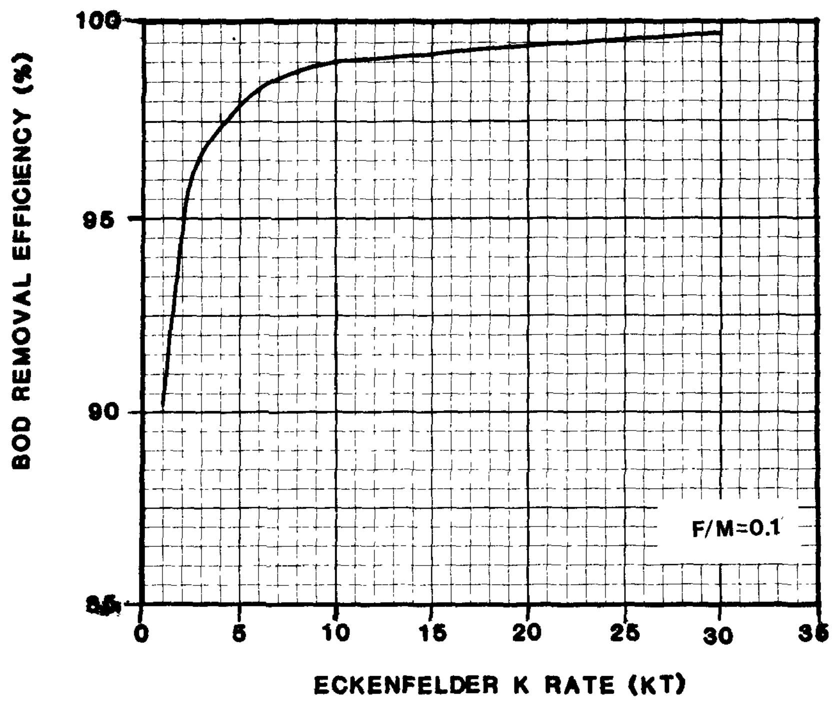


FIGURE IV.3.2.1-A6. BOD REMOVAL EFFICIENCY VERSUS MODIFIED ECKENFELDER K-RATE FOR F/M RATIO OF 0.1

rates for an activated sludge system operating at an F/M ratio of 0.3. Figure IV.3.2.1-A6 represents the BOD removal efficiency vs. KT rate for an activated sludge system operating at an F/M ratio of 0.1. These may be useful as general indicators of the potential performance of two common types of activated sludge systems.

ACTIVATED SLUDGE
SUMMARY WORK SHEET

REFERENCE: IV.3.2.1-A

I. DESIGN FACTOR		CAPITAL
a. Basin Volume = ______ million gallons b. FLOW = ______ mgd		
II. CAPITAL COST		
Cost = ______ (Cost from curve) × (______ (current index) ÷ 204.7) =		$ ______
III. VARIABLE O & M	$/day	O & M
a. Power = ______ (Hp) × ______ (EC, $/Kw-hr) × 17.9	= ______	
b. Defoamer = ______ (FLOW, mgd) × ______ (Defoamer, $/lb) × 4.17	= ______	
IV. FIXED O & M		
a. Labor: ______ (hr/day) × ______ ($/hr)	= ______	
b. Supervision: ______ (hr/day) × ______ ($/hr)	= ______	
c. Overhead: ______ (Labor, $/day) × ______ (%/100)	= ______	
d. Lab Labor: ______ (hr/day) × ______ ($/hr)	= ______	
e. Maint, Service, I&T: ______ (capital, $) × ______ % (%/100) ÷ 365 day/yr	= ______	
f. Service Water: ______ (thou gpd) × ______ ($/thou gal)	= ______	
V. YEARLY O & M	365 day/yr × ______ (sum $/day)	= ______ $/yr

VI. UNCOSTED ITEMS

a. Oxygen Transfer = ______ (OR) lb/hr

b. Ammonia = ______ (NH3) lb/day

c. Phosphorus = ______ (PO4) lb/day

d. Land = ______ (LAND) ft^2

e. Sludge Generated = ______ (SLUDGE) lb/day

ACTIVATED SLUDGE
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Capital Cost Index = ________

2. EC: Electricity Cost = ________ \$/Kw-hr

3. Defoamer Cost = ________ \$/lb

4. Labor = ________ \$/hr

5. Supervision = ________ \$/hr

6. Overhead = ________ % Labor ÷ 100 = ________ %/100

7. Lab Labor = ________ \$/hr

8. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor Sum = % ÷ 100 = ________ %/100

9. Service Water = ________ \$/thou gal

I. DESIGN FACTOR

a. Wastewater Characteristics

   FLOW ________________ mgd
   Inf. BOD (So) ________________ mg/L

b. Basin Volume Method

   1. F/M = ________
      Xv = ________ mg/L

   2. $t = \underset{\text{So, mg/L}}{\underline{\qquad\qquad}} \div (\underset{\text{Xv, mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{F/M}}{\underline{\qquad\qquad}}) = \underline{\qquad\qquad}$ days

   3. $BV = \underset{\text{t, days}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad}$ million gallons

c. Simplified Method

1. Select conditions:

Inf. BOD = ________ mg/L
F/M = ________
FLOW = ________ mgd

II. CAPITAL COST

a. For Basin Volume Method Use Figure IV.3.2.1-A2

Cost = $ ________

b. For Flow Method use either Figure IV.3.2.1-A3 or IV.3.2.1-A4

Cost = $ ________

III. VARIABLE O & M

a. Power = $(\underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 7.46) + 1.13 = \underline{\qquad\qquad}$ Hp

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Oxygen Transfer Requirement, Basin Volume Method

1. BODR = $(\underset{\text{So, mg/L}}{\underline{\qquad\qquad}} - \underset{\text{Se, mg/L}}{\underline{\qquad\qquad}}) \times (\underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}}) \times 0.348 = \underline{\qquad}$ lb/hr

2. BP = $0.014 - (0.004 \times \underset{\text{t, days}}{\underline{\qquad\qquad}}) = \underline{\qquad}$ lb O_2/hr/lb MLVSS, BP ≥ 0

3. BV (Basin Volume) = $\underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times \underset{\text{t, days}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad}$ million gallons

4. OR = $[0.7 \times \underset{\text{BODR, lb/hr}}{\underline{\qquad\qquad}}] + [\underset{\text{BP}}{\underline{\qquad\qquad}} \times (\underset{\text{Xv, mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{BV, mil gal}}{\underline{\qquad\qquad}} \times 8.34)]$

   = ________ lb/hr, oxygen transfer requirement

5. Oxygen Uptake Rate Check

   UT = $\underset{\text{OR, lb/hr}}{\underline{\qquad\qquad}} \div (\underset{\text{BV, mil gal}}{\underline{\qquad\qquad}} \times 8.34) = \underline{\qquad\qquad}$ mg/L/hr

If UT > 100 mg/L/hr, Basin volume must be increased and activated sludge system redesigned.

b. Oxygen Transfer Requirement, Simplified Method.

$$OR = \underset{\text{O2RATE}}{\underline{\qquad}} \times (\underset{\text{So, mg/L}}{\underline{\qquad}} - \underset{\text{Se, mg/L}}{\underline{\qquad}}) \times \underset{\text{FLOW, mgd}}{\underline{\qquad}} \times 0.348 = \underline{\qquad} \text{ lb/hr}$$

c. Ammonia Required

$$AR = [(0.05 \times \underset{\text{BOD, mg/L}}{\underline{\qquad}}) - \underset{\text{NH3 in, mg/L}}{\underline{\qquad}}] \times \underset{\text{FLOW, mgd}}{\underline{\qquad}} \times 8.34 = \underline{\qquad} \frac{\text{lb } NH_3}{\text{day}}$$

d. Phosphorus Required

$$PR = [(0.01 \times \underset{\text{BOD, mg/L}}{\underline{\qquad}}) - \underset{\text{PO4 in, mg/L}}{\underline{\qquad}}] \times \underset{\text{FLOW, mgd}}{\underline{\qquad}} \times 8.34 = \underline{\qquad} \frac{\text{lb } PO_4}{\text{day}}$$

e. Land Required

$$LAND = \underset{\text{BV, mil gal}}{\underline{\qquad\qquad}} \times 160{,}400 \div \underset{\text{DEPTH, ft}}{\underline{\qquad}} = \underline{\qquad} \text{ ft}^2$$

f. Sludge Generation

1. Activated Sludge

$$WS = [(\underset{\text{So, mg/L}}{\underline{\qquad}} - \underset{\text{Se, mg/L}}{\underline{\qquad}}) \times 0.354] = \underline{\qquad} \text{ mg/L}$$

2. Extended Aeration (WS based on above calculation)

$$NS = \underset{\text{WS, mg/L}}{\underline{\qquad}} \times [1.24 - (0.24 \times \underset{\text{t, day}}{\underline{\qquad}})] = \underline{\qquad} \text{ mg/L}$$

3. Sludge Mass

$$SLUDGE = \underset{\substack{\text{NS, t > 1 day} \\ \text{WS, t} \le \text{1 day}}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad}} \times 8.34 = \underline{\qquad} \text{ lb/day}$$

g. Simplified Sludge Estimate

$$SLUDGE = \underset{\text{WSR, lb/lb}}{\underline{\qquad}} \times (\underset{\text{So, mg/L}}{\underline{\qquad}} - \underset{\text{Se, mg/L}}{\underline{\qquad}}) \times \underset{\text{FLOW}}{\underline{\qquad}} \times 8.34 =$$

$$\underline{\qquad\qquad} \text{ lb/day}$$

IV.3.2.1-B. Aeration

Introduction

Aeration is a necessary component for aerobic, biological wastewater treatment processes. Available methods included mixing technologies (surface or submerged mixers) and diffused air systems (air or oxygen). The aeration technology is not specifically discussed in Volume III of the Treatability Manual, but it is included in discussions on Activated Sludge (Section III.3.2.1), Nitrification (Section III.3.2.3), and Digestion (Section III.3.4.2).

B 1. Basis of Design

This presentation is for design and costing of low speed, platform mounted surface turbine aerators for biological wastewater treatment systems. Factors influencing the design of an aeration system include: basin volume, oxygen transfer requirements, and mixing requirements. Aeration systems are designed in this method to maintain at least 2.0 mg/L dissolved oxygen in the basin at 30°C with a maximum transfer rate limit of 100 mg O_2/L-hr. The power required to effect the necessary oxygen transfer and the power required to maintain mixing in the basin are calculated and the larger of these values is selected as the basis of design. System costs are estimated on the basis of the number of aerators required and the cost of each aerator where cost per aerator is a function of its power rating. An initial estimate of the number of aerators and individual power rating of the aerators may be made by the user. Supplemental information on considerations such as commercially available sizes, spacing and basin surface coverage are presented in Section B5, Modifications.

a) Source

This cost estimate method was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries.

b) Required Input Data

Wastewater flow, L/s (mgd)
Oxygen Requirements of the unit processes, Kg O_2/hr (lb O_2/hr)
Volume of basin for which aeration system being designed, million liters (million gallons)

c) Limitations

The following limitations on the design of aeration systems are assumed [4-2]:

maximum 75 KW (100 Hp)/aerator
minimum 4 KW (5 Hp)/aerator
maximum transfer rate, 100 mg O_2/L-hr
minimum power for mixing, 20 KW/million liters (0.1 Hp/1000 gal)
minimum dissolved oxygen in basin, 2.0 mg/L

d) Pretreatment

Not Applicable.

e) Design Equation

The principal factor used in the design and costing of aeration systems is the power per aerator. This is a function of required oxygen transfer, mixing, temperature, and other factors discussed in Section B5. The power per aerator is based on the total number of units required to provide the total power requirement. The total power requirement is selected as the larger of the oxygen transfer or mixing requirement.

i) Total Power Requirements

- Total Power for Oxygen Transfer (at 30°C)

Metric

$$TKW = OR \div (1.02 \times 0.476)$$

where: TKW = total aeration power, KW
OR = Oxygen transfer requirement for the unit process, Kg O_2/hr (from activated sludge or nitrification designs)
1.02 = standard oxygen transfer rate, Kg O_2/KW-hr
0.476 = conversion factor for standard to actual oxygen transfer adjustment at 30°C (limiting case conditions)

English

$$THP = OR \div (3.0 \times 0.476)$$

where: THP = total aeration horsepower, Hp
OR = Oxygen transfer requirement for the unit process, (lb O_2/hr) (from activated sludge, or nitrification designs)
3.0 = standard oxygen transfer rate, lb O_2/Hp-hr
0.476 = conversion factor for standard to actual oxygen transfer adjustment at 30°C (limiting case conditions)

• Total Power for Mixing

Metric

$$TKWC = 20 \times BV$$

where: TKWC = total power required for mixing, KW
20 = minimum mixing power, KW/million liters
BV = basin volume, million liters

English

$$THPC = 0.1 \times BV \times 1,000$$

where: THPC = total horsepower required for mixing, Hp
0.1 = minimum mixing power, 0.1 Hp/1000 gallons
BV = basin volume, million gallons

• Total Power = greater value TKW or TKWC, (THP or THPC)

ii) Power Per Aerator

Metric

$$IKW = \text{Total Power} \div n$$

where: IKW = individual aerator size, KW
Total Power = total power requirement, KW
n = number of aerators

English

$$IHP = \text{Total Horsepower} \div n$$

where: IHP = individual aerator size, horsepower
Total Horsepower = total power requirement, Hp
n = number of aerators

The number of aerators may be estimated or selected based on total power requirements, commercially available aerator sizes, basin geometry, and aerator spacing. This is explained in more detail in Section B 5, Modifications.

f) Subsequent Treatment

Not Applicable

B 2. Capital Costs

The power per individual aerator is the principal cost factor necessary in estimating capital costs. The total cost is then developed by multiplying the cost per aerator derived from the cost curve (Figure IV.3.2.1-B1) by the number of aerators necessary. Costs estimated using these curves must be adjusted to a current value using an appropriate current cost index.

a) <u>Cost Data</u>

Items included in the capital cost curve estimates are as follows [4-2]:

Fixed mounted, low speed, turbine surface aerator
Platform support concrete piers, steel supports
Concrete abrasion pad
Railing and grating
Instrumentation

b) <u>Capital Cost Curve</u>

Curve - see Figure IV.3.2.1-B1.
- Cost (thousands of dollars) vs. Power per Aerator (kilowatts or horsepower)
- Curve basis, cost estimate on four standard size aerators 0.75, 7.5, 37 and 75 Kw (1, 10, 50, and 100 horsepower).

Scale factor
- The total cost is equal to the cost per aerator multiplied by the number of aerators required.

Total Cost = n × Cost per Aerator

c) <u>Cost Index</u>

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

B 3. Operation and Maintenance Costs

Operating costs are comprised of both variable and fixed components. Aerator power requirement is the only variable operating cost. Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) <u>Variable Cost</u>

i) Power Requirements = Total Power Requirements (see Section B 1,e, Design Equation)

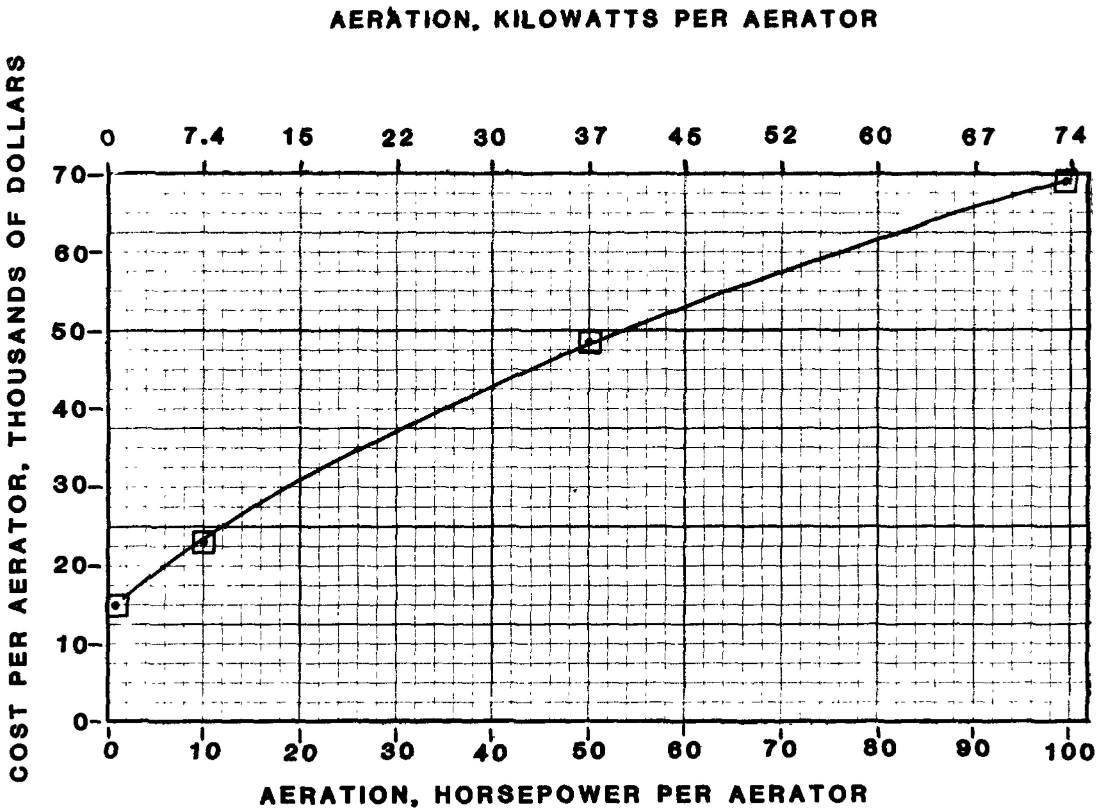


FIGURE IV.3.2.1-B1. CAPITAL COST ESTIMATE FOR AERATION [4-10]

ii) Power Cost

Metric

$$PC = (TKW \text{ or } TKWC) \times 24 \times EC$$

where: PC = power cost, $/day
TKW = total aerator power, KW
TKWC = total power required for mixing, KW
24 = hr/day
EC = electricity cost, $/KW-hr

English

$$PC = (THP \text{ or } THPC) \times 24 \times 0.746 \times EC$$

where: PC = power cost, $/day
THP = total aerator horsepower, Hp
THPC = total horsepower required for mixing, Hp
24 = hr/day
0.746 = KW-hr/Hp-hr
EC = electricity cost, $/Kw-hr

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.2.1-B1 [4-11].

B 4. Miscellaneous Costs

Costs for engineering, and common plant items such as piping and buildings, are calculated after the completion of costing for individual units (see Section IV.3.5). Aeration basins are costed in other technology sections.

B 5. Modification

The number and arrangement of aerators may be determined by considering the total power requirements, basin geometry, commercially available sizes of aerators, spacing, and circle of influence of the individual aerators.

a) Oxygen Transfer Performance Correction

A typical value of 1.02 Kg O_2/KW-hr (3.0 lb O_2/Hp-hr) is used for the standard oxygen transfer rate in the design equation. The standard oxygen transfer rate is based on tap water at 20°C. The correction factor included to convert the oxygen transfer rate to field conditions was computed using the following equation:

$$Na = NT \div [(\beta \times CSS - CL) \div 9.17] \times (1.025)^{T - 20} \times (\alpha)$$

TABLE IV.3.2.1-B1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR AERATION [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.10 Weeks (2.40 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.24 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.00 Shifts	$10.70/hr
Maintenance	5.24% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.00 Thou L (0.00 Thou gpd)	$ 0.13/Thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

where: Na = field condition oxygen transfer, Kg/KW-hr or lb/Hp-hr
NT = standard condition oxygen transfer, Kg/KW-hr or lb/Hp-hr
β = salinity - surface tension correction factor
CSS = oxygen saturation concentration for wastewater at given atmospheric conditions and temperature, mg/L
CL = operating oxygen concentration, mg/L
T = temperature, ^{o}C
α = oxygen transfer correction factor for wastewater
9.17 = saturation dissolved oxygen at 20°C, mg/L

The field oxygen transfer correction factor calculated for use in this design method is based on a basin temperature of 30°C using the conditions indicated below.

$$Na = 0.476 \times NT$$

where: Na = field condition oxygen transfer rate Kg/KW-hr or lb/Hp-hr
NT = standard condition oxygen transfer rate, Kg/KW-hr or lb/Hp-hr
β = 0.9
CSS = 7.63 mg/L at 30°C
CL = 2.0 mg/L
T = 30°C (worst case condition)
α = 0.7

The correction factor may be calculated for other operating conditions by substituting the appropriate conditions.

b) Total Power Requirements

The power required both for oxygen transfer and for adequate mixing is estimated. Mixing power and aeration power are compared and the greater power requirement is chosen for design and costing. The determination of total power requirements was discussed previously (Section B 1,e, Design Equation).

c) Surface Area and Basin Geometry

The surface area of the aeration basin affects the number and arrangement of individual aerators. The surface area of a basin of given volume is determined in the following manner:

i) For basin volumes <4.16 million liters (1.1 million gallons) the surface area is determined as follows (assuming a square basin, with vertical walls):

Metric

$$SA = BV \times 10^6 \div (1000 \times D)$$

where: SA = surface area, m^2
BV = basin volume, million liters
1000 = L/m^3
D = basin depth, m
(assumed to be 3.66 m)

English

$$SA = BV \times 10^6 \div (7.48 \times D)$$

where: SA = basin surface area, ft^2
BV = basin volume, million gallons
7.48 = conversion factor, gallon/ft^3
D = basin depth, ft
(assumed to be 12 ft)

ii) For basin volumes >4.16 million liters (1.1 million gallons) the surface area is determined as follows (assuming a rectangular basin with L = 2W, and 2:1 side slopes):

$$SA = L \times W$$
$$= L^2 \div 2$$

where: SA = basin surface area, m^2 or ft^2
W = basin width, m or ft
L = basin length, m or ft

Using the conditions stated above for side slopes and assuming a 3.66 m (12 ft) depth, the relationship between flow and length is computed as follows:

Metric

$$L = [(2 \times BV \times 10^6) \div (3660) - 53.5]^{0.5} - 11$$

where: L = length of basin at the water level, m
BV = basin volume, million liters

English

$$L = [(2 \times BV \times 10^6) \div (7.48 \times 12) - 576]^{0.5} - 36$$

where: L = length of the basin at the water level, ft
BV = basin volume, million gallons

d) Individual Aerator Power Selection

The number of individual aerators, required power rating of each unit, and adjustment of the size to agree with commercially available units is determined as follows:

i) Four aerators are initially assumed and the individual power is estimated. A minimum of 3.73 KW (5.0 Hp) per aerator and 3 aerators per basin are required.

$$IP = TP \div n$$

where: IP = individual power, IKW or IHP
TP = total power, TKW or TKP
n = number of aerators

ii) The calculated individual power ratings are converted to the next larger commercially available size. The sizes as used in this case are: 5, 7.5, 10, 15, 20, 30, 40, 50, 60, 75, and 100 horsepower. Metric equivalents are: 3.7, 5.6, 7.5, 11, 15, 22, 30, 37, 45, 56, and 75 KW.

If the calculated IP value is ≥75 KW (100 Hp), then the number of aerators is increased by two and a new IP is calculated until it is less than 75 KW (100 Hp).

e) Aerator Placement/Spacing

The selected number and size of the aerators is examined to ensure that the entire basin surface can be aerated. This requires that the center-to-center spacing of the aerators be estimated and compared to the circle of influence for the selected aerator size. The number of aerators then must be adjusted to ensure complete basin coverage.

i) The aerator spacing is determined as follows:

$$AERSP = (SA \div n)^{0.5}$$

where: AERSP = the center-to-center aerator spacing, m or ft
SA = basin surface area, m^2 or ft^2
n = number of aerators

This calculation models each aerator as a square covering an area of SA/n. It assumes that a symmetrical layout is used in a rectangular basin (i.e., an even number of aerators).

ii) The circles of influence of various size aerators were related by linear regression techniques as follows:

Metric

- If IKW < 11.2 Kw

$$COI = (1.66 \times IKW) + 3.96$$

- If IKW ≥ 11.2 Kw

$$COI = (0.233 \times IKW) + 19.2$$

where: COI = diameter (circle of influence), m
IKW = individual aerator power, KW

English

- If IHP < 15 Hp

$$COI = (4.07 \times IHP) + 13.0$$

- If IHP ≥ 15 Hp

$$COI = (0.571 \times IHP) + 63.0$$

where: COI = diameter (circle of influence), ft
IHP = individual power of aerators

iii) The aerator spacing and circle of influence are compared for the final selection of a design condition.

- If COI ≥ AERSP:
  leave n and IKW (IHP) as originally calculated

- If COI < AERSP:
  increase n by two and recalculate IKW (IHP), AERSP and COI

AERATION
SUMMARY WORK SHEET

REFERENCE: IV.3.2.1-B

I. DESIGN FACTOR — CAPITAL

Horsepower per Aerator = ________ Hp; Number = ________

II. CAPITAL COST

Cost = ________ (Cost from curve) × ________ (number of aerators)

× (________ (current index) ÷ 204.7) = $________

III. VARIABLE O & M — $/day — O & M

a. Power = ________ (Hp) × ________ (EC, $/Kw-hr) × 17.9 = ________

IV. FIXED O & M

a. Labor: ________ (hr/day) × ________ ($/hr) = ________

b. Supervision: ________ (hr/day) × ________ ($/hr) = ________

c. Overhead: ________ (Labor, $/day) × ________ (%/100) = ________

d. Lab Labor: ________ (hr/day) × ________ ($/day) = ________

e. Maint, Service, I&T: ________ (capital, $) × ________ (%/100) ÷ 365 (day/yr) = ________

f. Service Water: ________ (thou gpd) × ________ ($/thou gal) = ________

V. YEARLY O & M

365 (day/yr) × ________ (sum $/day) = ________ ($/yr)

VI. UNCOSTED ITEMS

AERATION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Capital Cost Index = ________

2. EC = Electricity Cost = ________ $/Kw-hr

3. Labor = ________ $/hr

4. Supervision = ________ $/hr

5. Overhead = ________ % Labor ÷ 100 = ________%/100

6. Lab Labor = ________ $/hr

7. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor Sum = ________ ÷ 100 = ________%/100

8. Service Water = ________ $/thou gal

I. DESIGN FACTOR

a. Total Horsepower Required for Oxygen Transfer

   THP = $\dfrac{\text{oxygen transfer requirement, lb/hr}}{}$ ÷ 1.43 = ________ Hp

   (blank: oxygen transfer requirement, lb/hr)

b. Total Horsepower Required for Mixing

   THPC = ________ × 100 = ________ Hp
   (blank: basin volume, mil gal)

c. Total Horsepower = greater of THP or THPC = ________ Hp

d. Initial Estimate of Individual Aerator Horsepower

   IHP = ________ ÷ ________ = ________ Hp
   (blanks: Total Horsepower, Hp; number aerators)

   minimum, 5 Hp per aerator and 3 aerators per basin

e. convert Aerators to next larger commercial size

   IHP = 5, 7.5, 10, 15, 20, 30, 40, 50, 60, 75, 100

   IHP = ________ Hp

f. Basin Geometry (surface area)

1. If basin volume < 1.1 million gallons, square

$$SA = \underset{BV,\ mil\ gal}{\underline{\qquad\qquad}} \times 11{,}100 = \underline{\qquad\qquad}\ ft^2$$

2. If basin volume > 1.1 million gallons, rectangular

$$SA = [(\underset{BV,\ mil\ gal}{\underline{\qquad\qquad}} \times 22{,}300 - 576)^{0.5} - 36\ ]^2 \div 2 = \underline{\qquad\qquad}\ ft^2$$

g. Check Aerator Spacing

1. $$AERSP = (\ \underset{SA,\ ft^2}{\underline{\qquad\qquad}} \div \underset{number\ aerators}{\underline{\qquad\qquad\qquad}}\ )^{0.5} = \underline{\qquad\qquad}\ ft$$

2. If IHP < 15 Hp

$$COI = 4.07 \times \underset{IHP,\ Hp}{\underline{\qquad\qquad}} + 13 = \underline{\qquad\qquad}\ ft$$

If IHP $\geq$ 15 Hp

$$COI = 0.571 \times \underset{IHP,\ Hp}{\underline{\qquad\qquad}} + 63 = \underline{\qquad\qquad}\ ft$$

3. If COI $\geq$ AERSP, leave n and IHP

If COI < AERSP, increase n and go back to step d.

II. CAPITAL COST

III. VARIABLE O & M

$$Power = \underset{IHP,\ Hp}{\underline{\qquad\qquad}} \times \underset{Number\ aerators}{\underline{\qquad\qquad\qquad}} = \underline{\qquad\qquad}\ Hp$$

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

IV.3.2.1-C. Nutrient Addition

Introduction

A nutrient addition system may be required for biological unit processes to provide sufficient nitrogen and phosphorous in the wastewater to ensure that neither nutrient becomes the limiting factor in the biological growth reactions. The nutrient addition technology is not discussed specifically in Volume III of the Treatability Manual, but it may be required for biological treatment (Section III.3.2).

C 1. Basis of Design

This presentation is for the addition of ammonia and phosphorus to biological wastewater treatment systems in order to maintain the proper nutrient balance. Systems of the type considered are represented in Figure IV.3.2.1-C1. The principal cost and design factor is the amount of each nutrient required per day. The nutrient addition systems are designed to serve the needs of the whole plant, rather than one unit process. Therefore, the nutrient requirements for all biological processes in the system should be summed in order to arrive at the proper design sizing for any nutrient addition system. Nutrient requirements may be accounted for in two ways: (1) the mass requirements of each unit process may be calculated individually and summed, or (2) the effluent concentration deficit of each nutrient may be calculated for each unit process, and the concentration of ammonia and phosphorus needed to make up the deficit determined at the end of the last biological process based on the sum of the deficits from all preceding units.

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

These are two input data possibilities.

i) Sum of previously calculated ammonia and phosphorus requirements for all biological processes, Kg/day (lb/day).

ii) Wastewater flowrate L/s (mgd) and ammonia and phosphorus deficit concentrations (mg/L).

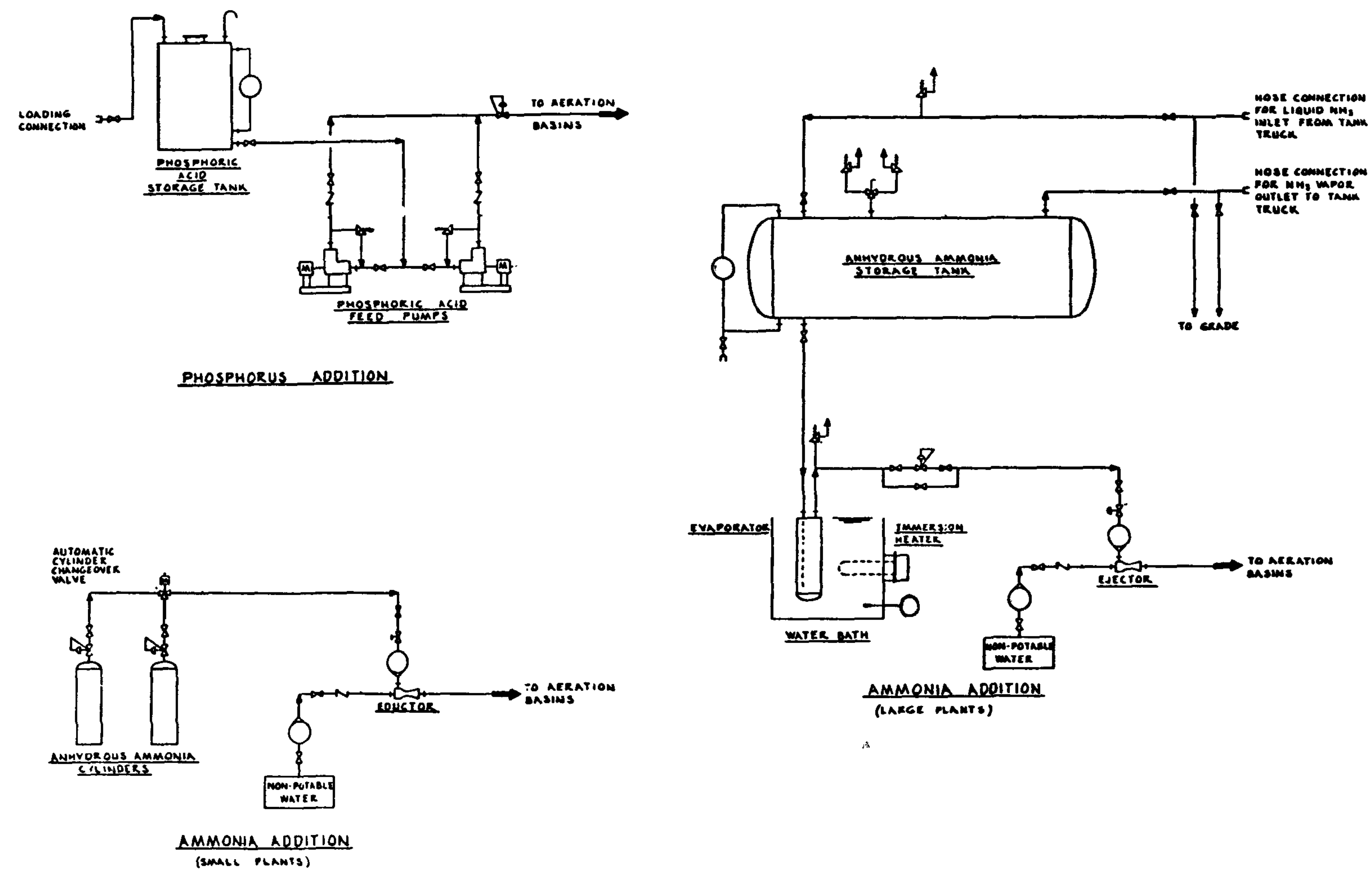


FIGURE IV.3.2.1-C1. PROCESS FLOW DIAGRAM FOR NUTRIENT ADDITION (AMMONIA AND PHOSPHORUS) [4-1]

c) Limitations

Nutrient addition is unnecessary if sufficient amounts of required nutrients are already present in the wastewater.

d) Pretreatment

None required.

e) Design Equation

Nutrient requirements may be based on the deficit in the final effluent. It is also possible to sum the calculated mass nutrient requirements for each affected unit process. Both methods are presented below.

i) Ammonia Requirement

- Summation method

$$NRQD = \Sigma\, AR$$

where: NRQD = total required ammonia, Kg/day or lb/day
AR = ammonia required for unit process, Kg/day or lb/day
(from the design of the unit processes)

- Concentration method (deficit)

Metric

$$NRQD = FLOW \times 0.086 \times NABS$$

where: NRQD = total required ammonia, Kg/day
FLOW = influent flow, L/s
0.086 = conversion factor
NABS = absolute value of the ammonia deficit concentration, mg/L

English

$$NRQD = FLOW \times 8.34 \times NABS$$

where: NRQD = total required ammonia, lb/day
FLOW = influent flow, mgd
8.34 = conversion factor
NABS = absolute value of the ammonia deficit concentration, mg/L

ii) Phosphorus Requirement

- Summation method

$$PREQD = \Sigma\ PR$$

where: PREQD = total required phosphorus (as PO_4), Kg/day or lb/day
PR = phosphorus requirement for unit process, Kg/day or lb/day (from the design of the unit processes)

- Concentration method

Metric

$$PREQD = FLOW \times 0.086 \times PABS$$

where: PREQD = total required phosphorus (as PO_4), Kg/day
FLOW = influent flow, L/s
0.086 = conversion factor
PABS = absolute value of the phosphorus deficit concentration, mg/L

English

$$PREQD = FLOW \times 8.34 \times PABS$$

where: PREQD = total required phosphorus (as PO_4), lb/day
FLOW = influent flow, mgd
8.34 = conversion factor
PABS = absolute value of the phosphorus deficit concentration, mg/L

f) Subsequent Treatment

None specified.

C 2. Capital Costs

The quantity of ammonia and phosphorus added per day is the principal cost factor in nutrient addition. The capital cost of ammonia and phosphorus addition systems is shown as a function of the amount of nutrient added in Figures IV.3.2.1-C2 and IV.3.2.1-C3 respectively. Costs estimated using these curves must be adjusted to a current value using an appropriate current cost index.

a) Cost Data

Items included in capital cost curve estimates are described below [4-2].

i) Ammonia

Metric

Ammonia storage tank:

System Flow	Storage Capacity
0 - 8.76 L/s	68 Kg cylinders
8.76 - 43.8 L/s	1030 liters
43.8 - 219 L/s	2720 liters
>219 L/s	8330 liters

Evaporator (for systems >8.76 L/s)
Metering pumps (all wetted parts glass or stainless)
Instrumentation, piping

English

Ammonia storage tank:

System Flow	Storage Capacity
0 - 0.2 mgd	150 lb cylinders
0.2 - 1.0 mgd	272 gallons
1.0 - 5.0 mgd	720 gallons
>5.0 mgd	2200 gallons

Evaporator (for systems >0.2 mgd)
Metering pumps (all wetted parts glass or stainless)
Instrumentation, piping

ii) Phosphorus

Phosphoric acid storage tank, 878 L or 232 gal, all flows
Metering Pumps (all wetted parts glass or stainless)
Instrumentation, piping

b) Capital Cost Curves

i) Ammonia Curve - see Figure IV.3.2.1-C2
- Cost (thousands of dollars) vs. nutrient (Kg/day or lb/day of ammonia).
- Curve basis, cost estimates at four flowrates 8.76, 43.8, 219, and 876 L/s (0.2, 1.0, 5.0, and 20 mgd).

ii) Phosphorus Curve - see Figure IV.3.2.1-C3
- Cost (thousands of dollars) vs. nutrient (Kg/day or lb/day phosphorus).
- Curve basis, cost estimates at four flowrates 8.76, 43.8, 219, and 876 L/s (0.2, 1.0, 5.0, and 10 mgd).

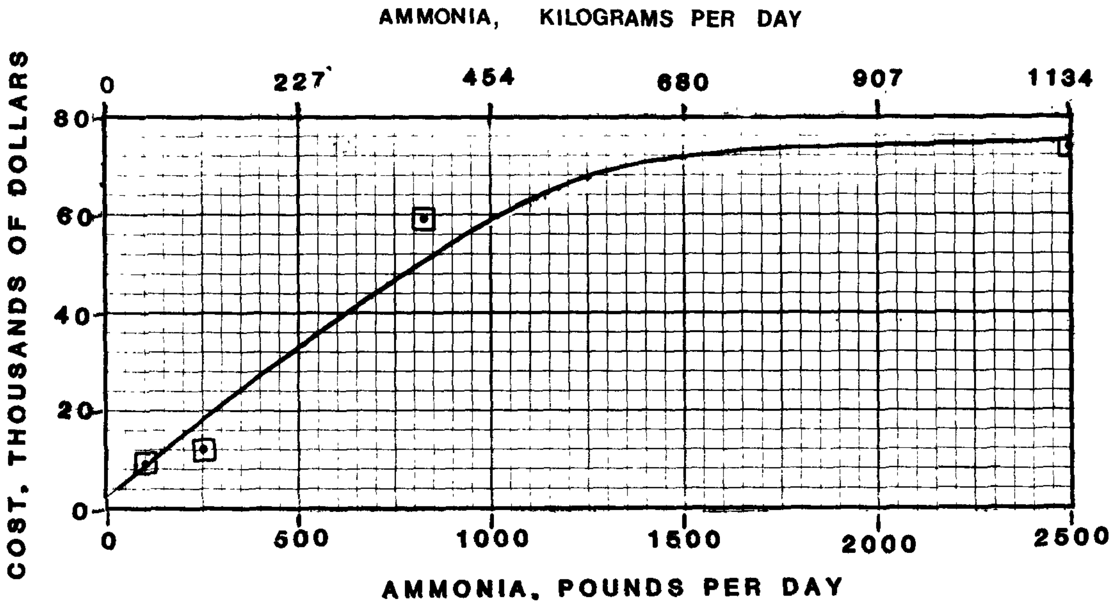


FIGURE IV.3.2.1-C2. CAPITAL COST ESTIMATE FOR NUTRIENT ADDITION (AMMONIA) [4-10]

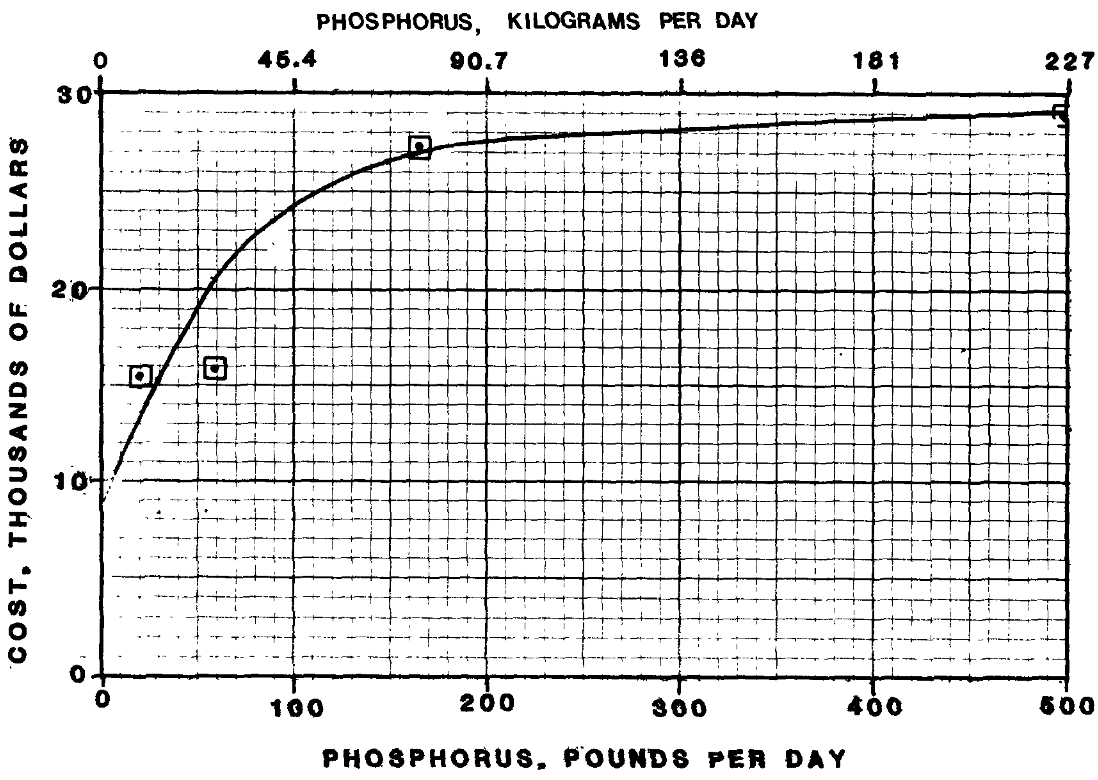


FIGURE IV.3.2.1-C3. CAPITAL COST ESTIMATE FOR NUTRIENT ADDITION (PHOSPHORUS) [4-10]

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

C 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. Nutrient chemical usage constitutes the only significant variable cost. The cost per Kg or lb of phosphoric acid remains relatively constant while the cost per Kg or lb of ammonia can vary significantly depending on whether it is delivered in cylinders or bulk tanks. Labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water are the fixed operating costs. All operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Costs

i) Power Requirements - minimal, not included in cost estimate

ii) Chemical Requirements - see Section C 1,e, Design Equation

iii) Chemical Costs, ammonia and phosphoric acid

$$CC = Q \times N$$

where: CC = Chemical cost, \$/day
Q = calculated requirement for nutrient, Kg/day or lb/day
N = unit cost of nutrient, \$/Kg or \$/lb

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.2.1-C1, including values for the cost basis and unit costs for both ammonia and phosphorus addition [4-11].

C 4. Miscellaneous Costs

Costs for engineering, and other common plant items such as piping and buildings, are calculated after the completion of costing for individual units (see Section IV.3.5).

C 5. Modifications

None.

TABLE IV.3.2.1-C1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR AMMONIA AND PHOSPHORUS ADDITION [4-11]

Ammonia Addition

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.5 Weeks (1.20 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.12 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.10 Shifts (0.57 hrs/day)	$10.70/hr
Maintenance	0.00% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.757 L/s (17.28 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

Phosphorus Addition

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.05 Weeks (1.20 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.12 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.00 Shifts	$10.70/hr
Maintenance	3.94% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.00 L/s (0.00 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).
(2) One week = 7 days = 168 hours = 4.2 shifts
(3) One shift = 40 hours

AMMONIA ADDITION
SUMMARY WORK SHEET

REFERENCE: IV.3.2.1-C

I. DESIGN FACTOR — CAPITAL

Ammonia = ________ lb/day, required for activated sludge

II. CAPITAL COST

Ammonia: $ ______________ (cost from curve) × (______________ (current index) ÷ 204.7) = $ ________

III. VARIABLE O & M — $/day — O & M

Ammonia Cost:

AC = ______________ (Ammonia lb/day) × __________ (Ammonia $/lb) = ________

IV. FIXED O & M

a. Labor: ________ (hr/day) × ________ ($/day) = ________

b. Supervision: ________ (hr/day) × ________ ($/hr) = ________

c. Overhead: ________ (Labor, $/day) × ________ (%/100) = ________

d. Lab Labor: ________ (hr/day) × ________ ($/hr) = ________

e. Maint, Service, I&T: ________ (capital, $) × ________ (%/100) ÷ 365 (day/yr) = ________

f. Service Water: ________ (thou gpd) × ________ ($/thou gal) = ________

V. YEARLY O & M — 365 (day/yr) × ________ (sum $/day) = ________ ($/yr)

VI. UNCOSTED ITEMS

PHOSPHORUS ADDITION
SUMMARY WORK SHEET

REFERENCE: IV.3.2.1-C

I. DESIGN FACTOR

CAPITAL

$PO_4 = \Sigma$ ______ (act sldg) + ______ (nitri) + ______ (denit) = ______ lb/day

II. CAPITAL COST

PO_4 = $ ______ (cost from curve) × (______ (current index) ÷ 204.7) = $ ______

III. VARIABLE O & M

$/day | O & M

Phosphorus Cost:

PC = ______ (PO_4 lb/day) × ______ (PO_4 $/lb) = ______

IV. FIXED O & M

a. Labor: ______ (hr/day) × ______ ($/hr) = ______

b. Supervision: ______ (hr/day) × ______ ($/hr) = ______

c. Overhead: ______ (Labor, $/day) × ______ % = ______

d. Lab Labor: ______ (hr/day) × ______ ($/hr) = ______

e. Maint, Service, I&T: ______ (capital, $) × ______ (%/100) ÷ 365 (day/yr) = ______

f. Service Water: ______ (thou gpd) × ______ ($/thou gal) = ______

V. YEARLY O & M

365 (day/yr) × ______ (sum $/day) = ______ $/yr

VI. UNCOSTED ITEMS

IV.3.2.1-D. Heating/Cooling

D 1. Basis of Design

This presentation is for the heating or cooling of a wastewater stream. The heating or cooling of a waste stream may be required for the adequate performance of a wastewater treatment process or operation or may be required for a wastewater discharge to meet water quality criteria. A costing methodology is described in this section for: (1) heating a wastewater stream by direct steam injection; (2) cooling a wastewater stream by a shell-and-tube heat exchanger; and (3) cooling a wastewater stream by a mechanical draft cooling tower. The extent of heating or cooling is set by the conditions required by the subsequent unit process (e.g., activated sludge system or other biological treatment system) or discharge conditions.

When heating is required, a direct steam injection system is used. Since the cost of the injectors are minor with respect to the cost of the steam generation equipment, no capital cost is estimated. The steam cost is included in the determination of operation costs.

When cooling is required, both a heat exchanger and a cooling tower are examined and the type of system that is appropriate for the required flow rate and heat exchange rate is selected. A heat exchanger, such as that illustrated in Figure IV.3.2.1-D1, is selected when such a unit would require less than 464 square meters (5,000 square feet) of exchanger capacity. The cost factor for a heat exchanger cooling system is the required cooling surface area.

A cooling tower system, such as that illustrated in Figure IV.3.2.1-D2, also is considered whenever cooling is required. The cooling duty and tower requirements are calculated on the basis of the ambient conditions (wet-bulb temperature), the waste characteristics (flow rate and inlet temperature), and the required outlet conditions (outlet temperature).

a) Source

This cost estimate method was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/ Plastics and Synthetic Fibers Industries [4-2].

b) Required Input Data

Wastewater flow L/s (gpm)
Wastewater characteristics: inlet temperature °C (°F); target outlet temperature °C (°F)
Ambient conditions: wet bulb temperature °C (°F)

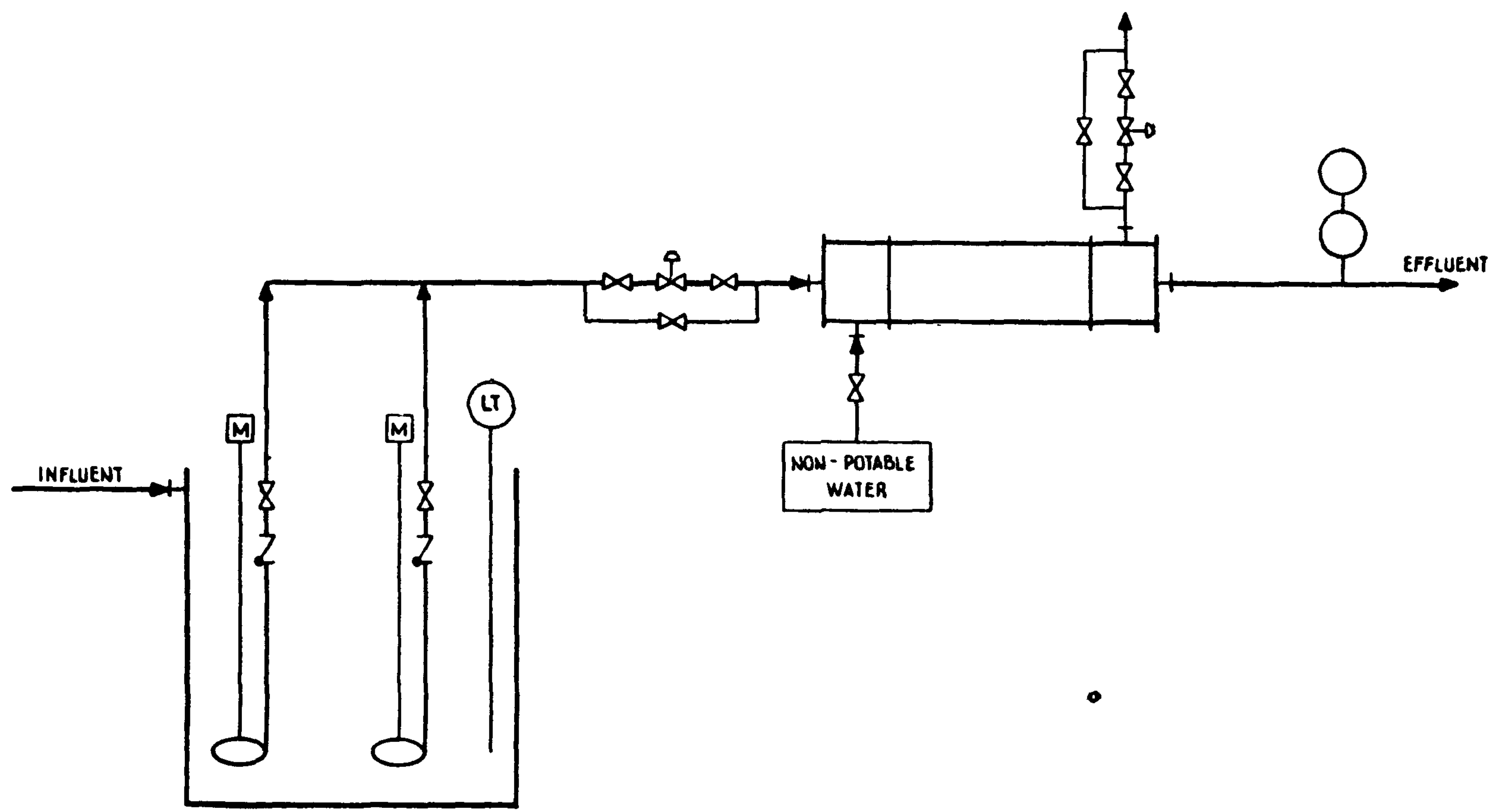


FIGURE IV.3.2.1-D1. PROCESS FLOW DIAGRAM FOR HEAT EXCHANGER [4-1]

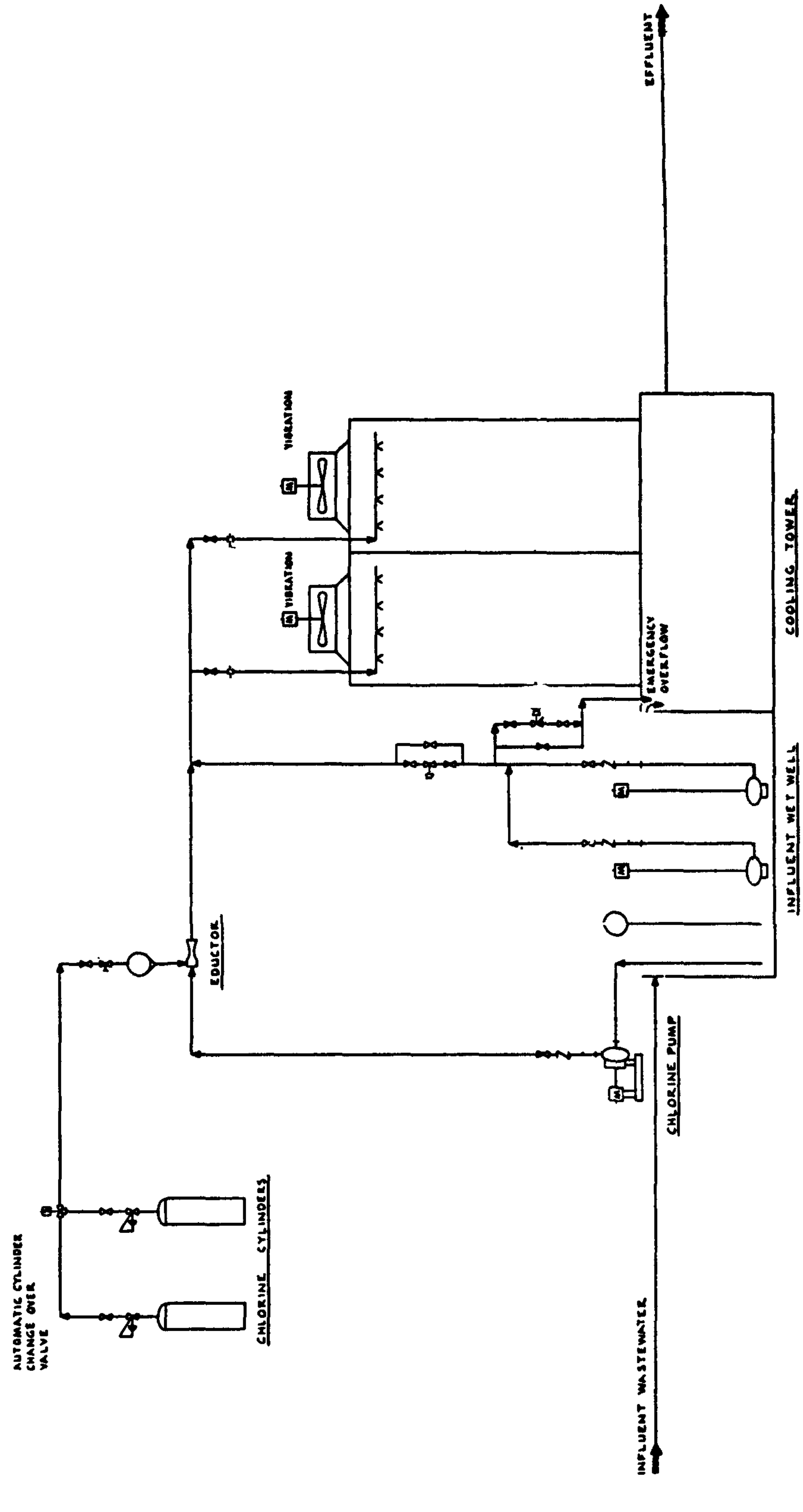


FIGURE IV.3.2.1-D2. PROCESS FLOW DIAGRAM FOR COOLING TOWER [4-1]

c) Limitations

Cooling - heat exchanger only used if required cooling surface area <464 m^2 (<5000 ft^2)

d) Pretreatment

None specified.

e) Design Factor

The need for heating or cooling is established by the need of subsequent unit operations. The design factors for these options are described.

i) Heating

There is no system design for heating. The entire cost is assumed to be the required steam usage (see Section D 3).

ii) Cooling

The design of a cooling system may include either a heat exchanger or a cooling tower. Both systems are evaluated and the lower cost system is selected. However, the heat exchanger system is not used if the exchanger area exceeds 464 square meters (5000 square feet).

- Heat Exchanger Method

The heat exchanger cost factor is the surface area required for achieving the required cooling.

Metric

$$AREA = DUTY \div [(TOUT - TCW) \times 1130]$$

where:
AREA = heat exchanger surface area, m^2
DUTY = heat transfer requirement, KJ/hr
= MFLOW × (TOUT - TIN) × 12.5
MFLOW = mass wastewater flow, Kg/hr
= FLOW × 3600
FLOW = flow, L/s
3600 = mass flow rate conversion, L/s to Kg/hr
TOUT = required wastewater outlet temperature, °C
TIN = wastewater inlet temperature, °C
12.5 = (10% flow variance) × (11.4 KJ/hr-m^2-°C)
TCW = cooling inlet water temperature, °C
1130 = water-water transfer rate, KJ/hr-m^2-°C

English

$$AREA = DUTY \div [(TOUT - TCW) \times 100]$$

where:
- AREA = heat exchanger surface area, ft^2
- DUTY = heat transfer requirement, BTU/hr
  = MFLOW × (TOUT - TIN) × 1.1
- MFLOW = mass wastewater flow, lb/hr
  = FLOW × 500
- FLOW = flow, gpm
- 500 = mass flow rate conversion, gpm to lb/hr
- TOUT = required wastewater outlet temperature, °F
- TIN = wastewater inlet temperature, °F
- 1.1 = (10% flow variation) × (1.0 BTU/hr ft^2-°F)
- TCW = cooling inlet water temperature, °F
- 100 = water-water transfer rate, BTU/hr-ft^2-°F

This design is based on cooling water provided at the same flow rate as the wastewater flow rate. Thus the (TOUT - TCW) term represents the log mean temperature difference between the wastewater and cooling water.

- Cooling Tower Method

  The cooling tower design factors are the number of cooling tower units required and the wastewater flow rate.

$$NCTU = FLOW \times RF$$

where:
- NCTU = number of cooling tower units
- FLOW = wastewater flow rate, L/s or gpm
- RF = rating factor
  $= A \times (RANGE)^B$
- A,B = coefficients (see Table IV.3.2.1-D1)
- WBT = wet bulb temperature, °C or °F
- RANGE = TIN - TOUT
- TOUT = required wastewater outlet temperature, °C or °F
- TIN = wastewater inlet temperature, °C or °F

The necessary coefficients A and B are functions of the ambient wet bulb temperature (WBT) and the approach temperature (APROACH). The wet bulb temperature represents the ambient conditions selected for the location of the treatment plant. The approach temperature represents the difference between the outlet temperature of the wastewater (TOUT) and the atmospheric wet-bulb

TABLE IV.3.2.1-D1. COEFFICIENTS FOR DETERMINING RATING FACTOR FOR THE COOLING TOWER SYSTEM [4-2]

WET BULB TEMPERATURE		DESIGN APPROACH*		RATING FACTOR COEFFICIENTS**	
°C	°F	°C	°F	A	B
26.7	80	11.1	20	0.102	0.536
		8.9	16	0.112	0.577
		6.7	12	0.134	0.606
		5.6	10	0.178	0.569
		4.4	8	0.221	0.562
25.6	78	11.1	20	0.105	0.542
		8.9	16	0.114	0.584
		6.7	12	0.156	0.570
		5.6	10	0.191	0.547
		4.4	8	0.223	0.570
24.4	76	11.1	20	0.0968	0.583
		8.9	16	0.112	0.603
		6.7	12	0.173	0.563
		5.6	10	0.174	0.612
		4.4	8	0.213	0.612
23.3	74	11.1	20	0.107	0.570
		8.9	16	0.125	0.598
		6.7	12	0.160	0.600
		5.6	10	0.189	0.595
		4.4	8	0.209	0.634
22.2	72	11.1	20	0.106	0.588
		8.9	16	0.124	0.612
		6.7	12	0.166	0.609
		5.6	10	0.200	0.603
		4.4	8	0.199	0.672
21.1	70	13.3	24	0.095	0.574
		10	18	0.107	0.633
		7.8	14	0.139	0.633
		5.6	10	0.200	0.624
		4.4	8	0.233	0.645
18.3	65	13.3	24	0.096	0.612
		11.1	20	0.108	0.637
		8.9	16	0.137	0.640
		6.7	12	0.180	0.649
		5.6	10	0.192	0.691
15.6	60	16.7	30	0.084	0.591
		13.3	24	0.094	0.661
		11.1	20	0.111	0.670
		8.9	16	0.147	0.659
		6.7	12	0.176	0.703

*cooling tower outlet temperature (TOUT) minus wet bulb temperature (WBT)
**coefficients: RF = A x (Range)(B)

plant. The approach temperature represents the difference between the outlet temperature of the wastewater (TOUT) and the atmospheric wet-bulb temperature. The coefficients in the table are selected for the conditions that correspond to the listed wet-bulb temperature, using the next highest wet-bulb temperature condition when the selected value is intermediate to those in the table. The approach is then used to select the A and B coefficients for calculating the rating factor. When the approach lies between conditions in the table, the rating factor is interpolated from the result of calculating the two rating factors. An approach that is lower than the values in the table cannot be achieved by this method requiring that the design conditions be adjusted (i.e., select a higher TOUT). The A and B coefficients for the largest approach are used if the actual approach exceeds the highest listed.

f) <u>Subsequent Treatment</u>

The heated/cooled wastewater will require treatment or discharge.

D 2 Capital Costs

There are no capital costs estimated for the heating option. The capital costs for the heat exchanger cooling system are based on the heat exchanger surface area requirements, with a maximum system size of 464 square meters (5000 square feet) (see Figure IV.3.2.1-D3). The capital costs for a cooling tower are based on two factors: flow and the number of cooling tower units. The flow is used to determine the cost of associated equipment (Figure IV.3.2.1-D4) as well as the cost of each cooling tower unit (Figure IV.3.2.1-D5). The number of cooling tower units, determined as described in Section Dl,e, is multiplied times the cost per cooling tower unit to establish the tower capital cost, which is added to the auxiliary equipment cost to get the system cost. Cost estimated using these curves must be adjusted to a current value using an appropriate current cost index.

a) <u>Cost Data</u>

i) Items included in the capital cost estimates for the heat exchanger cooling system include:

Tube and shell heat exchanger
Pumps, piping
Instrumentation, electrical

ii) Items included in the capital cost estimates for the cooling tower system include:

Cooling tower
Crossflow mechanical draft type

Auxiliary equipment
Pumps, piping
Instrumentation, electrical

b) Capital Cost Curves

i) Heat exchanger system - see Figure IV.3.2.1-D3
- Cost (thousands of dollars) vs. surface area (square meters or square feet)
- Curve basis, cost estimate on systems with surface areas of 18.6, 46.4, 186, and 464 m^2 (200, 500, 2000, and 5000 ft^2)

ii) Cooling tower system -

- Cost:

$$COST = EQUIP + (NCTU \times DCPTU)$$

where:
COST = capital cost for cooling tower system (in July 1977 dollars)
EQUIP = cost for auxiliary equipment - see Figure IV.3.2.1-D4, Cost (thousands of dollars) vs. flow (liters per second or thousand gpm)
NCTU = number of cooling tower units required (see Section D1,e)
DCPTU = dollar cost per cooling tower unit - See Figure IV.3.2.1-D5, Cost per Cooling Tower Unit (dollars) vs. Flow (liters per second or thousand gpm)

- Curve basis: vendor information

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

D.3 Operation and Maintenance Costs

Operating costs include both fixed and variable components. Variable components will depend upon the system selected and may include utilities (steam, cooling water) and power. Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

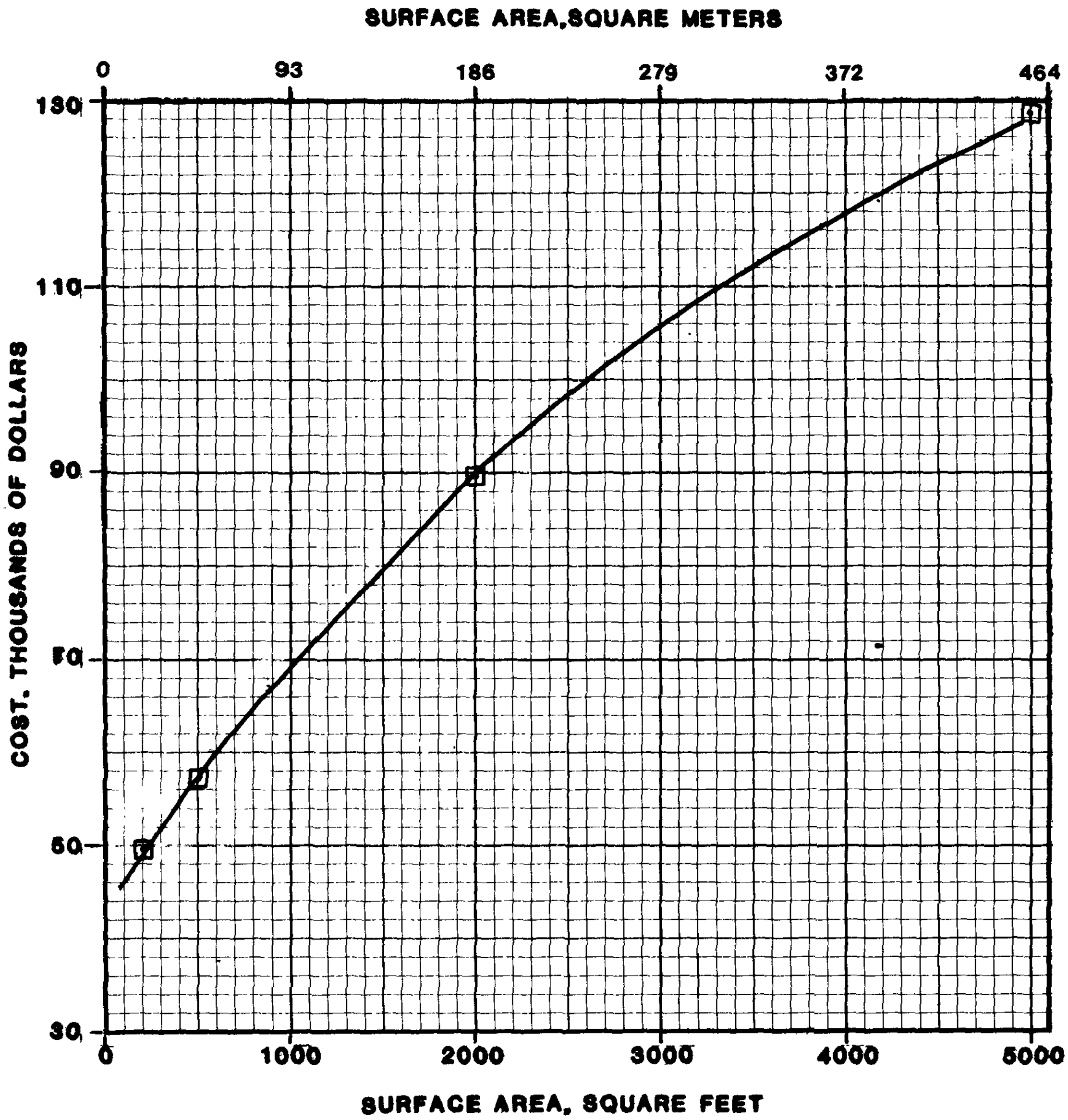


FIGURE IV.3.2.1-D3. CAPITAL COST ESTIMATE FOR HEAT EXCHANGER [4-10]

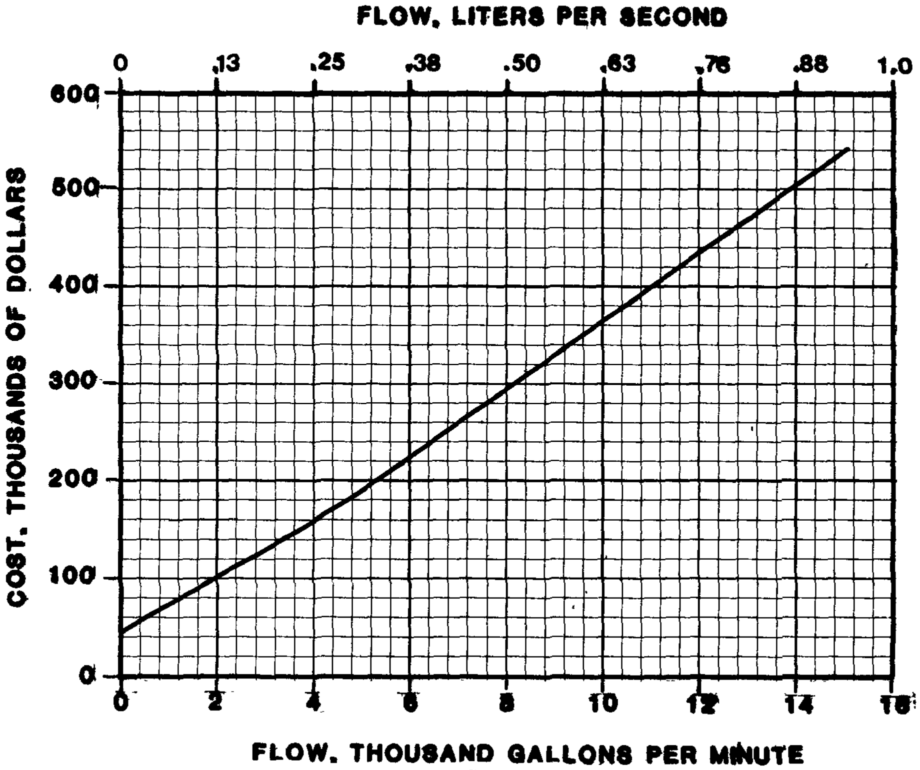


FIGURE IV.3.2.1-D4. CAPITAL COST ESTIMATE FOR COOLING TOWER AUXILIARY EQUIPMENT [4-10]

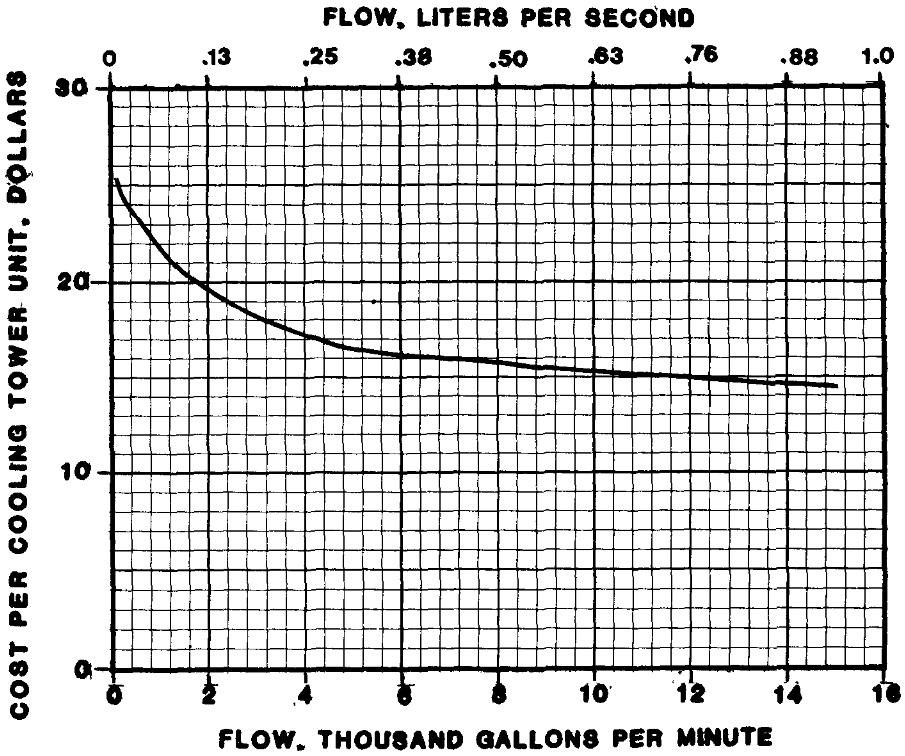


FIGURE IV.3.2.1-D5. CAPITAL COST ESTIMATE FOR COOLING TOWER UNIT COST (COST PER COOLING TOWER UNIT) [4-10]

a) Variable Costs - Heating

i) Utilities Required - steam is required for heating

Metric

$$STM = MFLOW \times (TOUT - TIN) \times 0.043$$

where:
- STM = steam usage, Kg/hr
- MFLOW = wastewater flow, Kg/hr
  - = FLOW × 69.6
- FLOW = wastewater flow, L/s
- 69.6 = mass flow rate conversion, L/s to Kg/hr
- TOUT = required outlet temperature, °C
- TIN = inlet temperature, °C
- 0.043 = 1.1 × 24 × 4.17 ÷ 2560
  - = (110% design factor) × (hr/day) × (KJ/Kg-°C) ÷ (KJ/Kg steam)

English

$$STM = MFLOW \times (TOUT - TIN) \times 0.024$$

where:
- STM = steam usage, lb/hr
- MFLOW = wastewater flow, lb/hr
  - = FLOW × 500
- FLOW = wastewater flow, gpm
- 500 = mass flow rate conversion, gpm to lb/hr
- TOUT = required outlet temperature, °F
- TIN = inlet temperature, °F
- 0.024 = 1.1 × 24 × 1 ÷ 1100
  - = (110% design factor) × (hr/day) × (BTU/lb-°F) ÷ (BTU/lb steam)

ii) Utilities Cost, Heating

$$TSC = STM \times 24 \times CPP$$

where:
- TSC = total steam cost, $/day
- STM = steam usage, Kg/hr or lb/hr
- 24 = hr/day
- CPP = cost per Kg or lb of steam, $/Kg or $/lb

b) Variable Costs - Cooling by Heat Exchanger

i) Power Requirements - total power includes pumps. The following equation was developed using regression analysis procedures [4-1].

Metric

$$TPHK = (0.039 \times AREA) - 0.105$$

where: TPHK = total power required for heat exchanger, Kw
AREA = heat exchanger surface area, m^2

English

$$TPHE = (0.00488 \times AREA) - 0.141$$

where: TPHE = total power required for heat exchanger, Hp
AREA = heat exchanger surface area, ft^2

ii) Utilities Required - cooling water is required as the heat transfer medium

$$CW = FLOW$$

where: CW = cooling water required, L/s or gpm
FLOW = wastewater flow, L/s or gpm

iii) Power Cost

Metric

$$PC = TPHK \times 24 \times EC$$

where: PC = total power cost, $/day
TPHK = total power for heat exchangers, Kw
24 = hr/day
EC = electricity cost, $/Kw-hr

English

$$PC = TPHE \times 0.746 \times 24 \times EC$$

where: PC = total power cost, $/day
TPHE = total power for heat exchangers, Hp
0.746 = Kw-hr/Hp-hr
24 = hr/day
EC = electricity cost, $/Kw-hr

iv) Cooling Water Cost

Metric

$$WC = CW \times 86400 \times CPL$$

where: WC = water cost, $/day
CW = cooling water, L/s
86400 = seconds/day
CPL = cost per liter, $/L

English

$$WC = CW \times 1440 \times CPG$$

where: WC = water cost, \$/day
CW = cooling water, gpm
1440 = minute/day
CPG = cost per gallon, \$/gal

c) Variable Costs - Cooling by Cooling Tower

i) Power Requirements - total power includes pumps. The following equation was developed using regression analysis procedures [4-1].

Metric

$$TPCK = (1.15 \times FLOW) - 15.7$$

where: TPCK = total power for cooling tower, Kw
FLOW = wastewater flow rate, L/s

English

$$TPCT = (0.097 \times FLOW) - 21.0$$

where: TPCT = total power for cooling tower, Hp
FLOW = wastewater flow rate, gpm

ii) Power Cost

Metric

$$PC = TPCK \times 24 \times EC$$

where: PC = power cost, \$/day
TPCK = total power for cooling tower, Kw
24 = hr/day
EC = electricity cost, \$/Kw-hr

English

$$PC = TPCT \times 0.746 \times 24 \times EC$$

where: PC = power cost, \$/day
TPCT = total power for cooling tower, Hp
0.746 = Kw-hr/Hp-hr
24 = hr/day
EC = electricity cost, \$/Kw-hr

d) Fixed Costs

The fixed O & M components for Heat Exchangers and Cooling Towers are listed in Table IV.3.2.1-D2 including values for the cost basis and the unit costs [4-11].

D.4 Miscellaneous Costs

Costs for engineering, and other common plant items such as land, piping, buildings, etc., are calculated after completion of costing for individual units (see Section IV.3.5).

A.5 Modifications

None are applicable.

TABLE IV.3.2.1-D2. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR HEAT EXCHANGERS AND COOLING TOWERS [4-11]

HEAT EXCHANGER

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.10 Weeks (2.40 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.24 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.00 Shifts	$10.70/hr
Maintenance	4.73% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.00 L/s (0.00 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

COOLING TOWER

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.10 Weeks (2.40 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.24 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.00 Shifts	$10.70/hr
Maintenance	4.00% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.00 L/s (0.00 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

HEATING/COOLING
SUMMARY WORK SHEET

REFERENCE: IV.3.2.1-D

I. DESIGN FACTOR (Heating or Heat Exchanger or Cooling Tower)

a. Heating by steam injection = no capital cost

b. Heat Exchanger Cooling: Surface Area = ________ ft^2

c. Cooling Tower: Flow = ________ gpm; NCTU = ________

II. CAPITAL COST

Cost = ____________ (Cost from curve) × (____________ (current index) ÷ 204.7) | $ ________

III. VARIABLE O & M

		$/day
a. Power	= ________ (HP) × ________ (EC, $/Kw-hr) × 17.9	= ________
b. Cooling water	= ________ (FLOW, gpm) × ________ (CPG,$/gal) × 1440	= ________
c. Steam	= ________ (STM,lb/hr) × ________ (CPP,$/lb) × 24	= ________

IV. FIXED O & M

a. Labor:	________ (hr/day) × ________ ($/hr)	= ________
b. Supervision:	________ (hr/day) × ________ ($/hr)	= ________
c. Overhead:	________ (Labor, $/day) × ________ (%/100)	= ________
d. Lab Labor:	________ (hr/day) × ________ ($/hr)	= ________
e. Maint, Service, I&T:	________ (capital, $) × ________ (%/100) ÷ 365	= ________
f. Service Water:	________ (thou gpd) × ________ ($/thou gal) × 1000	= ________

V. YEARLY O & M

365 (day/yr) × ________ (sum, $/day) = ________ $/yr

VI. UNCOSTED ITEMS

HEATING/COOLING
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS: TECHNOLOGY = ________
(select: a)heating; b)heat exhanger; c)cooling tower)

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ \$/Kw-hr

3. CPG: cooling water = ________ \$/gallon

4. CPP: steam cost = ________ \$/lb

5. Labor = ________ \$/hr

6. Supervision = ________ \$/hr

7. Overhead = ________ % Labor ÷ 100 = ________ %/100

8. Lab Labor = ________ \$/hr

9. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor Sum = % ÷ 100 = ________ %/100

10. Service Water = ________ \$/thou gal

I. DESIGN FACTOR

a. Heating - no capital cost

b. Heat Exchanger

1. MFLOW = $\underset{\text{FLOW, gpm}}{\underline{\qquad\qquad}}$ × 500 = ________ lb/hr

2. DUTY = $\underset{\text{MFLOW, lb/hr}}{\underline{\qquad\qquad}} \times (\underset{\text{TIN, °F}}{\underline{\qquad\quad}} - \underset{\text{TOUT, °F}}{\underline{\qquad\quad}}) \times 1.1 =$ ______ BTU/hr

3. AREA = $\underset{\text{DUTY, BTU/hr}}{\underline{\qquad\qquad}} \div [(\underset{\text{TOUT, °F}}{\underline{\qquad\quad}} - \underset{\text{TCW, °F}}{\underline{\qquad\quad}}) \times 100] =$ ________ ft^2

MFLOW = mass wastewater flow rate, lb/hr
TOUT,TIN = required discharge temperature and wastewater inlet temperature
TCW = cooling water temperature

4. If AREA <5000 ft^2, use heat exchanger for wastewater cooling purposes.

c. Cooling Tower

1. Rating Factor, RF

   FLOW = ________gpm, wastewater flow rate

2. Wet bulb temperature, WBT = ________°F

3. Approach = (________ - ________) = ________°F
   TOUT, °F   WBT, °F

4. Range = ________ - ________ = ________°F
   TOUT, °F   TIN, °F

5. Rating Factor Coefficients A = ________ B = ________
   (from Table IV.3.2.1-D1)

   RF = ________ × (________)$^{(\_\_\_\_\_\_\_\_)}$ = ________
   A   RANGE   B

6. Number of Cooling Tower Units, NCTU

   NCTU = ________ × ________ = ________
   FLOW, gpm   RF

II. CAPITAL COST

a. Heating - none

b. Heat Exchanger - from cost curve, Figure IV.3.2.1-D3

c. Cooling Tower -

   (i) Tower Cost (Basis, July 1977 Dollars)

   FLOW = ________ thousand gpm

   EQUIP = ________ (from Figure IV.3.2.1-D4)

   DPCTU = ________ (from Figure IV.3.2.1-D5)

   COST = ________ + (________ × ________) = ____________
   EQUIP   NCTU   DPCTU

   (note - adjust cost to reflect current index for heat exchanger or cooling tower as indicated on Summary Work Sheet)

III. VARIABLE O & M

a. Heating

Steam Requirements

1. MFLOW, lb/hr = $\underset{\text{FLOW, gpm}}{\underline{\hspace{3cm}}}$ × 500 = ________

2. STM = $\underset{\text{MFLOW, lb/hr}}{\underline{\hspace{3cm}}}$ × ($\underset{\text{TOUT, °F}}{\underline{\hspace{2cm}}}$ - $\underset{\text{TIN, °F}}{\underline{\hspace{2cm}}}$) × 0.024 = ________ lb/hr

b. Heat Exchanger

1. Power Requirements

TPHE = ($\underset{\text{AREA, ft}^2}{\underline{\hspace{3cm}}}$ × 0.00488) - 0.141 = ________ Hp

2. Cooling Water Required

CW = $\underset{\text{FLOW}}{\underline{\hspace{2cm}}}$ gpm

c. Cooling Tower

(i) Power Requirements

TPCT = ($\underset{\text{FLOW, gpm}}{\underline{\hspace{2.5cm}}}$ × 0.097) - 21.0 = ________ Hp

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

IV.3.2.3 NITRIFICATION/DENITRIFICATION

Introduction

Nitrification/denitrification represents two biological treatment processes, with the first representing the conversion of ammonia to nitrate (through the intermediate formation of nitrite) and the second process representing the conversion of nitrate to the free gas nitrogen. The processes are described in more detail in Volume III of the Treatability Manual, Section III.3.2.3. Costing methodologies and cost data for industrial wastewater treatment applications are presented below.

IV.3.2.3-A. Nitrification

A 1. Basis of Design

The cost estimate is for the biological conversion of ammonia to nitrate (nitrification). A system of the type considered is represented in Figure IV.3.2.3-A1. The capital cost factor is the basin volume required for the process. The system is assumed to convert 95 percent of influent ammonia to nitrate. The hydraulic detention time required to achieve this removal is computed assuming a basin mixed liquor volatile suspended solids concentration of 2,000 mg/L and a temperature-dependent reaction rate. The basin pH must be maintained between 7.0 and 9.0, with lime added as required to replace alkalinity destroyed by the reaction or not available in the influent. Nutrients may also be required. Aeration capital cost and operating cost are computed as shown in IV.3.2.1-B based on the horsepower required.

a) Source

This cost estimate method was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries.

b) Required Input Data

Wastewater flow L/s (mgd)
Wastewater characteristics
treatable pollutants (mg/L) [ammonia nitrogen, organic nitrogen, total Kjeldahl nitrogen (TKN)], alkalinity, (mg/L as $CaCO_3$), temperature (°C), pH, BOD_5 (mg/L), phosphate (mg/L)

c) Limitations

This process is not considered to be applicable if influent TKN is less than 10 mg/L.

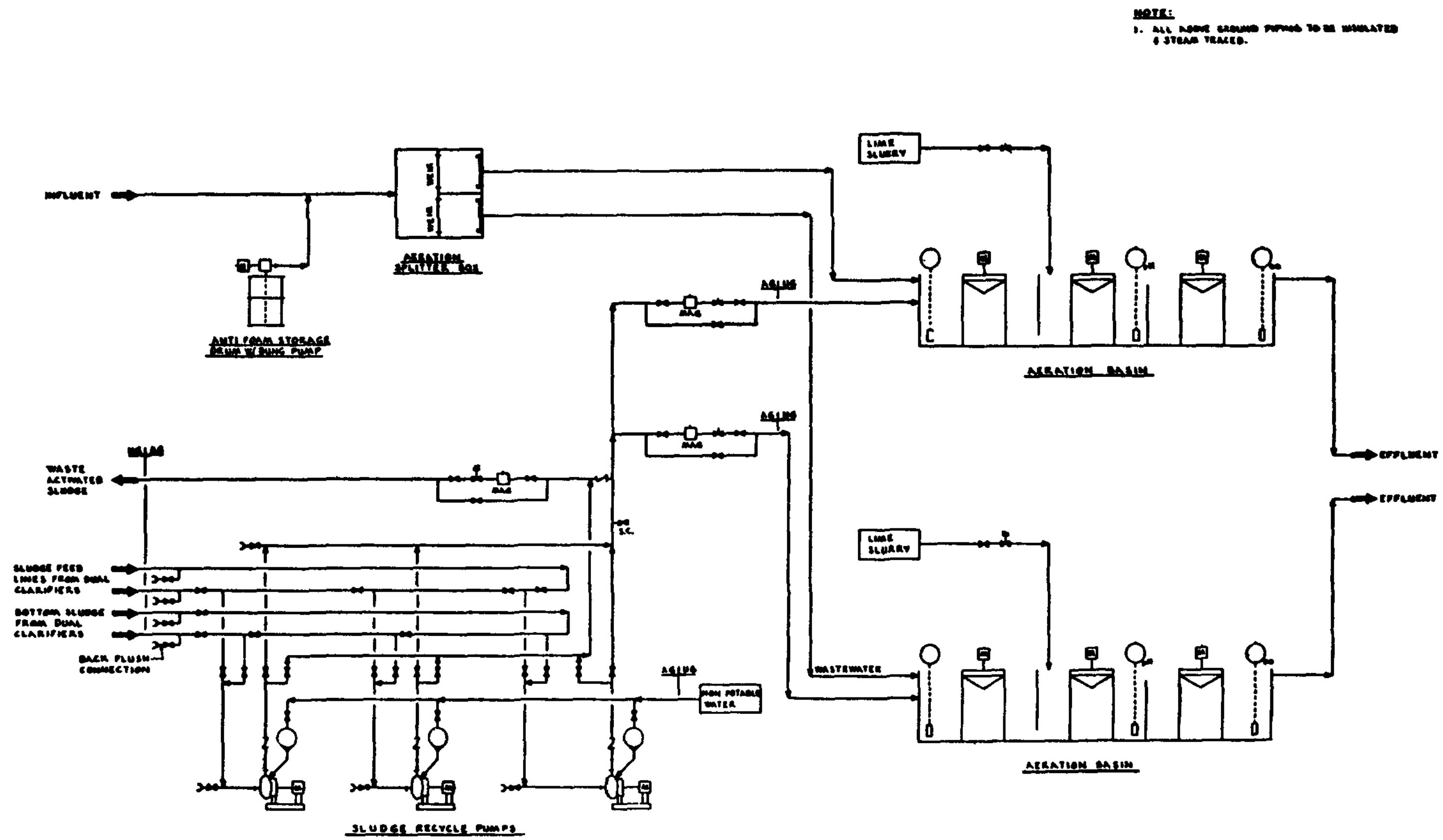


FIGURE IV.3.2.3-A1. PROCESS FLOW DIAGRAM FOR NITRIFICATION [4-1]

d) Pretreatment

The following conditions require pretreatment as indicated [4-1]:

i) If influent pH >9.0 or pH <7.0, then neutralization is required upstream of nitrification.

ii) If influent temperature >38°C or <10°C, then heat transfer (cooling or heating) is required upstream of nitrification.

iii) If influent BOD >125 mg/L, then activated sludge treatment is required upstream of nitrification.

iv) If influent BOD to TKN ratio >3.0, then activated sludge treatment is required upstream of nitrification.

v) If influent TDS >10,000 mg/L, then ion exchange is required upstream of nitrification.

vi) If influent ammonia plus organic nitrogen >2,000 mg/L, then ammonia stripping is required upstream of nitrification.

e) Design Equation

The cost factor for the nitrification process is the required basin volume. The basin volume may be computed as follows:

Metric

$$BV = FLOW \times 86400 \times DT$$

where:
- BV = bed volume, liters
- FLOW = influent flow, L/s
- 86400 = s/day
- DT = detention time, days
  $= \dfrac{No - Ne}{Qn \times Xv}$
- No = influent ammonia plus organic nitrogen, mg/L
- Ne = effluent ammonia plus organic nitrogen, mg/L
- Xn = MLVSS (default value 2000 mg/L)
- Qn = nitrification rate (16 to 38°C), day^{-1}

English

$$BV = FLOW \times DT$$

where:
- BV = basin volume, million gallons
- FLOW = influent flow, mgd

$$DT = \text{detention time, days}$$
$$= \frac{No - Ne}{Qn \times Xv}$$

No = influent ammonia plus organic nitrogen, mg/L
Ne = effluent ammonia plus organic nitrogen, mg/L
Xv = MLVSS (default value 2000 mg/L)
Qn = nitrification rate (16 to 38°C), day^{-1}

The effluent ammonia plus organic nitrogen concentration is estimated based on a 95% reduction or a minimum effluent concentration of 3 mg/L. The nitrification rate varies significantly with the wastewater temperature. The nitrification rate may be calculated as a percentage of the rate at 30°C as follows [4-1]:

$$Qn = 0.3 \times (0.036 \times T - 0.094)$$

where: 0.3 = nitrification rate at 30°C, day^{-1}
T = wastewater temperature in the basin, °C

Requirements for aeration, nutrient addition, lime addition, and byproducts handling must be calculated separately. These are discussed in Sections A 2,d, Associated Cost and A 4, Miscellaneous Costs.

f) <u>Subsequent Treatment</u>

i) Clarification will be required for solids separation.

ii) Denitrification may be required for nitrate removal.

A 2. Capital Costs

The nitrification process capital cost is based on the basin volume required to achieve the desired hydraulic detention time. The capital cost curve for the basin is presented in Figure IV.3.2.3-A2. Capital costs for aeration, nutrient addition, lime addition, and sludge handling must be calculated separately. Costs estimated using these curves must be adjusted to a current value using an appropriate current cost index.

a) <u>Cost Data</u>

Items included in the capital cost estimates for the nitrification basin are as follows [4-2]:

Splitter box
Nitrification basin, dual chamber (concrete up to 3.78 million liters (1.0 mil gal), or earthen basin with membrane liner >3.78 mil liters (>1.0 mil gal))
Sludge recycle pumps (three)
Piping
Instrumentation

b) Capital Cost Curves

Curve - see Figure IV.3.2.3-A2
- Cost (thousands of dollars) vs. basin volume, (million liters or million gallons).
- Curve basis, cost estimates on five systems with basin volumes of 0.148, 0.742, 3.72, 7.42, and 14.9 million liters (0.039, 0.196, 0.982, 1.96, and 3.93 million gallons) (basin volumes were based on a detention time of 4.7 hours for flow rates of 8.76, 43.8, 219, 438, and 876 L/s (0.2, 1.0, 5.0, 10, and 20 mgd)).

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

d) Associated Costs

The capital costs in Figure IV.3.2.3-A2 include only the basin structures and piping. The complete cost estimate for a nitrification system requires that capital costs also be developed for aeration, nutrient (phosphorus) addition, lime addition, and byproduct treatment.

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable component associated with the basin is power for pumps. In addition, variable costs will include phosphorus for nutrient requirements (if needed), lime for alkalinity control, aeration horsepower, and byproduct treatment (discussed in Section A 4, Miscellaneous Costs). Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Cost

i) Power Requirements - pumps; aeration equipment not included (see Section IV.3.2.1-B, Aeration). This equation was developed using regression analysis procedures [4-1].

Metric

$$KW = (9.97 \times VOL) + 0.586$$

where: KW = power required, kilowatts
VOL = basin volume, million liters

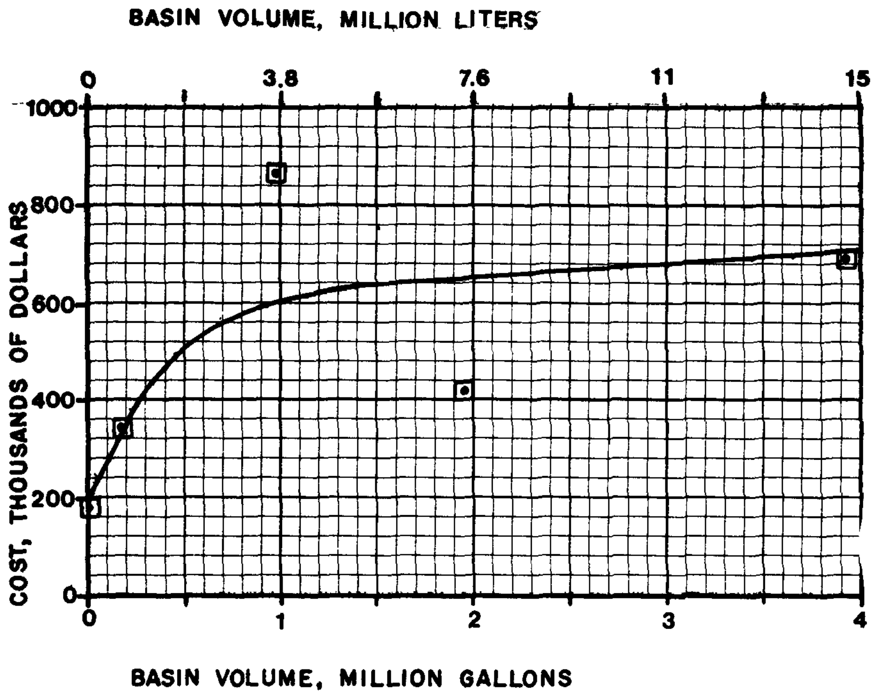


FIGURE IV.3.2.3-A2. CAPITAL COST ESTIMATE FOR NITRIFICATION [4-10]

English

$$HP = 50.6 \times VOL + 0.786$$

where: HP = power required, Hp
VOL = basin volume, million gallons

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, $/day
KW = power, KW
24 = hours/day
EC = electricity cost, $/KW-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, $/day
HP = power, Hp
24 = hr/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, $/Kw-hr

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.2.3-A1, including values for the cost basis and the unit costs [4-11].

A 4. Miscellaneous Costs

Costs for engineering, and common plant items such as land, piping, and buildings, are calculated after completion of costing for individual units (see Section IV.3.5). Accounts should be kept of the quantities of miscellaneous items required for use in subsequent costing procedures for aeration, nutrient addition, lime addition, and byproduct (sludge) treatment.

a) Land

The amount of land required for nitrification systems is estimated to be 120% of the surface area of the basin as follows:

Metric

$$LAND = VOL \times 1.2 \times 1000 \div 3.05$$

TABLE IV.3.2.3-A1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR NITRIFICATION [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1)	0.30 Weeks (7.20 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.72 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.20 Shifts (1.14 hrs/day)	$10.70/hr
Maintenance	1.36% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.08 Thou L (1.72 Thou gpd)	$0.13/Thou L ($0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

where: $LAND$ = land requirement, m^2
VOL = basin volume, million liters
1000 = conversion, m^3/million L
3.05 = basin depth, m

English

$$LAND = VOL \times (1.2 \times 10^6) \div (10 \times 7.48)$$

where: $LAND$ = land requirement, ft^2
VOL = basin volume, million gallons
10 = basin depth, ft
7.48 = conversion factor, gal/ft^3

b) Aeration

The oxygen transfer required to maintain the system as designed may be estimated as follows [4-1]. This information is then used in the design of an appropriate aeration system (see Section IV.3.2.1-B).

Metric

$$\begin{aligned} Na = {} & [0.7 \times 0.086 \times FLOW \times BOD \times 3600] \\ & + [BP \times 2000 \times BV \times 0.086] \\ & + [4.6 \times (NH3 + ORN) \times 0.086 \times FLOW \times 3600] \end{aligned}$$

where: Na = required amount of oxygen transfer, Kg/hr
0.7 = Kg O_2/Kg BOD removed
0.086 = conversion factor
$FLOW$ = influent wastewater flow, L/s
BOD = average BOD, mg/L
$BP = 0.014 - [0.004 \times BV \div (FLOW \times 86400)]$
BV = basin volume, million liters
2000 = MLVSS concentration, mg/L
4.6 = Kg O_2/Kg ammonia plus organic nitrogen
$NH3$ = average influent ammonia nitrogen, mg/L
ORN = average influent organic nitrogen, mg/L
3600 = s/hr
86400 = s/day

English

$$\begin{aligned} Na = {} & [(0.7 \times 8.34 \times FLOW \times BOD) \div 24] \\ & + [BP \times 2000 \times BV \times 8.34] \\ & + [4.6 \times (NH3 + ORN) \times 8.34 \times FLOW \div 24] \end{aligned}$$

where: Na = required amount of oxygen transfer, lb/hr
0.7 = lb O_2/lb BOD removed
8.34 = conversion factor
$FLOW$ = influent wastewater flow, mgd
BOD = average BOD, mg/L

$BP = 0.014 - (0.004 \times BV \div FLOW)$
BV = basin volume, million gallons
2000 = MLVSS concentration, mg/L
4.6 = lb O_2/lb ammonia plus organic nitrogen
NH3 = average influent ammonia nitrogen, mg/L
ORN = average influent organic nitrogen, mg/L
24 = hr/day

c) Nutrient (Phosphorus) Addition

Phosphorus addition is only required if the concentration in the influent to nitrification is less than the required concentration as calculated below:

$$PO4 = 0.01 \times [BOD + 0.167 \times (ORN + NH3)]$$

where: PO4 = phosphate concentration required, mg/L
0.01 = ratio of phosphorus to BOD
BOD = influent BOD_5, mg/L
0.167 = equivalent BOD demand of the nitrogen compounds
ORN = influent organic nitrogen, mg/L
NH3 = influent ammonia nitrogen, mg/L

The capital and operating cost to provide this nutrient for the whole plant can be developed in Section IV.3.2.1-C, Nutrient Addition.

d) Lime Addition

Lime is required to maintain alkalinity in the basin at a minimum of 200 mg/L. The amount of lime required to provide adequate influent alkalinity and replace that destroyed during nitrification may be estimated as follows:

Metric

$$LIME = 0.086 \times FLOW \times [0.74 \times (200 - ALK) + 5.4 \times (No - Ne)]$$

where: LIME = lime addition rate, Kg/hr
FLOW = influent flow rate, L/s
0.74 = ratio of lime to $CaCO_3$, equivalent weights
200 = desired alkalinity level as $CaCO_3$, mg/L
ALK = influent alkalinity as $CaCO_3$, mg/L
5.4 = ratio of hydrated lime to nitrogen removed
No = influent ammonia plus organic nitrogen, mg/L
Ne = effluent ammonia plus organic nitrogen, mg/L

English

$$LIME = 8.34 \times FLOW \times [0.74 \times (200 - ALK) + 5.4 \times (No - Ne)]$$

where: LIME = lime addition rate, lb/day
FLOW = influent flow rate, mgd
0.74 = ratio of lime to $CaCO_3$, equivalent weights
200 = desired alkalinity level as $CaCO_3$, mg/L
ALK = influent alkalinity as $CaCO_3$, mg/L
5.4 = ratio of hydrated lime to nitrogen removed
No = influent ammonia plus organic nitrogen, mg/L
Ne = effluent ammonia plus organic nitrogen, mg/L

The design and cost of lime addition systems is based on the needs of the entire plant rather than for individual unit processes. Lime costs are determined after completion of design of all unit processes (see Lime Handling, Section IV.3.1.13-C).

e) Sludge

The quantity of waste biological solids generated by the nitrification process are calculated for use in the subsequent design and costing of byproduct handling facilities. The amount of sludge generated by the nitrification process may be estimated as follows [4-1]:

Metric

$$SLDG = 0.086 \times FLOW \times [0.05 \times (NH3 + ORN) + (0.3 \times BOD)]$$

where: SLDG = waste sludge generated, Kg/day
0.086 = conversion factor
FLOW = influent flow rate, L/s
0.05 = Kg sludge generated/Kg nitrogen
NH3 = influent ammonia nitrogen, mg/L
ORN = influent organic nitrogen, mg/L
0.3 = Kg sludge generated/Kg BOD
BOD = influent BOD to nitrification unit, mg/L

English

$$SLDG = 8.34 \times FLOW \times [0.05 \times (NH3 + ORN) + (0.3 \times BOD)]$$

where: SLDG = waste sludge generated, lb/day
8.34 = conversion factor
FLOW = influent flow rate, mgd
0.05 = lb sludge generated/lb nitrogen
NH3 = influent ammonia nitrogen, mg/L
ORN = influent organic nitrogen, mg/L
0.3 = lb sludge generated/lb BOD
BOD = influent BOD to nitrification unit, mg/L

A 5. Modifications

None required.

NITRIFICATION
SUMMARY WORK SHEET

REFERENCE: IV.3.2.3-A

I. DESIGN FACTOR		CAPITAL
a. Basin Volume = ______ (BV) million gallons		
II. CAPITAL COST		
Cost = ______ (Cost from curve) × (______ (current index) ÷ 204.7)		$ ______
III. VARIABLE O & M	$/day	O & M
a. Power = ______ (Hp) × ______ (EC, $/Kw-hr) × 17.9	= ______	
IV. FIXED O & M		
a. Labor: ______ (hr/day) × ______ ($/hr)	= ______	
b. Supervision: ______ (hr/day) × ______ ($/hr)	= ______	
c. Overhead: ______ (Labor, $/day) × ______ (%/100)	= ______	
d. Lab Labor: ______ (hr/day) × ______ ($/hr)	= ______	
e. Maint, Service, I&T: ______ (capital, $) × ______ (%/100) ÷ 365 (day/yr)	= ______	
f. Service Water: ______ (thou gpd) × ______ ($/thou gal)	= ______	
V. YEARLY O & M	365 (day/yr) × ______ (sum, $/day)	= ______ $/yr

VI. UNCOSTED ITEMS

a. Land = ______ (LAND) ft^2

b. Oxygen = ______ (Na) lb/hr

c. Nutrient = ______ (PO4) lb/day

d. Lime = ______ (LIME) lb/day

e. Biological Sludge = ______ (SLDG) lb/day

NITRIFICATION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ $/Kw-hr

3. Labor = ________ $/hr

4. Supervision = ________ $/hr

5. Overhead = ________ % Labor ÷ 100 = ________ %/100

6. Lab Labor = ________ $/hr

7. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = % Capital
   Other O & M Factor Sum = ________ ÷ 100 = ________ %/100

8. Service Water = ________ $/1000 gal

I. DESIGN FACTOR

a. Wastewater Characteristics

Influent Flow =	________	mgd (FLOW)
Influent Alkalinity =	________	mg/L (ALK)
Wastewater temperature =	________	°C (T)
Influent Ammonia-Nitrogen =	________	mg/L (NHO)
Influent Organic-Nitrogen =	________	mg/L (ORN)
Influent Phosphorus =	________	mg/L (PO4)
Influent BOD_5 =	________	mg/L (BOD)

b. Influent Ammonia + Organic Nitrogen

$$No = \underset{\text{Influent Ammonia-Nitrogen (NHO), mg/L}}{\underline{\qquad\qquad}} + \underset{\text{Influent Organic-Nitrogen (ORN), mg/L}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ mg/L}$$

c. Effluent Ammonia + Organic Nitrogen

$$Ne = 0.95 \times \underset{\text{No, mg/L}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ mg/L}$$

If Ne < 3.0 mg/L, then use Ne = 3.0 mg/L

d. Determine nitrification rate

$$Qn = 0.30 \times (0.036 \times \underset{T,\ ^\circ C}{\underline{\qquad\qquad}} - 0.094) = \underline{\qquad} \text{ day}^{-1}$$

If T ≥ 30°C, use Qn = 0.30 day^{-1}

e. Hydraulic Detention Time

$$DT = (\underset{No, mg/L}{\underline{\qquad\qquad}} - \underset{Ne, mg/L}{\underline{\qquad\qquad}}) \div (\underset{Qn,\ day^{-1}}{\underline{\qquad\qquad}} \times 2000) = \underline{\qquad\qquad} \text{ days}$$

f. Basin Volume

$$BV = \underset{FLOW,\ mgd}{\underline{\qquad\qquad}} \times \underset{DT,\ days}{\underline{\qquad\qquad}} = \underline{\qquad\qquad\qquad} \text{ million gallons}$$

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements

$$HP = (50.6 \times \underset{BV,\ million\ gallons}{\underline{\qquad\qquad\qquad\qquad}}) + 0.786 = \underline{\qquad\qquad} \text{ Hp}$$

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Land Requirements

$$LAND = (\underset{BV,\ mil\ gal}{\underline{\qquad\qquad}} \times 1.2 \times 10^6) \div (74.8) = \underline{\qquad\qquad} \text{ ft}^2$$

b. Aeration (oxygen) Requirements

$$Na = \{0.243 \times \underset{FLOW, mgd}{\underline{\qquad\qquad}} \times \underset{BOD, mg/L}{\underline{\qquad\qquad}}\}$$

$$+ \{[0.014 - (0.004 \times \underset{BV, mil\ gal}{\underline{\qquad\qquad}} \div \underset{FLOW, mgd}{\underline{\qquad\qquad}})] \times \underset{BV, mil\ gal}{\underline{\qquad\qquad}} \times 16700\}$$

$$+ \{1.60 \times (\underset{NHO,\ mg/L}{\underline{\qquad\qquad}} + \underset{ORN,\ mg/L}{\underline{\qquad\qquad}}) \times \underset{FLOW,\ mgd}{\underline{\qquad\qquad}}\} = \underline{\qquad\qquad} \text{ lb/hr}$$

c. Nutrient (Phosphorus) Requirements

$$PO4 = 0.01 \times [\underset{\text{BOD,mg/L}}{\underline{\qquad\qquad}} + 0.167 \times (\underset{\text{ORN,mg/L}}{\underline{\qquad\qquad}} + \underset{\text{NHO,mg/L}}{\underline{\qquad\qquad}})]$$

$$= \underline{\qquad\qquad} \text{ mg/L}$$

d. Lime Requirements

$$LIME = \underset{\text{FLOW,mgd}}{\underline{\qquad\qquad}} \times 8.34 \times [0.74 \times (200 - \underset{\text{ALK,mg/L}}{\underline{\qquad\qquad}})$$

$$+ \; 5.4 \times (\underset{\text{No, mg/L}}{\underline{\qquad\qquad}} - \underset{\text{Ne, mg/L}}{\underline{\qquad\qquad}})] = \underline{\qquad\qquad} \text{ lb/day}$$

e. Waste Biological Sludge Production

$$SLDG = \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times 8.34 \times [0.05 \times (\underset{\text{NH3, mg/L}}{\underline{\qquad\qquad}} + \underset{\text{ORN mg/L}}{\underline{\qquad\qquad}}) +$$

$$(0.3 \times \underset{\text{BOD mg/L}}{\underline{\qquad\qquad}}) = \underline{\qquad\qquad} \text{ lb/day}$$

IV.3.2.3-B. Denitrification

B 1. Basis of Design

This cost estimate is for the biological conversion of nitrate to nitrogen gas (denitrification). A system of the type considered is represented in Figure IV.3.2.3-B1. The cost factor is the basin volume required for the process. The system is based on a continuous-flow stirred-tank denitrification basin with an associated aerated stabilization basin for stripping gaseous CO_2 and N_2 byproducts. It is assumed that an effluent organic plus nitrate and nitrite nitrogen concentration of 2.0 mg/L can be attained. The hydraulic detention time required to achieve the assumed or target effluent concentration must be calculated. Methanol is required as the carbon source for this process, at a ratio of 4:1 methanol to nitrate/nitrite nitrogen.

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemical/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

Wastewater flow L/s (mgd)
Wastewater characteristics
nitrate plus nitrite nitrogen (mg/L), temperature (°C), pH, total dissolved solids (mg/L), phosphorus (mg/L)

c) Limitations

Process is not applicable if influent nitrate plus nitrite nitrogen is less than 2 mg/L.

d) Pretreatment

Pretreatment should be provided as indicated for the following conditions:

i) If influent pH >8.0 or pH <6.0, then neutralization is required upstream of denitrification.

ii) If influent temperature >38°C or <10°C, then heat transfer (cooling or heating) is required upstream of denitrification.

iii) If total dissolved solids >10,000 mg/L, then ion exchange is required upstream of denitrification.

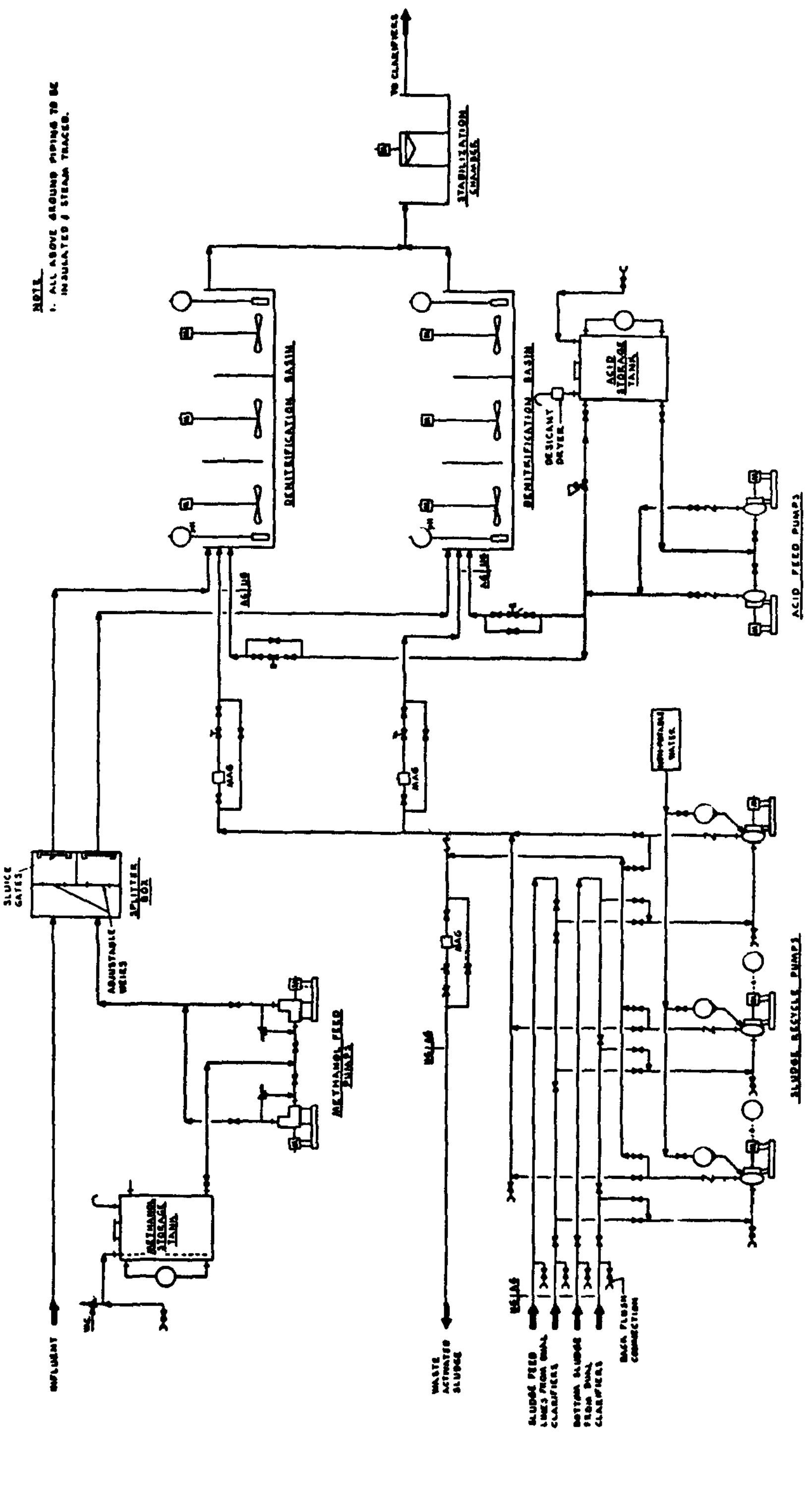


FIGURE IV.3.2.3-B1. PROCESS FLOW DIAGRAM FOR DENITRIFICATION [4-1]

e) Design Equation

The cost factor for the denitrification process is the required basin volume. The basin volume is computed as follows:

Metric

$$VOL = FLOW \times DT \times 86400$$

where:
- VOL = denitrification basin volume, liters
- FLOW = influent flow, L/s
- DT = detention time, days $= \dfrac{Do - De}{\mu \times Xv}$
- Do = influent NO_3-N + NO_2-N, mg/L
- De = effluent NO_3-N + NO_2-N, mg/L
- Xv = MLVSS, mg/L
- μ = denitrification rate, day^{-1} $= 0.25 \times [(0.0416 \times T) - 0.244]$, day^{-1}
- T = temperature, °C (T <30°C)
- 86400 = seconds per day

English

$$VOL = FLOW \times DT$$

where:
- VOL = denitrification basin volume, million gallons
- FLOW = influent flow, mgd
- DT = detention time, days $= \dfrac{Do - De}{\mu \times Xv}$
- Do = influent NO_3-N + NO_2-N, mg/L
- De = effluent NO_3-N + NO_2-N, mg/L
- Xv = MLVSS, mg/L,
- μ = denitrification rate, day^{-1} $= 0.25 \times [(0.0416 \times T) - 0.244]$, day^{-1}
- T = temperature, °C (T <30°C)

The estimated effluent quality (2 mg/L organic plus nitrate and nitrite nitrogen) is dependent on certain assumptions regarding temperature, pH, and operating conditions. Influent pH is assumed to be 6.0 to 8.0 units, dissolved oxygen <0.1 mg/L, TDS <10,000 mg/L, and methanol feed 4 Kg CH_3OH/Kg NO_3-N + NO_2-N (4 lb CH_3OH/lb NO_3-N + NO_2-N).

Requirements for land, nutrient (phosphorus) addition, and by-products (sludge) handling must be costed separately. These requirements are discussed in Section B 4, Miscellaneous Costs.

f) Subsequent Treatment

i) Clarification will be required for solids separation.

ii) Byproduct treatment is required for excess biological sludge production.

B 2. Capital Costs

The denitrification capital cost is based on the denitrification basin volume required to achieve the desired hydraulic detention time. The capital cost curve is presented in Figure IV.3.2.3-B2. Costs estimated using this curve must be adjusted to a current value using an appropriate current cost index.

a) Cost Data

The items included in the capital cost estimates include [4-2]:

Flow splitter box
Denitrification basin (concrete, except at 11.4 mill liters (3.0 mil gal), where denitrification basin is an earthen basin with membrane liner)
Stabilization basin (attached to denitrification basin, sized for 0.5 hour hydraulic detention).
Mixers (six, sized for 0.013 Kw/1000 L (0.067 Hp/1000 gal))
Aerator, fixed mounted (one to six, sized for 0.02 Kw/1000 L (0.1 Hp/1000 gal) stabilization basin volume)
Methanol storage tank (two week supply)
Methanol feed pumps (two, variable speed)
Sulfuric acid storage tank
Acid feed pumps (two)
Piping
Instrumentation

b) Capital Cost Curves

Curve - see Figure IV.3.2.3-B2
- Cost (thousands of dollars) vs. basin volume (million liters or million gallons)
- Curve basis, cost estimates on four denitrification systems having a denitrification basin volume of 0.114, 0.568, 2.84, and 11.4 million liters (0.03, 0.15, 0.75, and 3.0 million gallons). These correspond to flows of 8.76, 43.8, 219, and 876 L/s (0.2, 1.0, 5.0, and 20 mgd).

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

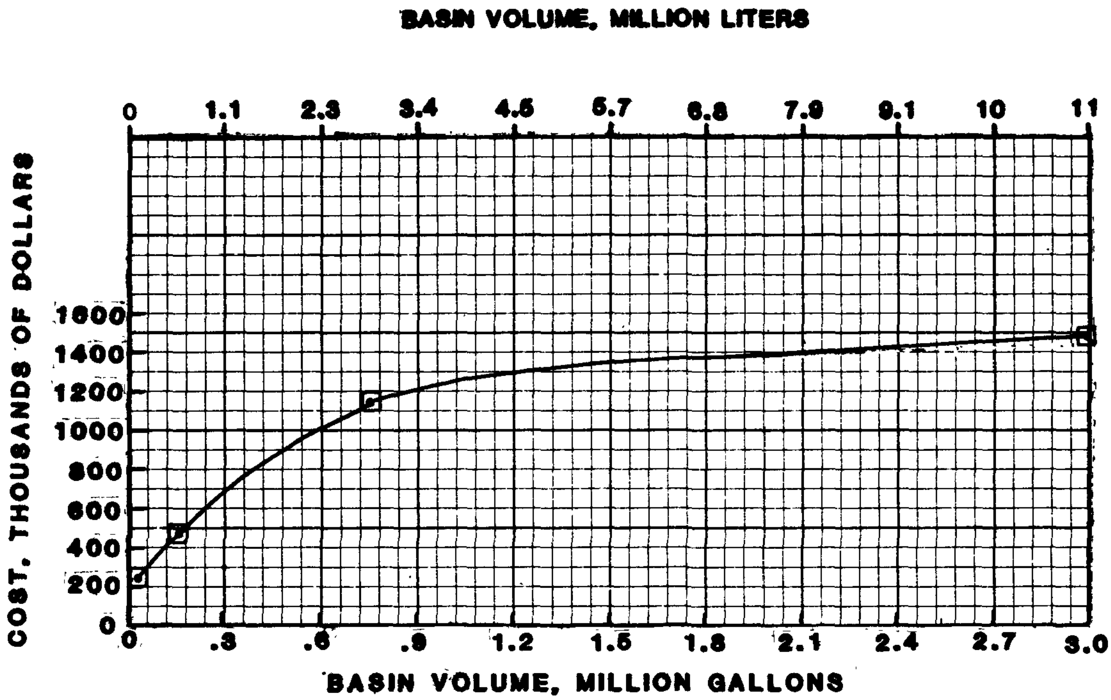


FIGURE IV.3.2.3-B2. CAPITAL COST ESTIMATE FOR DENITRIFICATION [4-10]

B 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. Variable components include power for the mixers, aerator, and pumps; and methanol costs. In addition, variable cost will include phosphorus for nutrient requirements (if needed) and byproduct treatment (discussed in B 4, Miscellaneous Costs). Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Costs

i) Power Requirements - Pumps, mixers, aerators. The following equations were developed using regression analysis procedures [4-1].

Metric

$$KW = (23.4 \times VOL) + 0.586$$

where: KW = power, kilowatts
VOL = basin volume, million liters

English

$$HP = (119 \times VOL) + 0.786$$

where: HP = power, Hp
VOL = basin volume, million gallons

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, $/day
KW = power, kilowatts
24 = hr/day
EC = electricity cost, $/KW-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, $/day
24 = hr/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, $/Kw-hr

iii) Methanol Requirements

Metric

$$MF = 4 \times Do \times 0.086 \times FLOW$$

where:
- MF = methanol feed rate, Kg/day
- 4 = methanol to nitrogen feed ratio
- Do = influent NO_2-N + NO_3-N, mg/L
- 0.086 = conversion factor
- FLOW = influent flow, L/s

English

$$MF = 4 \times Do \times 8.34 \times FLOW$$

where:
- MF = methanol feed rate, lb/day
- 4 = methanol to nitrogen feed ratio
- Do = influent NO_2-N + NO_3-N, mg/L
- 8.34 = conversion factor
- FLOW = influent flow, mgd

iv) Methanol Cost

$$MC = MF \times CC$$

where:
- MC = methanol feed cost, $/day
- MF = methanol feed rate, Kg/day or lb/day
- CC = methanol chemical cost, $/Kg or $/lb

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.2.3-B1, including the cost basis and unit costs [4-11].

B 4. Miscellaneous Costs

Costs for engineering, and other common plant items such as land, piping, and buildings, are calculated after completion of costing for individual units (see Section IV.3.5). Accounts should be kept of the quantities of miscellaneous items required for use in subsequent costing procedures.

a) Land

The land requirements for the basin and associated equipment are estimated to be 120% of the basin surface area [4-1].

Metric

$$LAND = VOL \times (1.2 \times 10^6) \div (3.048 \times 1000)$$

where: LAND = land requirement, m^2
VOL = volume, million liters
3.048 = basin depth, m
1000 = conversion L/m^3

English

$$LAND = VOL \times (1.2 \times 10^6) \div (10 \times 7.48)$$

where: LAND = land requirement, ft^2
VOL = basin volume, million gallons
10 = basin depth, ft
7.48 = conversion factor, gal/ft^3

b) Nutrient (Phosphorus) Addition

Phosphorus addition is only required if the concentration in the influent to denitrification is less than the required concentration.

$$PO4 = 0.0233 \times DO$$

where: PO4 = phosphate concentration required, mg/L
0.0233 = required ratio of phosphate to NO_2-N + NO_3-N
DO = influent NO_2-N + NO_3-N, mg/L

The capital and operating cost to provide this nutrient can be developed in Section IV.3.2.1-C, Nutrient Addition.

c) Sludge Generation

Waste biological sludge that will require treatment and/or disposal is computed for use in subsequent design and costing of byproduct handling facilities:

Metric

$$SLDG = 0.7 \times (Do - De) \times 0.086 \times FLOW$$

where: SLDG = waste sludge generated, Kg/day
0.7 = Kg sludge generated/Kg NO_2-N + NO_3-N removed
Do = influent NO_2-N + NO_3-N, mg/L
De = effluent NO_2-N + NO_3-N, mg/L
0.086 = conversion factor
FLOW = influent flow, L/s

English

$$SLDG = 0.7 \times (Do - De) \times 8.34 \times FLOW$$

where: SLDG = waste sludge generated, lb/day
0.7 = lb sludge generated/lb NO_2-N + NO_3-N removed
Do = influent NO_2-N + NO_3-N, mg/L
De = effluent NO_2-N + NO_3-N, mg/L
8.34 = conversion factor
FLOW = influent flow, mgd

B 5. Modifications

None required.

TABLE IV.3.2.3-B1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR DENITRIFICATION [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.30 Weeks (7.20 hr/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.72 hr/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.20 Shifts (1.14 hr/day)	$10.70/hr
Maintenance	2.68% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.075 L/s (1.72 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

DENITRIFICATION
SUMMARY WORK SHEET REFERENCE: IV.3.2.3-B

I. DESIGN FACTOR		CAPITAL
a. Basin Volume = ______ million gallons VOL		
II. CAPITAL COST		
Cost = ______ × (______ ÷ 204.7) Cost from curve, current index		$ ______
III. VARIABLE O & M	$/day	O & M
a. Power = ______ × ______ × 17.9 Hp, EC, $/Kw-hr	= ______	
b. Methanol = ______ × ______ MF, lb/day, CC, $/lb	= ______	
IV. FIXED O & M		
a. Labor: ______ × ______ hr/day, $/hr	= ______	
b. Supervision: ______ × ______ hr/day, $/hr	= ______	
c. Overhead: ______ × ______ Labor, $/day, %/100	= ______	
d. Lab Labor: ______ × ______ hr/day, $/hr	= ______	
e. Maint, Service, I&T: ______ × ______ ÷ 365 capital, $, %/100, day/yr	= ______	
f. Service Water: ______ × ______ thou gpd, $/thou gal	= ______	
V. YEARLY O & M	365 day/yr × ______ sum, $/day	= ______ $/yr
VI. UNCOSTED ITEMS		
a. Land = ______ ft^2 b. Nutrient (phosphorous) = ______ mg/L c. Biological Sludge Produced = ______ lb/day		

DENITRIFICATION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ \$/Kw-hr

3. MC: Methanol Feed Cost = ________ \$/lb

4. Labor = ________ \$/hr

5. Supervision = ________ \$/hr

6. Overhead = ________ % Labor ÷ 100 = ________%/100

7. Lab Labor = ________ \$/hr

8. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor Sum = ________ ÷ 100 = ________ %/100

9. Service Water = ________ \$/thou gal

I. DESIGN FACTOR

a. Wastewater Characteristics

Influent Flow = __________ mgd (FLOW)
Influent pH = 6.0 < __________ < 8.0
Design Wastewater Temperature = 10°C < __________ < 38°C (T)
T

Influent nitrate plus nitrite conc. = ________ mg/L (DO)
Influent total dissolved solids = ________ mg/L (TDS)
Effluent nitrate plus nitrite conc. = ________ mg/L (DE) (2.0 mg/L minimum level)

b. Denitrification Rate

1. If T ≥30°C, $\mu = 0.25$

2. If T <30°C, $\mu = 0.25 \times [(0.0416 \times \underset{T,\ ^\circ C}{\underline{\qquad\qquad}}) - 0.244] = \underline{\qquad\qquad}$ day^{-1}

c. Hydraulic Detention Time

$$DT = (\underset{DO, mg/L}{\underline{\qquad\qquad}} - \underset{DE,\ mg/L}{\underline{\qquad\qquad}}) \div (\underset{\mu,\ day^{-1}}{\underline{\qquad\qquad}} \times 2000) = \underline{\qquad\qquad} \text{ days}$$

d. Basin Volume

$$VOL = \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} \times \underset{\text{DT, days}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ million gallons}$$

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements

$$HP = (119 \times \underset{\text{VOL, mil gal}}{\underline{\qquad\qquad\qquad}}) + 0.786 = \underline{\qquad\qquad} \text{ horsepower}$$

b. Methanol Requirements

$$MF = 33.4 \times \underset{\text{DO, mg/L}}{\underline{\qquad\qquad}} \times \underset{\text{FLOW, mgd}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ lb/day}$$

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Land Requirements (10 foot depth)

$$LAND = (\underset{\text{VOL, mil gal}}{\underline{\qquad\qquad}} \times 16{,}000) = \underline{\qquad\qquad} \text{ ft}^2$$

b. Nutrient (Phosphorus) Requirements

$$PO4 = 0.0233 \times \underset{\text{DO, mg/L}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ mg/L}$$

c. Sludge Produced

$$SLDG = 0.7 \times (\underset{\text{DO, mg/L}}{\underline{\qquad\qquad}} - \underset{\text{DE, mg/L}}{\underline{\qquad\qquad}}) \times 8.34 \times \underset{\text{FLOW,mgd}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ lb/day}$$

IV.3.4.1 GRAVITY THICKENING

Introduction

Thickening operations are intended to reduce the volume of sludge to be further processed and normally constitute intermediate steps precedina dewatering or stabilization. The most common methods of sluuge thickening are the gravity thickening and dissolved air flotation (DAF) thickening. For further details on thickening processes, refer to Volume III, Section III.4.1 of the Treatability Manual. Costing methodologies and cost data for this technology are presented below.

IV.3.4.1-A. Gravity Thickening

A 1. Basis of Design

This is a presentation of design factors and costs for gravity thickening of wastewater sludges. Gravity thickening is basically a sedimentation process in which solids are settled to the thickener bottom, raked to a sludge hopper, and are periodically removed and discharged to a dewatering process. A system of the type considered is illustrated in Figure IV.3.4.1-A1. The supernatant or overflow, containing some solids (500 mg/L assumed) and probably a high BOD, is returned to the plant for further treatment.

Determination of the primary design factor, thickener surface area, is based on surface solids loading in $Kg/m^2/day$ ($lb/ft^2/day$). Typical solids loadings vary depending on the type of sludge being thickened. For combinations of sludge types, a weighted average approach is used to define the solids loading to the thickener. Typical values for the solids loading rate, influent solids concentration, and expected underflow solids concentration of each sludge type are shown in Table IV.3.4.1-A1.

a) Source

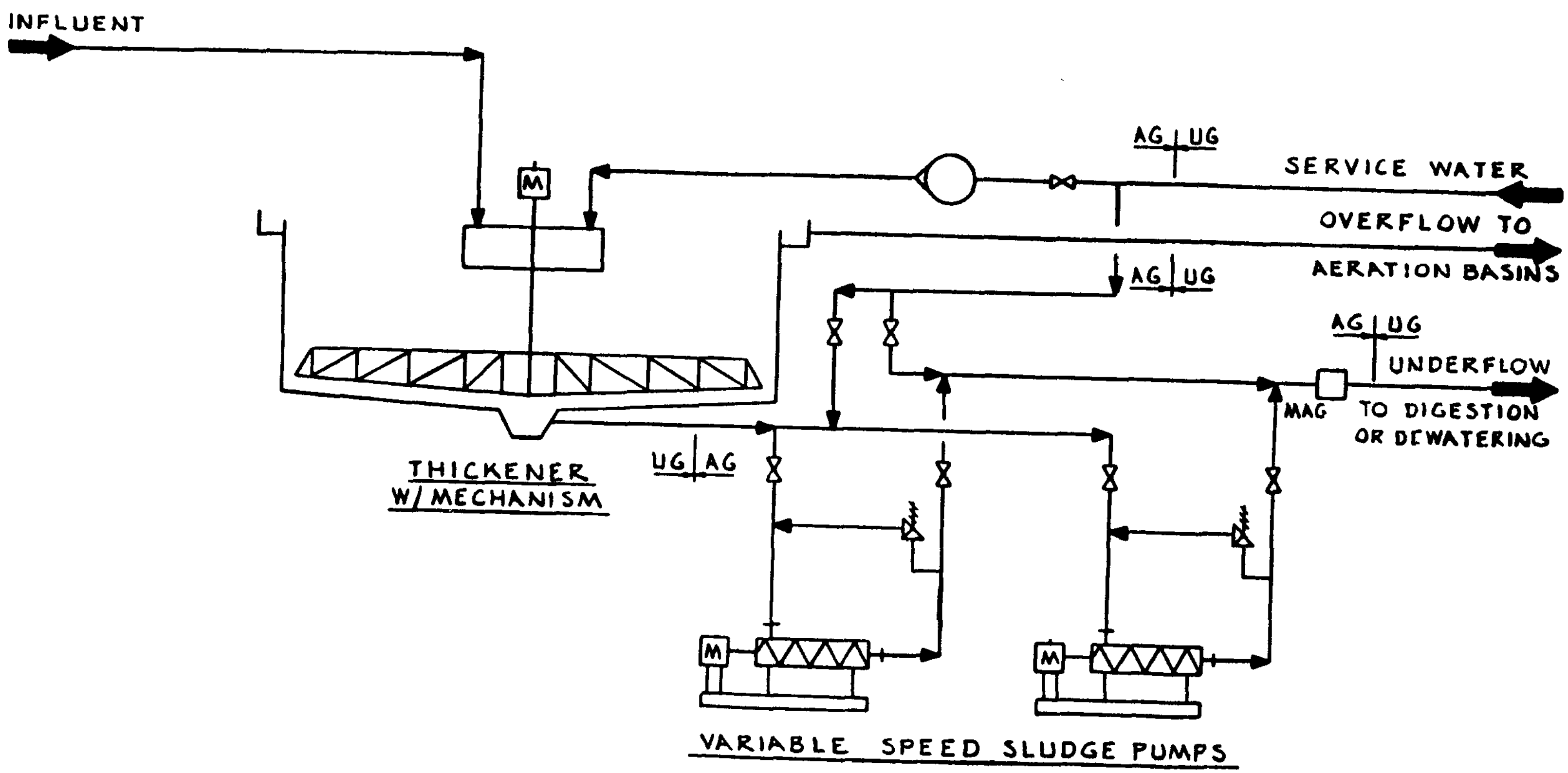
The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2].

b) Required Input Data

Type of sludge
Amount of each type of sludge to be thickened Kg/day (lb/day)
Total quantity of solids to be thickened Kg/day (lb/day)

c) Limitations

None specified.



NOTE:

1. ALL ABOVE GROUND PIPING TO BE INSULATED AND STEAM TRACED.

FIGURE IV.3.4.1-A1. PROCESS FLOW DIAGRAM FOR GRAVITY THICKENING [4-1]

TABLE IV.3.4.1-A1. VALUES OF SOLIDS LOADING RATE, INFLUENT SOLIDS CONCENTRATION, AND UNDERFLOW SOLIDS CONCENTRATION [4-1].

Sludge Number	Sludge Type	Solids Loading Rate (lb/ft²/day)	Solids Loading Rate (Kg/m²/day)	Expected Influent Solids Concentration (%)	Expected Underflow Concentration (%)
11	Lime Precipitate	40	195	10.0	15
12	Aluminum Precipitate	24	117	1.5	10
13	Iron Precipitate	15	73	3.0	30
14	Sulfide Precipitate	15	73	3.0	10
50	Primary Solids	20	98	3.0	9
51	Scrubber Sludge	20	98	3.0	9
*60	Waste Activated Sludge	5	24	1.0	3
65	Digested Sludge	5	24	1.5	3
80	Filter Backwash (Inorganic)	20	98	3.0	9
*90	Filter Backwash (Organic)	5	24	1.0	3

*If digested sludge (65) appears as an input, waste activated sludge (60) and organic filter backwash (90) are set to zero.

d) Pretreatment

None specified.

e) Design Equation

The total thickener surface area is calculated by summing the individual area required for each sludge type based on the solids loading rates from Table IV.3.4.1-A1.

Metric

$$AREA = \Sigma\ [Q(i) \div LOADING\ (i)]$$

where: AREA = total area requirement for thickener, m^2
Q (i) = quantity of sludge type (i), Kg/day
LOADING (i) = solids loading rate for sludge type (i), $Kg/m^2/day$ (Table IV.3.4.1-A1)

English

$$AREA = \Sigma[Q(i) \div LOADING(i)]$$

where: AREA = total area requirement for thickening, ft^2
Q (i) = quantity of sludge type (i), lbs/day
LOADING (i) = solids loading rate for sludge type (i), $lb/ft^2/day$ (Table IV.3.4.1-A1).

f) Subsequent Treatment

Further sludge dewatering such as vacuum or pressure filtration generally is required prior to final diposal of sludge. Thickener overflow also is returned to the plant for treatment.

A 2. Capital Costs

The cost factor for gravity thickening is the surface area of the unit. This parameter is the independent variable of the capital cost curve for this unit process (Figure IV.3.4.1-A2). Costs estimated using this curve must be adjusted to a current value using an appropriate cost index.

a) Cost Data

Items included in the capital cost curve estimates are as follows [4-2]:

Thickening tank, steel
Thickener mechanism, picket type except hopper bottom for smallest 2.13 m dia (7 ft. dia) unit
Pumps, progressive cavity (2)

Piping
Instrumentation

b) Capital Cost Curves

Curve - Figure IV.3.4.1-A2.
- Cost (hundred thousand dollars) vs total surface area (hundred square meters or hundred square feet).
- Curve basis, cost estimates for the gravity thickening process based on total surface area of gravity thickeners of 2.13, 3.05, 4.57, 9.14, 12.2, and 18.3 m (7, 10, 15, 30, 40, and 60 feet) in diameter with surface areas of 3.53, 7.34, 16.7, 66, 117, and 263 m^2 (38, 79, 180, 710, 1260, and 2830 ft^2) respectively.

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable component includes power, while the fixed component includes labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Cost

i) Power Requirements - mechanism and pump

Metric

$$KW = (0.02 \times AREA) + 0.556$$

where: KW = power required, kilowatts
AREA = total required thickener surface area, m^2

English

$$HP = (0.00248 \times AREA) + 0.746$$

where: HP = power required, Hp
AREA = total required thickener surface area, ft^2

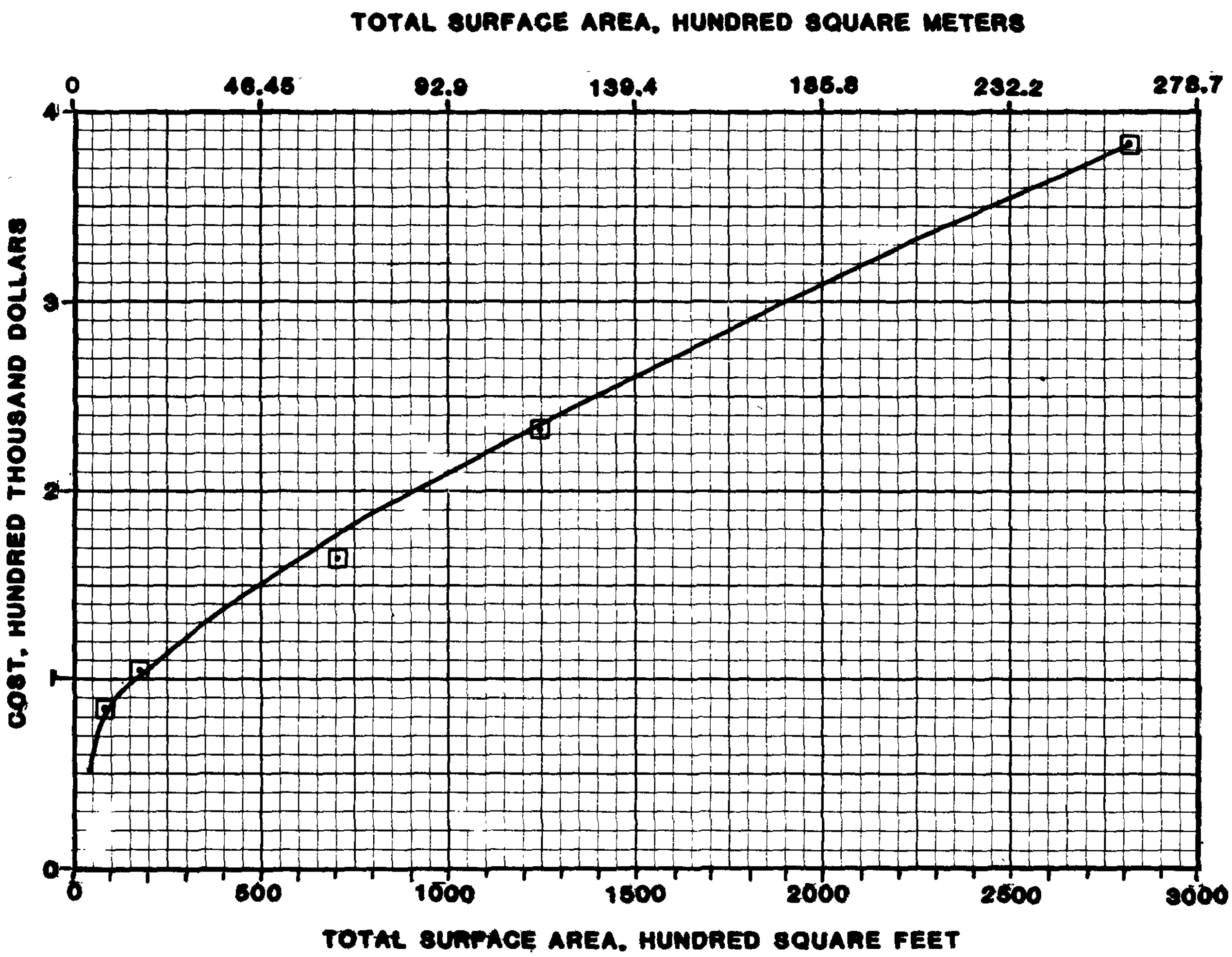


FIGURE IV.3.4.1-A2. CAPITAL COST ESTIMATE FOR GRAVITY THICKENING [4-10]

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, \$/day
KW = power required, kilowatts
24 = hr/day
EC = electricity cost, \$/Kw-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, \$/day
HP = power required, Hp
24 = hr/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, \$/Kw-hr

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.4.1-A2, including the cost basis and unit costs [4-11].

A 4. Miscellaneous Costs

Costs for engineering, and other common plant items such as piping and buildings, are calculated after the completion of costing for individual units (Section IV.3.5).

A 5. Modifications

None necessary.

TABLE IV.3.4.1-A2. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR GRAVITY THICKENING [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.15 Weeks (3.60 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.36 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.10 Shifts (0.57 hrs/day)	$10.70/hr
Maintenance	7.37% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.08 L/s (1.83 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

GRAVITY THICKENING
SUMMARY WORK SHEET

REFERENCE: IV.3.4.1-A

I. DESIGN FACTOR			CAPITAL
Total Thickener Surface Area = ______ ft^2			
II. CAPITAL COST			
Cost = ______ (Cost from curve) × (______ (current index) ÷ 204.7)			$ ______
III. VARIABLE O & M		$/day	O & M
Power = ______ (Hp) × ______ (EC, $/Kw-hr) × 17.9	=	______	
IV. FIXED O & M			
a. Labor: ______ (hr/day) × ______ ($/hr)	=	______	
b. Supervision: ______ (hr/day) × ______ ($/hr)	=	______	
c. Overhead: ______ (Labor, $/day) × ______ (%/100)	=	______	
d. Lab Labor: ______ (hr/day) × ______ ($/hr)	=	______	
e. Maint, Service, I&T: ______ (capital,) × ______ (%/100) ÷ 365 (day/yr)	=	______	
f. Service Water: ______ (thou gpd) × ______ ($/thou gal)	=	______	
V. YEARLY O & M 365 (day/yr) × ______ (sum, $/day)			= ______ $/yr
VI. UNCOSTED ITEMS			

GRAVITY THICKENING
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = _______ Capital Cost Index

2. EC: Electricity Cost = _______ $/Kw-hr

3. Labor = _______ $/hr

4. Supervision = _______ $/hr

5. Overhead = _______ % Labor ÷ _______ %/100

6. Lab Labor = _______ $/hr

7. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = _______ % Capital
   Other O & M Factor Sum = _______ ÷ 100 = _______ %/100

6. Service Water = _______ $/thou gal

I. DESIGN FACTOR

a. See Work Table 1.

   1. Enter quantity of each sludge type in Column A.

   2. Divide quantity of each sludge (from Column A) by corresponding solids loading rate (from Column B) and enter the results in Column C.

   3. Sum Column C to get the total thickener surface area.

$$\text{AREA} = \underset{\text{Sum Column C}}{\underline{\hspace{3cm}}}\ \text{ft}^2$$

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements

$$\text{HP} = (0.00248 \times \underset{\text{AREA, ft}^2}{\underline{\hspace{3cm}}}) + 0.746 = \underline{\hspace{2cm}}\ \text{Hp}$$

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

WORK TABLE 1. CALCULATIONS FOR DETERMINING TOTAL THICKENER SURFACE AREA

Sludge Number	Sludge Type	A *Quantity of Sludge, Q* (lbs/day)	B *Solids Loading Rate* (lbs/sq ft/day)	C Area = A/B (sq ft)
11	Lime Precipitate		40	
12	Aluminum Precipitate		24	
13	Iron Precipitate		15	
14	Sulfide Precipitate		15	
50	Primary Solids		20	
51	Scrubber Sludge		20	
*60	Waste Activated Sludge		5	
65	*Digested Sludge*		5	
80	Filter Backwash (Inorganic)		20	
*90	Filter Backwash (Organic)		5	
			Sum C = (Total Area)	

*If digested sludge (65) appears as an input, waste activated sludge (60) and organic filter backwash (90) are set to zero.

IV.3.4.2 DIGESTION

Introduction

Digestion is a method of sludge stabilization that uses bacteria to degrade organic matter. Alternatives include aerobic and anaerobic processes. The process is described in more detail in Volume III of the Treatability Manual, Section III.4.2. Costing methodologies and cost data for industrial wastewater treatment applications are presented below.

IV.3.4.2-A. Aerobic Digestion

A 1. Basis of Design

This presentation is for aerobic digestion of waste activated sludge and filter backwash organic solids. A system of the type considered here is represented in Figure IV.3.4.2-A1. The cost factor for the digestion system is the volume of the required aeration basin. The design of the system involves quantification of the amount of sludge to be treated and sizing of the digester basin volume based on the concentration of influent waste solids.

a) Application

This cost estimate method was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries.

b) Required Input Data

Sludge flow rate, L/s (gpd; where sludge flow is reported in Kg/day or lb/day, it is necessary to compute flow using the sludge solids concentration)
Temperature (°C)

c) Limitations

This technology is applied primarily to waste activated sludge or organic solids from filter backwash.

d) Pretreatment

Aerobic digestion may be preceded by gravity thickening.

e) Design Equation

The principal design and cost factor for this technology is the digester basin volume. Unless some other volume is specified by the user, the digester volume is calculated based on a hydraulic detention time of 15 days. An influent solids concentration of 2.5% is used with thickening preceding digestion, with 1.0% used without thickening preceding the unit.

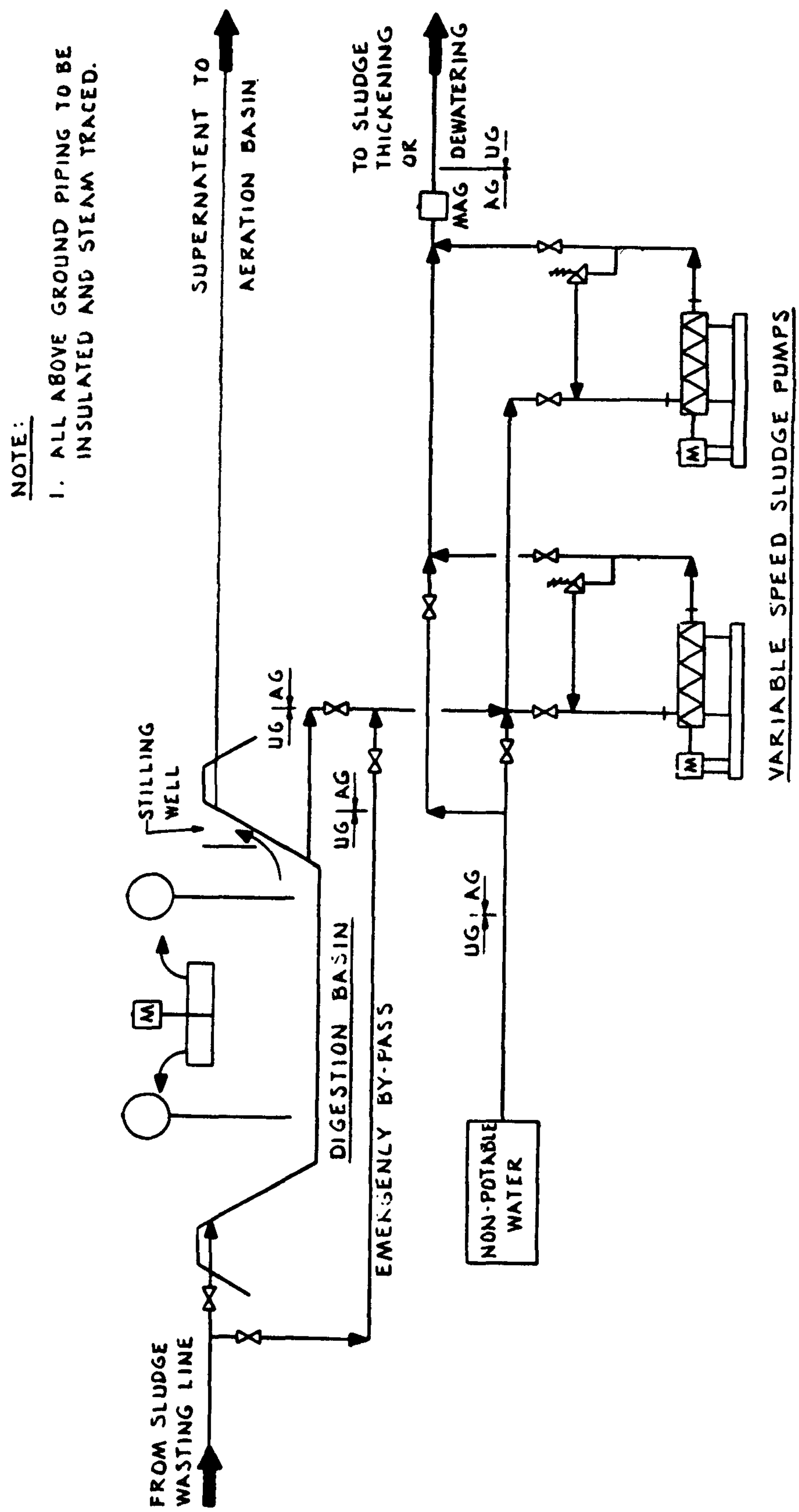


FIGURE IV.3.4.2-A1. PROCESS FLOW DIAGRAM FOR AEROBIC DIGESTION [4-1]

Metric

$$VOL = RT \times LPS \times 86{,}400$$

where: VOL = digester basin volume, L
RT = hydraulic retention time, days (15 days unless otherwise specified)
LPS = sludge flow rate, L/s
= SLDG ÷ SC
SLDG = total sludge to be digested, Kg/day (dry solids basis; sum of activated sludge and organic backwash solids)
SC = influent solids concentration, % ÷ 100 (SC = 0.01 without or SC = 0.025 with thickening) [4-1]
86,400 = sec/day

English

$$VOL = RT \times GPD$$

where: VOL = digester basin volume, gallon
RT = hydraulic retention time, days (15 days unless otherwise specified) [4-1]
GPD = sludge flowrate, gpd
= SLDG ÷ (SC × 8.34)
SLDG = total sludge to be digested, lb/day (dry solids basis; sum of activated sludge and organic backwash solids)
8.34 = lb/gal
SC = influent solids concentration, % ÷ 100 (SC = 0.01 without or SC = 0.025 with thickening) [4-1]

f) Subsequent Treatment

Normally aerobic digestion is followed by solids separation and dewatering. The supernatant or filtrate is returned to treatment and the solids are disposed of by landfilling or incineration.

A 2. Capital Costs

The principal cost factor for aerobic digestion is the required digester basin volume. The estimated capital cost for aerobic digestion is presented in Figure IV.3.4.2-A2 as a function of basin volume. Costs estimated using the cost curve must be adjusted to a current value using an appropriate current cost index.

a) Cost Data

The items included in the capital cost estimates are [4-2]:

Digestion basin, depth 3.66 m (12 ft) plus 0.914 m (3 ft) freeboard (Steel tank for 114,000, 397,000, and 1,140,000 liters (30,000, 105,000, and 300,000 gallon) designs, with earthen basin and membrane liner for 3,410,000 (900,000 gallon) basin)
Pumps, variable speed progressive cavity (two)
Floating low speed aerators (two)
Piping
Instrumentation

b) Capital Cost Curves

Curve - see Figure IV.3.4.2-A2
- Cost (thousands of dollars) vs. volume (thousands liters or thousand gallons).
- Curve basis, cost estimate for four systems with basin volumes of 114,000, 397,000, 1,140,000, and 3,410,000 liters (30,000, 105,000, 300,000, and 900,000 gallons).

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable component includes power, while the fixed component includes labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Cost

i) Power Requirements - aerators and pumps. The following equation was developed using regression analysis procedures [4-1].

Metric

$$KW = (2.38 \times 10^{-5} \times VOL) - 1.44$$

where: KW = power, kilowatts
VOL = digester basin volume, liter

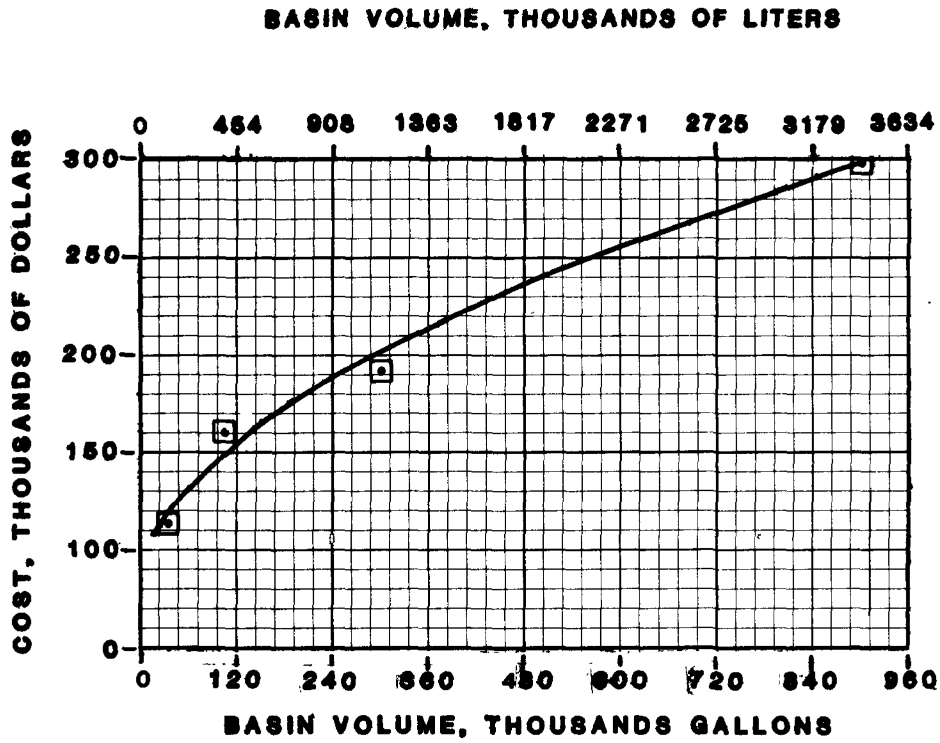


FIGURE IV.3.4.2-A2. CAPITAL COST ESTIMATE FOR AEROBIC DIGESTION [4-10]

English

$$HP = (1.21 \times 10^{-4} \times VOL) - 1.93$$

where: HP = power, Hp
VOL = digester basin volume, gallon

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, \$/day
KW = power, kilowatts
24 = hr/day
EC = electricity cost \$/Kw-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where: PC = power cost, \$/day
24 = hr/day
0.746 = Kw-hr/Hp-hr
EC = electricity cost, \$/Kw-hr

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.4.2-A1, including the cost basis and the unit costs [4-11].

A 4. Miscellaneous Costs

Costs for engineering, and other common plant items such as land, piping, and buildings, are calculated after completion of costing for individual units (see Section IV.3.5). The amount of sludge remaining after digestion should be calculated for use in the sizing and costing of subsequent sludge handling systems.

a) Remaining Sludge Quantity

The quantity of sludge remaining after aerobic digestion is calculated based on an assumed ratio of 80% volatile to 20% non-volatile influent solids and a reduction of 4% per day at 20°C of the volatile fraction to a maximum 70% reduction [4-1]. This rate may be adjusted for temperature as necessary.

$$SLGR = NVSS + [VSS \times (1 - RATE)^{RT}]$$

TABLE IV.3.4.2-A1. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR AEROBIC DIGESTION [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.15 Weeks (3.60 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.36 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.10 Shifts (0.57 hrs/day)	$10.70/hr
Maintenance	2.39% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.056 L/s (1.29 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

where: SLGR = quantity of sludge remaining after digestion, Kg/day or lb/day
NVSS = influent nonvolatile solids, Kg/day or lb/day
= $0.2 \times$ SLDG, [4-1]
SLDG = total influent sludge, Kg/day or lb/day
VSS = influent volatile solids, Kg/day or lb/day
= $0.8 \times$ SLDG, [4-1]
RATE = reduction rate of VSS per day
= $0.04 \times (1.06)^{T-20}$ [4-1]
0.04 = rate of reduction (4%/day) at T = 20°C [4-1]
T = reaction temperature, °C
RT = hydraulic retention time, days
= (15 days unless otherwise specified) [4-1]

A 5. Modifications

None Required.

AEROBIC DIGESTION SUMMARY WORK SHEET

REFERENCE: IV.3.4.2-A

I. DESIGN FACTOR			**CAPITAL**
Basin Volume = ________ thousand gallons			
II. CAPITAL COST			
Cost = ____________ (Cost from curve) × (__________ (current index) ÷ 204.7)			$ ________
III. VARIABLE O & M		**$/day**	**O & M**
Power = ________ (Hp) × ________ (EC, $/Kw-hr) × 17.9	=	________	
IV. FIXED O & M			
a. Labor: ________ (hr/day) × ________ ($/hr)	=	________	
b. Supervision: ________ (hr/day) × ________ ($/hr)	=	________	
c. Overhead: ________ (Labor, $/day) × ________ (%/100)	=	________	
d. Lab Labor: ________ (hr/day) × ________ ($/hr)	=	________	
e. Maint, Service, I&T: ________ (capital, $) × ________ (%/100) ÷ 365 (day/yr)	=	________	
f. Service Water: ________ (thou gpd) × ________ ($/thou gal)	=	________	
V. YEARLY O & M	365 (day/yr) ×	________ (sum, $/day)	= ________ ($/yr)
VI. UNCOSTED ITEMS			
a. Digested Biological Sludge Remaining = ________ lb/day			

AEROBIC DIGESTION
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ \$/Kw-hr

3. Labor = ________ \$/hr

4. Supervision = ________ \$/hr

5. Overhead = ________ % Labor ÷ 100 = ________ %/100

6. Lab Labor = ________ \$/hr

7. Maintenance = % Capital
Services = % Capital
Insurance/Taxes = ________ % Capital
Other O & M Factor sum = ________ ÷ 100 = ________ %/100

8. Service Water = ________ \$/thou gal

I. DESIGN FACTOR

a. Quantity of waste activated sludge (WAS) = ________ lb/day

b. Quantity of organic filter backwash (OFB) = ________ lb/day

c. Total quantity of sludge to be digested

$$\text{SLDG} = (\underset{\text{WAS, lb/day}}{\underline{\hspace{3cm}}}) + (\underset{\text{OFB, lb/day}}{\underline{\hspace{3cm}}}) = \underline{\hspace{2cm}} \text{ lb/day}$$

d. Sludge Flow Rate

1. If thickening is not provided:

$$\text{GPD} = (\underset{\text{SLDG, lb/day}}{\underline{\hspace{3cm}}}) \div 0.0834 = \underline{\hspace{2cm}} \text{ gpd,}$$

2. If thickening is provided:

$$\text{GPD} = (\underset{\text{SLDG, lbs/day}}{\underline{\hspace{3cm}}}) \div 0.209 = \underline{\hspace{2cm}} \text{ gpd,}$$

e. Digester basin Volume

$$\text{VOL} = (\underset{\text{GPD, gpd}}{\underline{\hspace{2cm}}}) \times (\underset{\text{RT = 15, days}}{\underline{\hspace{3cm}}}) = \underline{\hspace{2cm}} \text{ gallons}$$

II. CAPITAL COST

III. VARIABLE O & M

Power Requirements

$$HP = (\underset{\text{VOL, gallons}}{\underline{\qquad\qquad}} \times 1.21 \times 10^{-4}) - 1.93 = \underline{\qquad\qquad} \text{ Hp}$$

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Remaining Sludge Quantity

1. Rate of Reduction of VSS
   Temperature, T = ________ °C

   $$RATE = 0.04 \times (1.06)^{(\underline{\qquad} - 20)} = \underline{\qquad\qquad} \text{ fraction/day}$$

2. Influent Solids

   $$NVSS = \underset{\text{SLDG, lb/day}}{\underline{\qquad\qquad}} \times 0.20 = \underline{\qquad\qquad} \text{ lb/day}$$

   $$VSS = \underset{\text{SLDG, lb/day}}{\underline{\qquad\qquad}} \times 0.80 = \underline{\qquad\qquad} \text{ lb/day}$$

3. Retention Time
   RT = ________ days

4. Sludge Remaining

   $$SLGR = \underset{\text{NVSS, lb/day}}{\underline{\qquad\qquad}} + \underset{\text{VSS, lb/day}}{\underline{\qquad\qquad}} \times (1 - \underset{\text{RATE}}{\underline{\qquad}})^{\overline{\text{RT, days}}}$$

   $$= \underline{\qquad\qquad} \text{ lb/day}$$

IV.3.4.3 DEWATERING

Introduction

Dewatering is desirable to reduce sludge volume prior to transporting and landfilling, or to prepare sludge for incineration or composting. Some dewatering processes use natural means (e.g., evaporation, percolation) for moisture removal. Others use mechanical devices (e.g., filters, centrifuges) to hasten the dewatering process. Further details describing these dewatering processes can be found in Volume III, Section III.4.3 of the Treatability Manual. Costing methodologies and cost data for industrial wastewater treatment applications are presented below.

A. Vacuum and Pressure Filtration

A 1. Basis of Design

This presentation is for vacuum filtration (rotary vacuum filters) or pressure filtration (filter press) of wastewater sludge. Process flow diagrams for vacuum and pressure filtration are presented in Figures IV.3.4.3-A1 and A2, respectively. Vacuum filtration is used for most applications because of lower cost. However, pressure filtration may be considered for use prior to incineration of biological sludge since it produces a sludge (35 to 50% solids) which is dry enough for self-sustained combustion. Pressure filtration may also be selected for its greater ability to reduce sludge volume in cases where landfill area is limited.

The surface area of the operating filter is the basis for determining costs associated with a filtration sludge dewatering system. Factors which affect filter surface area are filter yield and operation time. Incoming sludges are characterized as to amount (Kg/day, lb/day) and sludge type. The amount of conditioning chemicals (lime and $FeCl_3$) and the expected filter yield are then estimated for each sludge type from factors presented in Table IV.3.4.3-A1 depending on whether a vacuum or pressure filter is to be used. The total filter area is then computed based on the amount of surface area required for each type of sludge, the expected time of operation, and practical limitations on the sizes of filter units commercially available. Most vacuum filters require that the filter surface be washed after the cake has been removed. If a pressure filter is selected, a thin layer of diatomaceous earth also is applied on the pressure filter medium to enhance the filter's ability to remove suspended solids.

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assump-

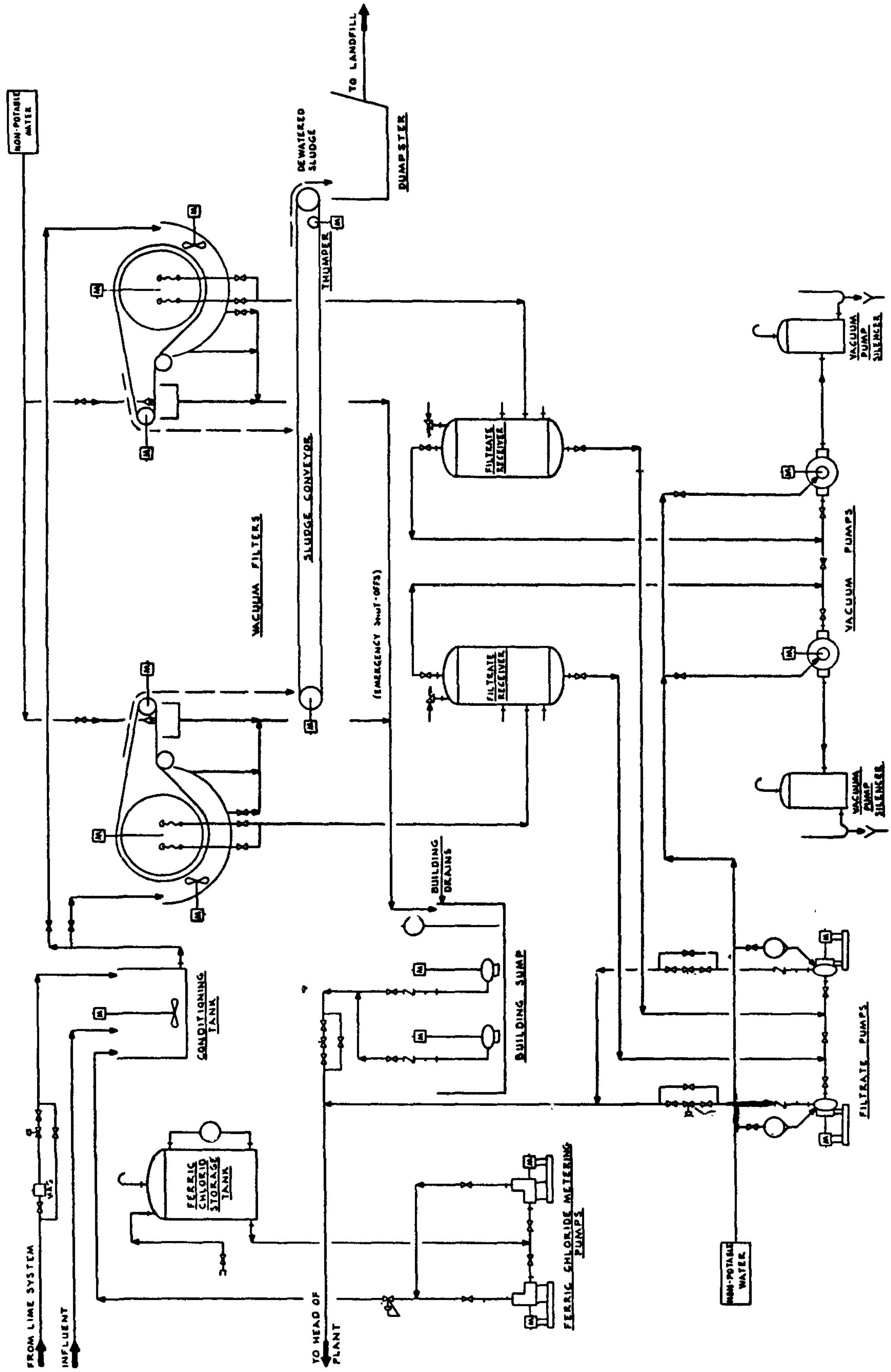


FIGURE IV.3.4.3-A1. PROCESS FLOW DIAGRAM FOR VACUUM FILTRATION [4-1]

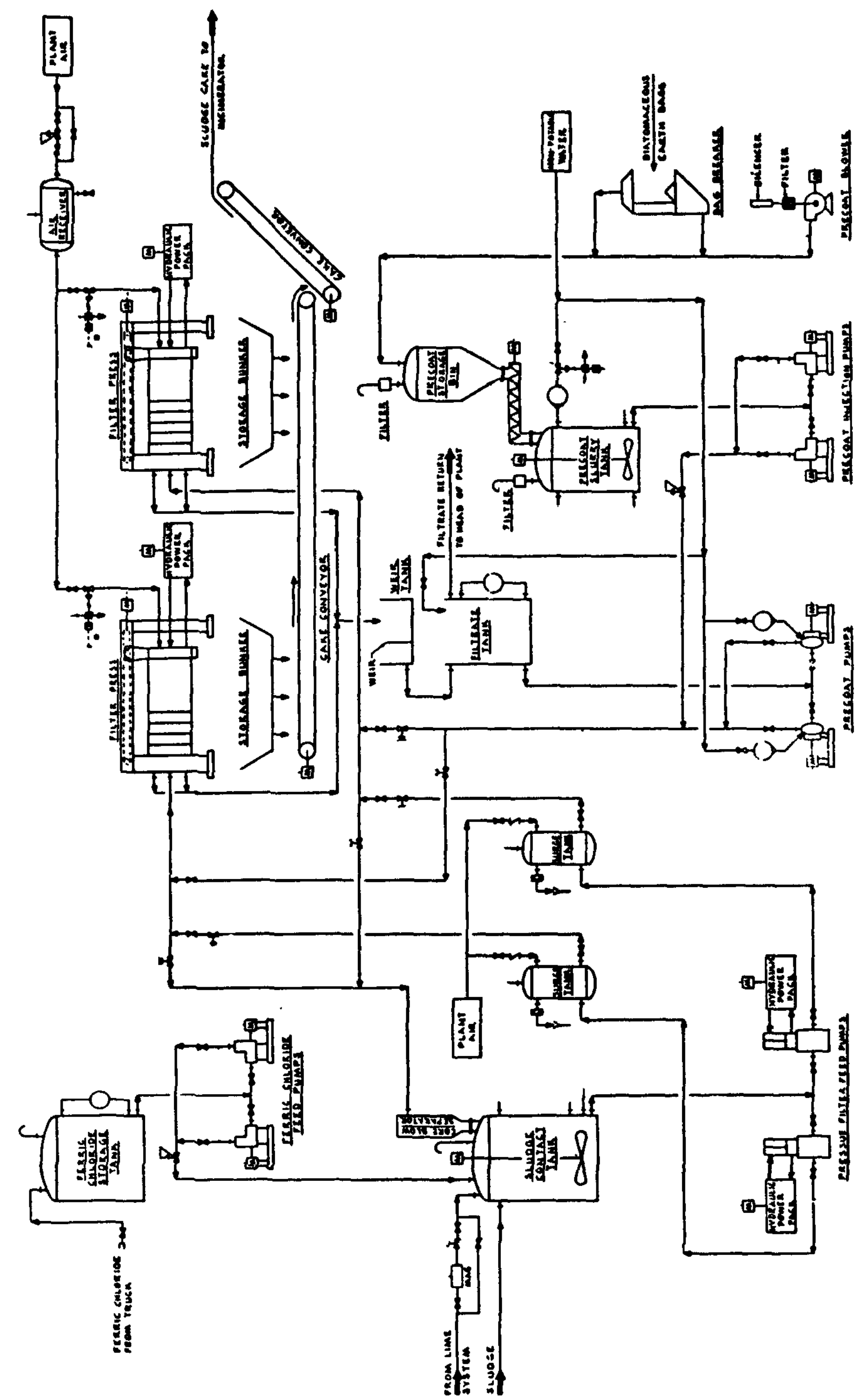


FIGURE IV.3.4.3-A2. PROCESS FLOW DIAGRAM FOR PRESSURE FILTRATION [4-1]

TABLE IV.3.4.3-A1. CHEMICAL CONDITIONING REQUIREMENTS AND DESIGN PERFORMANCE FACTORS FOR VACUUM FILTRATION AND PRESSURE FILTRATION OF WASTEWATER SLUDGE [4-1], [4-2]

Sludge Number	Sludge Description	Ferric Chloride Required, %(c)		Lime Required, %(c)		Filter Yield Kg(dry)/hr/sq m		Filter Yield lb (dry)/hr/sq ft		Filter Cake % Solids	
		Vacuum	Pressure	Vacuum	Pressure	Vacuum	Pressure	Vacuum	Pressure	Vacuum	Pressure
11	Lime Precipitate	0	0	0	0	49	3.6	10	3.6	40	50
12	Alum Precipitate	0	30	20	0	3.9	1.6	0.8	1.6	20	40
13	Ferric Chloride Precipitate	0	30	20	0	5.8	1.6	1.2	1.6	20	40
14	Sulfide Precipitate	0	0	20	30	3.9	1.6	0.8	1.6	20	40
20	D.A.F. Chemical Float(a)	1.5	10	8	5	39	2.2	8	2.2	25	45
50	Process (Primary) Solids	1.5	10	8	5	39	2.2	8	2.2	25	45
51	Incinerator Scrubber Sludge	1.5	10	8	5	39	2.2	8	2.2	25	45
60	Waste Activated Sludge	4.0	15	15	8	2.0	1.5	2	1.5	12	35
65	Digested W.A.S.(b)	4.0	15	15	8	2.0	1.5	2	1.5	12	35
80	Filter Backwash (Inorganic)	1.5	10	8	5	39	2.2	8	2.2	25	45
90	Filter Backwash (Organic)	4.0	15	15	8	2.0	1.5	2	1.5	12	35

a. Float from Dissolved Air Flotation
b. Digested Waste Activated Sludge
c. Chemical dosages reported as % of dry weight solids

tions and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

Amount and type of each sludge to be dewatered Kg/day (lb/day)
Number of hours of operation per week
Desired dewatered sludge solid content (%)
Ultimate means of sludge disposal (incineration or landfill)

c) Limitations

i) Sludge dewatering is not used for combustible type residuals (DAF float, oil, solvent extraction residues, and steam stripping residues).

ii) Maximum size for vacuum filters is considered to be 35 m^2/unit (377 ft^2/unit).

iii) Maximum size for pressure filters is considered to be 465 m^2/unit (5,000 ft^2/unit).

d) Pretreatment

Thickening is generally used prior to dewatering but is not required in every case.

e) Design Factor

i) Vacuum Filter

The primary factor used for design of vacuum filters is the surface area per filter. The total filter area is the sum of the filter area required for dewatering each sludge type. The filter area required for each sludge type is determined by summing the amount of each type of sludge with the amount of chemicals (lime and ferric chloride) required for conditioning and dividing the sum by the expected filter yield for that sludge type (Table IV.3.4.3-A1). Surface area per filter is calculated by taking the total filter area and adjusting for the hours of operation and the number of filters. The maximum area per filter is assumed to be 35 m^2 (377 ft^2) [4-1].

$$\text{AREA} = \Sigma\{[Q(n) + (Q(n) \times \text{LIME}(n)) + (Q(n) \times \text{FECL}(n))] \div \text{YIELD}(n)\} \times 7 \div (\text{HR} \times \text{N})$$

where: Q(n) = quantity of sludge of type (n), Kg/day or lb/day

LIME(n) = lime loading factor for sludge type (n), as fraction of sludge, %/100 (Table IV.3.4.3-A1)

FECL(n) = ferric chloride loading factor for sludge type (n), as fraction of sludge, %/100 (Table IV.3.4.3-A1)

YIELD(n) = expected yield for sludge type (n), (Table IV.3.4.3-A1)

7 = days/week

HR = hours per week of operation, hr/week

N = number of operating filters

The hours per week of operation are balanced against the maximum practical size for an individual filter, assumed to be 35 m^2 (377 ft^2). Several trial runs are made to determine the optimum number of filters and hours of operation. It is initially assumed that the filter operates five days per week, eight hours per day (40 hr/wk). If the filter area required exceeds the maximum practical area (35 m^2, 377 ft^2), the hours of operation are increased to two shifts (80 hr) then three shifts (120 hr) up to three shifts, seven days per week (168 hr) until the required area equals the available area. If the required filter area cannot be met with a three shift operation, additional filters are added and the operation hours procedure is repeated until the required area is met.

Once the area of a single filter is computed, it is adjusted to one of the standard filter sizes shown in Table IV.3.4.3-A2. In addition to operating filters, each system is assumed to include one spare filter unit.

TABLE IV.3.4.3-A2. STANDARD VACUUM FILTER SIZES AND BASE POWER REQUIREMENTS [4-2]

Filter Area		Base Power		Filter Area		Base Power	
(m^2)	(ft^2)	Kilowatts	Horsepower	(m^2)	(ft^2)	Kilowatts	Horsepower
0.93	10	4.1	5.4	6.6	71	18	24
1.8	19	6.0	8.1	9.2	99	24	32
2.6	28	9.7	13	12 & 14	132 & 151	31	42
4.4	47	11	15	19 & 23	207 & 251	46	62
5.8	62	13	18	28 & 35	302 & 377	84	112

ii) Pressure Filter

The primary factor used for design of pressure filters is the area per filter. First, the total filter area is determined by summing the filter surface area required for each sludge type. The filter surface area required for each sludge type is calculated by summing the amount of each type of sludge with the amount of chemicals (lime and ferric chloride) required for conditioning and dividing the sum by the expected filter yield for that sludge type (Table IV.3.4.3-A1). Total filter area is then determined by summing the area requirements for all types of sludge being dewatered. Surface area per filter is determined by adjusting the total filter area for the hours of operation and the number of filters required. The maximum practical size for an individual filter is to be 465 m^2 (5000 ft^2) in this case [4-1].

$$\text{AREA} = \Sigma\{[Q(n) + Q(n) \times \text{LIME}(n) + Q(n) \times \text{FECL}(n)] \div \text{YIELD}(n)\} \times 7 \div (\text{CYCLES} \times 2.67 \times N)$$

where:
AREA = surface area per filter, m^2 or ft^2 (maximum = 35 m^2 or 5,000 ft^2)
Q(n) = quantity of sludge of type (n), Kg/day or lb/day
LIME(n) = lime requirement for sludge of type (n), as fraction of sludge, %/100 (Table IV.3.4.3-A1)
FECL(n) = $FeCl_3$ requirement for sludge of type (n), as fraction of sludge, %/100 (Table IV.3.4.3-A1)
7 = days/week
CYCLES = number of filter operation cycles per week
2.67 = hr/cycle
N = number of filters required (initially 2)
YIELD(n) = expected filter yield for sludge of type (n), (Table IV.3.4.3-A1), Kg/hr/m^2 or lb/hr/ft^2

The number and surface area of the filter units is determined by balancing the cycles per week of operation against the maximum practical filter size, 465 m^2 (5,000 ft^2). It is initially assumed that the filter operates five days per week, three cycles per day (15 cycles per week). If the surface area per filter estimated using these conditions exceeds the maximum practical size, the cycles of operation are increased to two shifts (30 cycles/week) or three shifts (45 cycles/week) on up to three shifts, seven days per week (63 cycles/week) until the estimated area of a single filter no longer exceeds the 465 m^2 (5,000 ft^2) limit or the decision is reached to add another filter. If at the conclusion of the surface area calculation, the number of cycles/week exceeds 30, another operating filter is added. One spare filter is always included in addition to the operating units.

f) <u>Subsequent Treatment</u>

Landfill or incineration.

A 2. Capital Costs

Vacuum Filtration

The cost factor for vacuum filtration is the surface area of the operating filter drum(s). This parameter is the independent variable of the cost curve for this unit process (Figure IV.3.4.3-A3). Since the curve gives the cost per filter, the cost must be multiplied by the number of filters (operating plus one spare) to obtain capital cost. The number of filters is the scale factor for this unit process.

Pressure Filtration

The cost factor for pressure filtration is the required surface area of the individual filter press. This parameter is the independent variable of the cost curve for this unit process (Figure IV.3.4.3-A4). Since the curve gives the cost per filter, the cost must be multiplied times the number of filters (operating plus one spare) to obtain capital cost. The number of filters is the scale factor for this unit process.

Costs estimated using these cost curves must be adjusted to current values using an appropriate current cost index.

a) <u>Cost Data</u>

i) The items included in the capital cost estimates for the vacuum filtration process are as follows [4-10]:

Package Vacuum Filter Units -
- vacuum filter,
- vacuum pumps,
- filtrate pumps,
- filtrate receivers,
- vacuum pump silencers.

Belt conveyors
Tanks, vessels and drums
Miscellaneous mechanical equipment
Piping
Instrumentation

ii) The items included in the capital cost estimates for the pressure filtration process are as follows [4-10]:

Package Pressure Filter Units -
- pressure filter,
- ferric chloride system,

pre-coat system,
conveyors,
control valves and pumps.

b) <u>Capital Cost Curves</u>

i) Vacuum Filtration

Curve - Figure IV.3.4.3-A3.
- Cost (thousands of dollars) vs. surface area of individual operating filter drum (square meters or square feet)
- Curve basis, cost estimates to dewater the sludge produced by systems at four flow rates, 8.76, 43.8, 219, and 876 L/s (0.2, 1.0, 5.0, and 20 mgd) corresponding to filter areas of 1.8, 5.3, 14, and 44 m^2, (19, 57, 150, and 470 ft^2)

Scale Factor - number of filters (operating plus spare)

Capital Cost = cost per filter × no. filters

ii) Pressure Filtration

Curve - Figure IV.3.4.3-A4.
- Cost (thousands of dollars) vs. surface area of individual filter (square meters or square feet)
- Curve basis, cost estimates to dewater the sludge produced by systems at four flow rates, 8.76, 43.8, 219, and 876 L/s (0.2, 1.0, 5.0, and 20 mgd)

Scale Factor - number of filters (operating plus one spare)

Capital cost = cost per filter × no. filters

c) <u>Cost Index</u>

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable component includes power, chemicals, and wash water. The fixed component includes labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

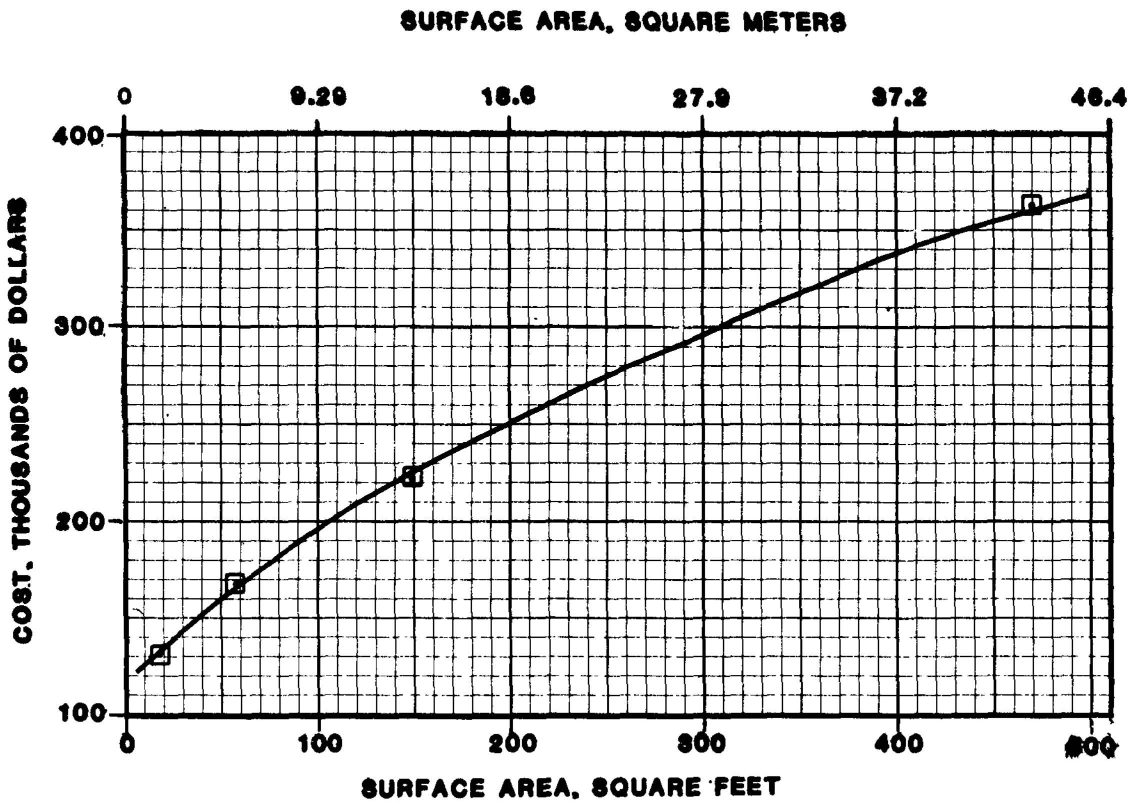


FIGURE IV.3.4.3-A3. CAPITAL COST ESTIMATE FOR VACUUM FILTRATION [4-10]

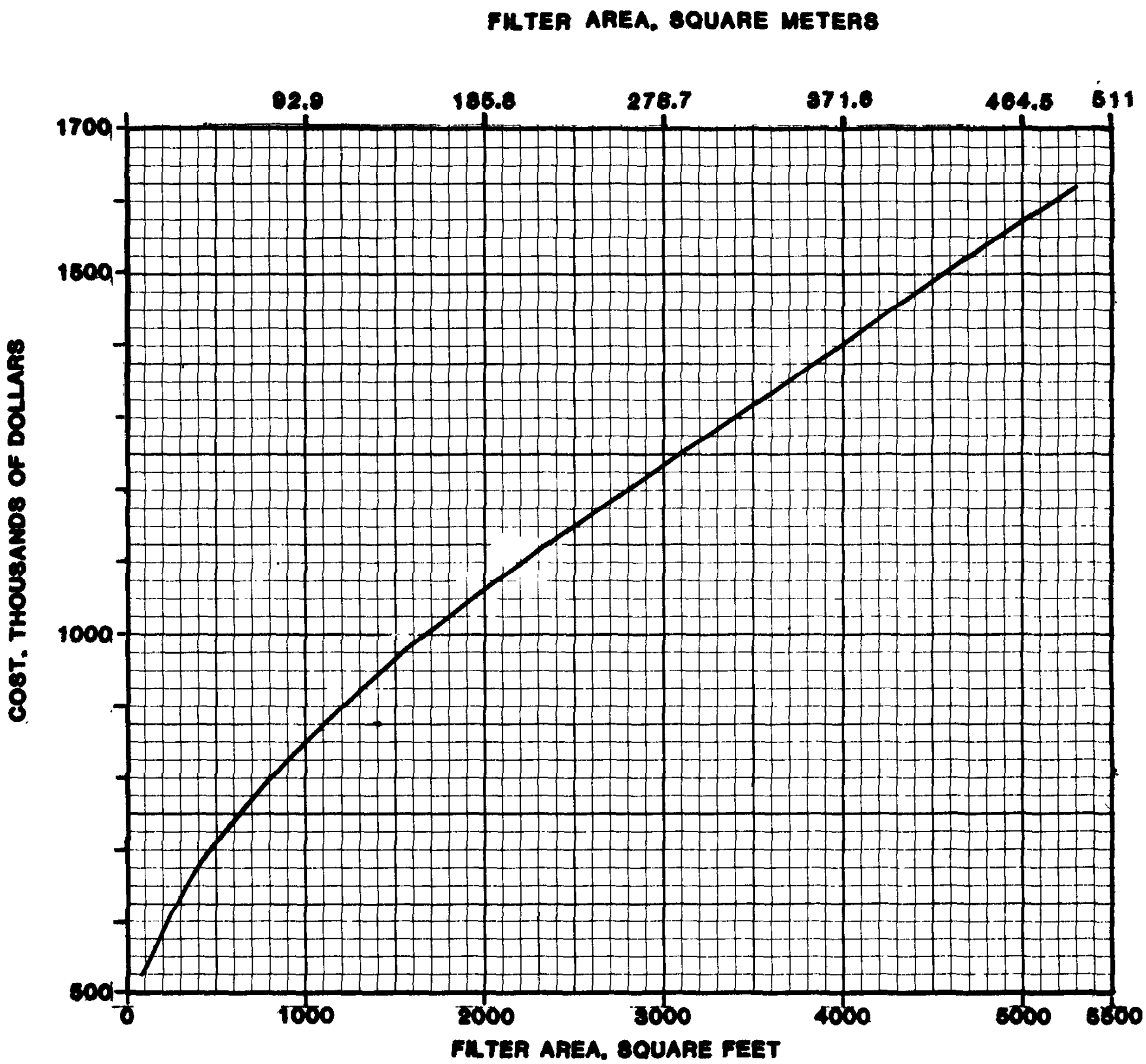


FIGURE IV.3.4.3-A4. CAPITAL COST ESTIMATE FOR PRESSURE FILTRATION [4-10]

a) Variable Cost

i) Power Requirements Vacuum Filtration - pumps, conveyors, mixers. This equation was developed using regression analysis procedures.

Metric

$$KW = [BKW + (0.0334 \times AREA) + 1.89] \times HR \times N \div 168$$

where:
- KW = power requirement, kilowatts
- BKW = base power for standard filter size (Table IV.3.4.3-A2)
- AREA = individual filter area, m^2
- HR = hours of operation per week, hr
- N = number of filters
- 168 = hours per week

English

$$HP = [BHP + (0.00414 \times AREA) + 2.53] \times HR \times N \div 168$$

where:
- HP = horsepower requirement, Hp
- BHP = base horsepower for standard filter sizes (Table IV.3.4.3-A2)
- AREA = individual filter area, ft^2

ii) Power Requirements - Pressure Filtration - pumps, conveyors, mixers. This equation was developed using regression analysis procedures.

Metric

$$KW = [(0.056 \times AREA) + 26.3] \times N \times CYCLES \times 2.67 \div 168$$

where:
- KW = power requirement, kilowatts
- AREA = individual filter area, m^2
- N = number of filters
- CYCLES = filter cycles per week
- 2.67 = hours per cycle
- 168 = hours per week

English

$$HP = [(0.007 \times AREA) + 35.3] \times N \times CYCLES \times 2.67 \div 168$$

where: HP = horsepower requirement, HP
AREA = individual filter area, ft^2

iii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where: PC = power cost, \$/day
KW = power requirements, kilowatts
24 = hr/day
EC = electricity cost, \$/Kw-hr

English

$$PC = HP \times 0.746 \times 24 \times EC$$

where: PC = power cost, \$/day
HP = horsepower required, Hp
0.746 = kw-hr/Hp-hr

iv) Chemical Requirements

Ferric chloride and lime
- The amount of ferric chloride and lime required for either vacuum or pressure filtration is determined as follows:

Metric

$$LIME = \Sigma[Q(n) \times LIME(n)]$$
$$FECL = \Sigma[Q(n) \times FECL(n)]$$

where: LIME = total amount of lime required, Kg/day
FECL = total amount of ferric chloride required, Kg/day
Q(n) = amount of sludge of type (n), Kg/day
FECL(n) = $FeCL_3$ requirement for sludge of type (n), as fraction of sludge, %/100 (see Table IV.3.4.3-A1)
LIME(n) = lime requirement for sludge of type (n), as fraction of sludge, %/100 (see Table IV.3.4.3-A1)

English

$$LIME = \Sigma[Q(n) \times LIME(n)]$$
$$FECL = \Sigma[Q(n) \times FECL(n)]$$

where: LIME = total amount of lime required, lb/day
FECL = total amount of ferric chloride required, lb/day
Q(n) = amount of sludge of type(n), lb/day

Diatomaceous Earth

- The amount of diatomaceous earth required to precoat a pressure filter is determined by:

Metric

$$DE = AREA \times CYCLES \times 0.39 \times N$$

where: DE = quantity of diatomaceous earth, Kg/day based on an application rate of 39 Kg of precoat per 100 m^2 of filter
AREA = individual filter area, m^2
CYCLES = number of filter cycles per day
0.39 = application rate, 39 Kg/100 m^2
N = number of filters

English

$$DE = AREA \times CYCLES \times 0.08 \times N$$

where: DE = quantity of diatomaceous earth, lb/day based on an application rate of 8 lbs of precoat per 100 ft^2 of filter
AREA = individual filter area, ft^2
0.08 = application rate, 8 lb/100 ft^2

v) Chemical Cost (except lime*)

The cost of ferric chloride and diatomaceous earth may be determined as follows:

Ferric chloride

$$FC = FECL \times CCF$$

where: FC = daily cost for ferric chloride, $/day
FECL = total amount of ferric chloride required, Kg/day or lb/day
CCF = cost of ferric chloride, $/Kg or $/lb

Diatomaceous Earth

$$DEC = DE \times CCD$$

where: DEC = daily cost for diatomaceous earth, \$/day
DE = daily quantity of diatomaceous earth, Kg/day or lb/day
CCD = cost of diatomaceous earth, \$/Kg or \$/lb

*It is assumed that lime is supplied to each unit from a central lime handling facility. Thus, the cost of lime for any one process depends on the total lime requirements of the plant as a whole. Lime requirements for these and other unit processes requiring lime should be summed and the costs estimated as shown in the Lime Handling Section (Section IV.3.1.13-C).

vi) Wash Water Requirements for Vacuum Filter

Metric

$$WATER = (16 \times AREA \times N \times HR \times 1440) \div (168 \times 1000)$$

where: WATER = wash water requirement, thousand liters/day
16.3 = wash rate, L/min-m^2
AREA = surface area of each filter, m^2
N = number of operating filters
HR = hours of operation per week, hr
1440 = minutes/day
168 = hours/week

English

$$WATER = (0.4 \times AREA \times N \times HR \times 1440) \div (168 \times 1000)$$

where: WATER = wash water requirement, thousand gallons/day
0.4 = wash rate, gal/min-ft^2
AREA = surface area of each filter, ft^2
N = number of operating filters
HR = hours of operation per week, hr
1440 = minutes/day
168 = hours/week

vii) Water Cost

$$WC = WATER \times CPT$$

where: WC = water cost, \$/day
CPT = cost of water, \$/thou liters or \$/thou gal
WATER = total water required, thou liters/day or thou gal/day

b) Fixed Costs

The fixed O & M components for both vacuum and pressure filtration are listed in Table IV.3.4.3-A3 including the cost basis and the unit costs [4-11].

A 4. Miscellaneous Costs

Cost for engineering, and common plant items such as piping and buildings, are calculated for the plant as a whole after completion of costing for individual units (See Section IV.3.5).

A 5. Modifications

a) Filter Cake Weight

The total filter cake weight (dry sludge plus remaining moisture) is calculated by dividing each dry sludge weight by the fraction of solids in the cake after filtration (See Table IV.3.4.3-A1).

$$WW = \Sigma[Q(n) \div F(n)]$$

where: WW = total wet weight of filter cake, Kg/day or lb/day
Q(n) = quantity of sludge solids of type (n), Kg/day (dry) or lb/day (dry)
F(n) = fraction of solids in cake after filtration for sludge type (n), as %/100 (see Table IV.3.4.3-A1)

TABLE IV.3.4.3-A3. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR VACUUM FILTRATION AND PRESSURE FILTRATION [4-11]

VACUUM FILTRATION

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2,4)	--	\$ 9.80/hr
Supervision (1,4)	10% Labor	\$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.10 Shifts (0.57 hrs/day)	\$10.70/hr
Maintenance	6.10% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.038 L/s (0.86 Thou gpd)	\$ 0.13/thou liters (\$ 0.50/thou gal)

PRESSURE FILTRATION

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2,4)	--	\$ 9.80/hr
Supervision (1,4)	10% Labor	\$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.10 Shifts (0.57 hrs/day)	\$10.70/hr
Maintenance	0.50% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.79 L/s (18.10 Thou gpd)	\$ 0.13/thou liters (\$ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

(4) Labor and Supervision requirements are scaled to conform with the hours of operation or cycles of operation calculated in Section A,1e.

Vacuum Filtration	Pressure Filtration
Labor = HR ÷ 7	Labor = (CYCLES × 2.67) ÷ 7
Supervision = 0.1 × Labor	Supervision = 0.1 × Labor

VACUUM FILTER DEWATERING
SUMMARY WORK SHEET

REFERENCE: IV.3.4.3A

I. DESIGN FACTOR | CAPITAL

a. Filter Area of individual operating drum = ________ ft^2

b. Scale Factor = $\dfrac{\qquad\qquad}{\text{total number of filters}}$

II. CAPITAL COST

Cost = ________ (Cost from curve) × ________ (scale factor) × (________ (current index) ÷ 204.7) | $ ________

III. VARIABLE O & M | $/day | O & M

		$/day
a. Power	= ________ (Hp) × ________ (EC, $/Kw-hr) × 17.9	= ________
b. Ferric Chloride	= ________ (lbs/day) × ________ ($/lb)	= ________
c. Wash water	= ________ (thou gal/day) × ________ ($/thou gal)	= ________

IV. FIXED O & M

		$/day
a. Labor:	________ (LQ, hr/day) × ________ ($/hr)	= ________
b. Supervision:	________ (SQ, hr/day) × ________ ($/hr)	= ________
c. Overhead:	________ (Labor, $/day) × ________ (%/100)	= ________
d. Lab Labor:	________ (hr/day) × ________ ($/hr)	= ________
e. Maint, Service, I&T:	________ (capital, $) × ________ (%/100) ÷ 365 (day/yr)	= ________
f. Service Water:	________ (thou gpd) × ________ ($/thou gal)	= ________

V. YEARLY O & M 365 (day/yr) × ________ (sum, $/day) = ________ $/yr

VI. UNCOSTED ITEMS

a. Lime = ________ lbs/day

VACUUM FILTER DEWATERING
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ $/Kw-hr

3. Ferric Chloride = ________ $/lb

4. Labor = ________ $/hr

5. Supervision = ________ $/hr

6. Overhead = ________ % Labor ÷ 100 = ________ %/100

7. Lab Labor = ________ $/hr

8. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor Sum = % ÷ 100 = ________ %/100

9. Wash water and
   Service Water = ________ $/thou gal

I. DESIGN FACTOR

a. To determine the total filter surface area, see Work Table 1

1. Enter dry weight (lb/day) of each sludge type in Column A

2. Multiply quantity of each sludge type (from Column A) by factor for ferric chloride requirement (from Column B) and enter results in Column C

3. Multiply quantity of each sludge type (from Column A) by factor for lime requirement (from Column D) and enter results in Column E

4. Sum the ferric chloride requirement from Column C and lime requirement from Column E for each sludge type and enter results in Column F

5. Sum the sludge weight from Column A and the chemical weight from Column F for each sludge type and enter results in Column G

6. To get the area required to filter each sludge type, divide the total cake weight (Column G) by the filter yield (Column H) for each sludge type and enter results in Column I

7. Sum Column I to determine total area required to filter the total quantities of all sludge and conditioning chemicals applied

WORK TABLE 1. CALCULATIONS TO DETERMINE OPERATING AREA OF VACUUM FILTER

Sludge Number	Sludge Type	A Quantity of Sludge lb/day	B Factor for Ferric Chloride Requirement	C Ferric Chloride Required (AxB) lb/day	D Factor for Lime Requirement	E Lime Required (AxE) lb/day	F Total Chemical Required (C + E) lb/day	G Quantity of Sludge & Chemicals (A + F) lb/day	H Expected Filter Yield lbs/sq ft/hr	I Area Required to Filter Each Sludge (G/H) sq ft hr/day
11	Lime Precipitate		0.000		0.00				10.0	
12	Aluminum Precipitate		0.000		0.20				0.8	
13	Ferric Chloride Precipitate		0.000		0.20				1.2	
14	Sulfide Precipitate		0.000		0.20				0.8	
20	D.A.F. Chemical Float		0.015		0.08				8.0	
50	Process (Primary) Solids		0.015		0.08				8.0	
51	Incinerator Scrubber Sludge		0.015		0.08				8.0	
60	Waste Activated Sludge		0.040		0.15				2.0	
65	Digested W.A.S.		0.040		0.15				2.0	
80	Filter Backwash (Inorganic)		0.015		0.08				8.0	
90	Filter Backwash (Organic)		0.040		0.15				2.0	
				SUM C = FECL		SUM E = LIME				SUM I = (Total Area)

b. To determine the design area per filter use, use Work Table 2 to test various combinations of filter numbers and hours of operation

1. Enter the sum of Column I from Work Table 1 on the first line of Column A of Work Table 2

2. Compute the initial operating area of an individual filter by multiplying Column A by the factor (7 ÷ (HR × N)) in Column D. Enter the product in Column E and test to see if it exceeds the maximum filter area (377 ft^2). If the initial estimate of filter area exceeds 377 ft^2, increase the number of hours and number of filters and recalculate area until the individual operating areas (Column E) does not exceed 377 ft^2

WORK TABLE 2. CALCULATIONS TO DETERMINE ADJUSTMENT FACTORS SO AS NOT TO EXCEED MAXIMUM FILTER AREA

A Sum I	B Number of filters, N	C Hrs of Operation per week, HR	D Factor	E Indiv. Operating Area A × D (not to exceed 377 ft^2)
	1	40	0.175	
	1	80	0.088	
	1	120	0.058	
	1	168	0.042	
	2	40	0.088	
	2	80	0.044	
	2	120	0.029	
	2	168	0.021	
	.	.	.	
	.	.	.	
	.	.	.	
	.	.	.	
	n	168	n	

3. The minimum number of working filters (N) in Work Table 2 with operating area less than or equal to 377 ft^2 is the design selected.

4. For the N-value selected, the minimum number of hours of operation per week is the design mode selected.

   HR = ________ hours/week

5. Compute the individual filter area

   AREA = ($\underset{\text{SUM I, ft}^2\text{ hr/day}}{\underline{\hspace{5cm}}}$ × 7) ÷ ($\underset{\text{HR, hrs}}{\underline{\hspace{2cm}}}$ × $\underset{\text{N, filters}}{\underline{\hspace{3cm}}}$) = ________ ft^2

6. Scale Factor for cost purposes

   If AREA > 10 ft^2

   SCALE FACTOR = Total number of filters = $\underset{\text{N, filters}}{\underline{\hspace{3cm}}}$ + 1 = ______ filters

<u>If</u> AREA < 10 ft^2

SCALE FACTOR = Total number of filters = $\underset{N}{\underline{\hspace{2cm}}}$ filters

7. Using the table below, select the appropriate standard filter size (FS) and the base horsepower (BHP) for the individual filter area (AREA) estimated in step 5. This is the area that should be used for costing purposes.

Filter Size Computed (AREA), ft^2	Filter Size Standardized (FS), ft^2	Base Horsepower (BHP)
AREA < 5	10	5.4
5 < AREA ≤ 20	19	8.1
20 < AREA ≤ 30	28	13
30 < AREA ≤ 47	47	15
47 < AREA ≤ 62	62	18
62 < AREA ≤ 71	71	24
71 < AREA ≤ 100	99	32
100 < AREA ≤ 132	132	42
132 < AREA ≤ 165	151	42
165 < AREA ≤ 207	207	62
207 < AREA ≤ 251	251	62
251 < AREA ≤ 302	302	112
302 < AREA ≤ 377	377	112

Design filter area = ________ ft^2, Base Horsepower = ________ Hp

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements

$$HP = [\underset{BHP}{\underline{\hspace{1cm}}} + (0.00414 \times \underset{AREA,\ ft^2}{\underline{\hspace{3cm}}}) + 2.53] \times \underset{HR,\ hr}{\underline{\hspace{2cm}}} \times \underset{N}{\underline{\hspace{1cm}}} \div 168 = \underline{\hspace{2cm}}\ Hp$$

b. Ferric Chloride Requirements:

$$FECL = \underset{\text{Sum of Column C in Work Table 1}}{\underline{\hspace{6cm}}}\ \text{lbs/day}$$

c. Wash Water Requirements

$$WATER = (\underset{AREA,\ ft^2}{\underline{\hspace{3cm}}} \times \underset{N}{\underline{\hspace{2cm}}} \times \underset{HR}{\underline{\hspace{2cm}}} \times 0.00343 = \underline{\hspace{2cm}}\ \text{thou gal}$$

IV. FIXED O & M

a. Labor Quantity

LQ = $\underset{\text{HR, hr/week}}{\underline{\hspace{3cm}}}$ ÷ 7 = ________ hr/day

b. Supervision Quantity

SQ = $\underset{\text{LQ, hr/day}}{\underline{\hspace{3cm}}}$ × 0.1 = ________ hr/day

V. YEARLY O & M

VI. UNCOSTED ITEMS

Lime Requirements

LIME = $\underset{\text{Sum of Column E in Work Table 1}}{\underline{\hspace{8cm}}}$ lbs/day

PRESSURE FILTER DEWATERING
SUMMARY WORK SHEET — REFERENCE: IV.3.4.3A

I. DESIGN FACTOR — CAPITAL

a. Surface area of filter = ______ ft^2

b. Scale Factor = ______ total number of filters

II. CAPITAL COST

Cost = ______ Cost from curve × ______ scale factor × (______ current index ÷ 204.7) — $ ______

III. VARIABLE O & M — $/day — O & M

a. Power = ______ Hp × ______ EC, $/Kw-hr × 17.9 = ______

b. Ferric Chloride = ______ lbs/day × ______ $/lb = ______

c. Diatomaceous Earth = ______ lbs/day × ______ $/lb = ______

IV. FIXED O & M

a. Labor: ______ LQ, hr/day × ______ $/hr = ______

b. Supervision: ______ SQ, hr/day × ______ $/hr = ______

c. Overhead: ______ Labor, $/day × ______ %/100 = ______

d. Lab Labor: ______ hr/day × ______ $/hr = ______

e. Maint, Service, I&T: ______ capital, $ × ______ %/100 ÷ 365 day/yr = ______

f. Service Water: ______ thou gpd × ______ $/thou gal = ______

V. YEARLY O & M — 365 day/yr × ______ sum, $/day = ______ $/yr

VI. UNCOSTED ITEMS

a. Lime = ______ lbs/day

PRESSURE FILTER DEWATERING
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ \$/Kw-hr

3. Ferric Chloride = ________ \$/lb

4. Diatomaceous Earth = ________ \$/lb

5. Labor = ________ \$/hr

6. Supervision = ________ \$/hr

7. Overhead = ________ % Labor ÷ 100 = ________ %/100

8. Lab Labor = ________ \$/hr

9. Maintenance = % Capital
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor Sum = ________ ÷ 100 = ________ %/100

10. Service Water = ________ \$/thou gal

I. DESIGN FACTOR

a. To determine the total filter surface area, see Work Table 1

   1. Enter dry weight (lb/day) of each sludge type in Column A

   2. Multiply quantity of each sludge type (from Column A) by factor for ferric chloride requirement (from Column B) and enter results in Column C

   3. Multiply quantity of each sludge type (from Column A) by factor for lime requirement (from Column D) and enter results in Column E

   4. Sum the ferric chloride requirement from Column C and the lime requirement from Column E for each sludge type and enter results in Column F

   5. Sum the sludge weight from Column A and the chemical weight from Column F for each sludge type and enter results in Column G

   6. To get the area required to filter each sludge type, divide the total cake weight (Column G) by the filter yield (Column H) for each sludge type and enter results in Column I

7. Sum Column I to determine total area required to filter the total quantities of sludge and conditioning chemicals applied

b. Make an initial estimate of the individual filter surface area

1. AREA = ($\underset{\text{Sum I, ft}^2\text{-hr/day}}{\underline{\hspace{4cm}}}$ × 7) ÷ ($\underset{\text{CYCLES = 15}}{\underline{\hspace{2.5cm}}}$ × $\underset{\text{N = 2}}{\underline{\hspace{2cm}}}$ × 2.67)

   = ________ ft^2

2. If AREA > 5000 ft^2, go to Step c

3. If AREA < 5000 ft^2, the initial estimate of individual surface area is adequate and the AREA, CYCLES, and number of filters (n) may be used to estimate capital cost

c. To determine the design area per filter for greater than the minimum conditions, use Work Table 2 to test various combinations of filter numbers and cycles of operation

1. Enter the sum of Column I from Work Table 1 on the first line of Column A of Work Table 2

2. Columns B and C show the number of cycles per week of operation and number of filters for each trial. Multiply the total area (SUM I) by the factor [7 ÷ (CYCLES × N × 2.67)] in Column D and enter the results in Column E. If the area exceeds 5000 ft^2, increase the cycles of operation and/or the number of filters until the area in Column E no longer exceeds 5000 ft^2

WORK TABLE 2. CYCLES PER WEEK AND CORRESPONDING NUMBER OF FILTERS

A SUM I	B Cycles/wk (CYCLES)	C Number of Filters (N)	D Factor	E Individual Filter Area (A × D) (not to exceed 5000 ft^2)
	30	2	0.0437	
	45	2	0.0291	
	63	2	0.0208	
	15	3	0.0582	
	30	3	0.0291	
	45	3	0.0194	
	63	3	0.0139	
	•	•		
	•	•		
	•	•		
	•	•		
	63	n		

3. List the information needed for costing as determined from Work Table 2

AREA = ________ ft^2

N = ________ filters

CYCLES = ________ cycles/week

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements

$$HP = [(0.007 \times \underset{\text{AREA, sq ft}}{\underline{\qquad\qquad}}) + 35.3] \times \underset{\text{N}}{\underline{\qquad\qquad}} \times \underset{\text{CYCLE}}{\underline{\qquad\qquad}} \times 0.016 = \underline{\qquad\qquad} \text{ Hp}$$

b. Ferric Chloride Requirements:

$$FECL = \underset{\text{Sum of Column C in Work Table 1}}{\underline{\qquad\qquad\qquad\qquad\qquad\qquad}} \text{ lb/day}$$

c. Diatomaceous Earth Requirements

$$DE = \underset{\text{AREA, sq ft}}{\underline{\qquad\qquad}} \times \underset{\text{CYCLES}}{\underline{\qquad\qquad}} \times 0.08 \times \underset{\text{N}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ lb/day}$$

IV. FIXED O & M

a. Labor Quantity

$$LQ = \underset{\text{CYCLE, cycles/week}}{\underline{\qquad\qquad\qquad\qquad}} \times 0.381 = \underline{\qquad\qquad} \text{ hr/day}$$

b. Supervision Quantity

$$SQ = 0.1 \times \underset{\text{LQ, hr/day}}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ hr/day}$$

V. YEARLY O & M

VI. UNCOSTED ITEMS

Lime Requirements

$$LIME = \underset{\text{Sum of Column E in Work Table 1}}{\underline{\qquad\qquad\qquad\qquad\qquad\qquad}} \text{ lb/day}$$

WORK TABLE 1. CALCULATIONS TO DETERMINE TOTAL OPERATING AREA OF PRESSURE FILTER

Sludge Number	Sludge Type	A Quantity of Sludge lb/day	B Factor for Ferric Chloride Requirement	C Ferric Chloride Required (AxB) lb/day	D Factor for Lime Requirement	E Lime Required (AxE) lb/day	F Total Chemical Required (C + E) lb/day	G Quantity of Sludge & Chemicals (A + F) lb/day	H Expected Filter Yield lb/sq ft/hr	I Area Required to Filter Each Sludge (G/H) sq ft hr/day
11	Lime Precipitate		0.000		0.00				3.6	
12	Aluminum Precipitate		0.300		0.00				1.6	
13	Ferric Chloride Precipitate		0.300		0.00				1.6	
14	Sulfide Precipitate		0.000		0.30				1.6	
20	D.A.F. Chemical Float		0.100		0.05				2.2	
50	Process (Primary) Solids		0.100		0.05				2.2	
51	Incinerator Scrubber Sludge		0.100		0.05				2.2	
60	Waste Activated Sludge		0.150		0.08				1.5	
65	Digested W.A.S.		0.150		0.08				1.5	
80	Filter Backwash (Inorganic)		0.100		0.05				2.2	
90	Filter Backwash (Organic)		0.150		0.08				1.5	
				SUM C = FECL		SUM E = LIME				SUM I = (Total Area)

IV.3.4.4 COMBUSTION

Introduction

Combustion is employed to reduce the quantity of sludges and process residuals requiring disposal. Combustion may also be employed to finally stabilize sludges, destroy toxics and recover energy from waste materials. Variations of the process include direct incineration of process waste streams prior to any kind of waste treatment and incineration of biological sludges or liquid waste treatment residues prior to disposal. Incineration processes are described in more detail in Volume III, Section III.4.4 of the Treatability Manual. Costing methodologies and cost data for industrial wastewater treatment applications are presented below.

IV.3.4.4-A. Multiple Hearth Incineration

A 1. Basis of Design

This presentation is for determining the cost of a multiple hearth furnace, considered applicable for the incineration of biological sludges and mixed biological and liquid residue wastes. A typical multiple hearth incinerator for combustion of biological and mixed sludges is shown in Figure IV.3.4.4-A1. For liquid residues alone, a vertical liquid waste-type incinerator is used. Liquid residues are considered to include oil and residues from extractional and distillation processes and contain no biological sludges whatsoever. The various types of sludges or residues that are considered combustible in a multiple hearth incinerator are identified along with important physical characteristics in Table IV.3.4.4-A1.

The principal design factor for biological sludge and mixed waste incineration is the effective surface area of the multiple hearth incinerator. Determination of the hearth surface area, which dictates associated costs, is based on a surface solids loading rate of 39 Kg wet sludge/m^2/hr (8 lb wet sludge/ft^2/hr) [4-2]. The inlet temperature of biological and mixed sludges and residues is assumed to be 15.5°C (60°F), and the incinerating temperature is assumed to be 982°C (1800°F).

a) Source

This cost estimate method was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/ Plastics and Synthetic Fibers Industries [4-2].

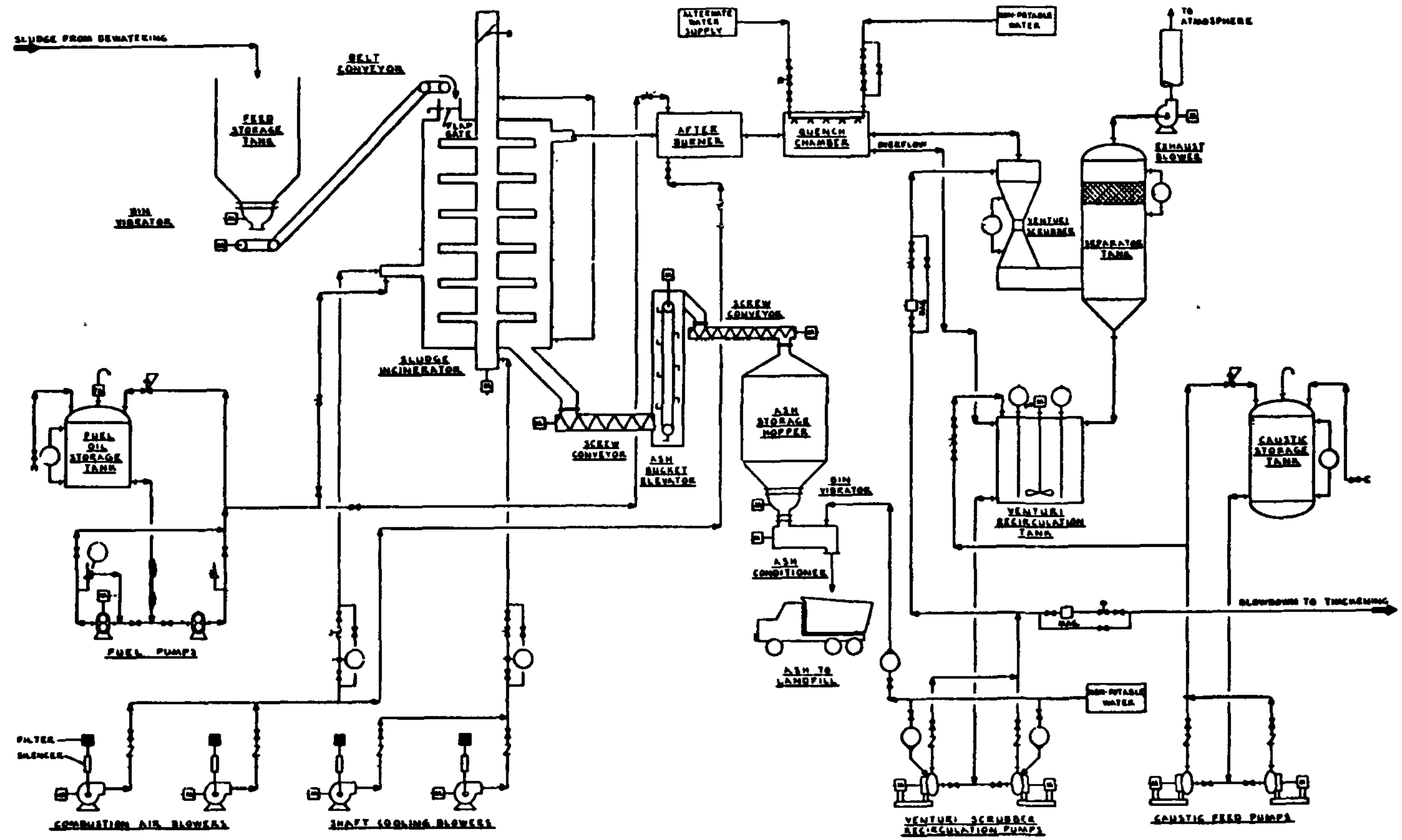


FIGURE IV.3.4.4-A1. PROCESS FLOW DIAGRAM FOR MULTIPLE HEARTH INCINERATOR[4-1]

TABLE IV.3.4.4-A1. SIGNIFICANT PHYSICAL FACTORS AND DESIGN INFORMATION FOR WASTE MATERIALS TREATABLE BY MULTIPLE HEARTH INCINERATOR

SLUDGE NUMBER AND DESCRIPTION	SOLIDS RATIO FOR WET SLUDGE (Dry/Wet)		NON-WATER CONTENT IN LIQUID WASTE (Fraction)	ASH CONTENT		HEAT VALUE			FUEL VALUE
	Vacuum Filtered	Pressure Filtered		Vacuum Filtered	Pressure Filtered	KJ/Kg	(Btu/lb)	KJ/Kg-MOLE	(Btu/lb-mole)
SOLID WASTE									
20 DAF Chemcial Float	0.2	0.3	-	0.35	0.42	22,100	(9,500)	22,500	(9,700)
40 Oil and Solids from DAF	0.5	0.5	-	0.05	0.06	37,200	(16,000)	32,000	(13,800)
60 Waste Activated Sludge	0.12	0.35	-	0.35	0.42	18,600	(8,000)	22,500	(9,700)
*65 Digested Sludge	0.12	0.35	-	0.35	0.42	11,600	(5,000)	22,500	(9,700)
90 Filter Backwash (organic) and Biological Solids (one of the above)	0.12	0.35	-	0.35	0.42	18,600	(8,000)	22,500	(9,700)
LIQUID WASTE									
30 Oil	-	-	0.95	0.05	0.06	37,200	(16,000)	32,000	(13,800)
70 Solvent Extraction Residue	-	-	0.65	0.05	0.06	27,900	(12,000)	32,000	(13,800)
71 Steam Stripping Residue	-	-	0.95	0.05	0.06	27,900	(12,000)	22,500	(9,700)

*If digested waste activated sludge (65) is present, it is assumed that no waste activated sludge (60) or organic filter backwash (90) is present

b) Required Input Data

Type(s) of waste to be incinerated
Amount of each type of waste to be incinerated Kg/day (lb/day)

c) Limitations and Default Values

The waste material must be combustible and combustion must be complete to avoid possible production of toxic byproducts.

d) Pretreatment

Biological solids are assumed to be dewatered prior to incineration. Digestion of biological solids prior to incineration is considered uneconomical and is not recommended [4-1].

e) Design Equation

i) Multiple Hearth Incinerator

If any type of sludge, mixture of sludges, or mixture of sludges and liquid wastes is present, a multiple hearth incinerator is used. For liquid residues or process streams alone, a vertical liquid waste incinerator (not addressed) is used. The primary factor used for design of a multiple hearth incinerator is the required effective furnace surface area. The required hearth surface area is calculated by dividing the wet weight of biological and mixed sludge to be incinerated by the solids loading rate.

Metric

$$\text{AREA} = Q \div 39$$

where:
AREA = required hearth surface area, m^2
Q = total weight of material passing into the incinerator, Kg/hr
= $[\Sigma(Q(n) \div SR(n))] \div 24$
Q(n) = dry quantity of each type of biological sludge or mixed sludge present, Kg/day
SR(n) = solids ratio for each type of sludge depending on the method of dewatering (Table IV.3.4.4-A1)
39 = assumed solids loading rate, $Kg/m^2/hr$ [4-1]

English

$$\text{AREA} = Q \div 8$$

where: AREA = required hearth surface area, ft^2
Q = total wet weight of material passing into the incinerator, lb/hr
$= [\Sigma(Q(n) \div SR(n))] \div 24$
Q(n) = dry quantity of each type of biological sludge or mixed sludge present, lb/day
SR(n) = solids ratio for each type of sludge depending on the method of dewatering (Table IV.3.4.4-A1)
8 = assumed solids loading rate, $lb/ft^2/hr$ [4-1]

f) Subsequent Treatment

Final disposal of ash is carried out by landfilling or contract hauling.

A 2. Capital Costs

The primary factor used for determining capital cost for multiple hearth incineration is the effective surface area of the hearth (Figure IV.3.4.4-A2). Costs estimated using these curves must be adjusted to a current value using an appropriate cost index.

a) Cost Data

The items included in the capital cost estimate for the multiple hearth incinerator are as follows [4-2]:

- Multiple Hearth Incinerator including:
  - Furnace
  - Gas scrubber
  - Exhaust packed tower
  - Ash handling system
- Fuel oil storage tank, horizontal flat ends
- Scrubber recirculation storage tank, vertical open top
- Sludge feed and storage tank, 2 weeks supply, truncated cone bottom
- Caustic storage tank, insulated, covered and heated
- Packed tower pumps
- Fuel oil pumps, gear type (2)
- Sump pumps (2)
- Scrubber recirculating pumps, centrifugal (2)
- Caustic feed pumps, centrifugal (2)
- Air blowers
- Tower agitators
- Feed conveyor
- Piping
- Instrumentation

b) Capital Cost Curve

i) Multiple Hearth Incinerator
Curve - Figure IV.3.4.4-A2.
- Cost (thousands of dollars) vs. surface area (square meters or square feet).
- Curve basis, cost estimates for systems to incinerate dewatered sludge produced by four flow rates, 8.76, 43.8, 219, and 876 L/s (0.2, 1.0, 5.0, and 20.0 mgd).

c) Cost Index

Base Period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. Variable operating costs include power, water, supplemental fuel, and steam. Fixed operating costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Costs

i) Power Requirements - for fuel oil pumps, scrubber recirculation pumps, caustic feed pumps, sump pumps, conveyor, bin discharger, and incinerator. The following equation was developed using regression analysis procedures [4-1].

Metric

$$KW = (1.81 \times AREA) + 19.3$$

where: KW = power required, kilowatts
AREA = required hearth area, m^2

English

$$HP = (0.225 \times AREA) + 25.9$$

where: HP = power required, Hp
AREA = required hearth area, ft^2

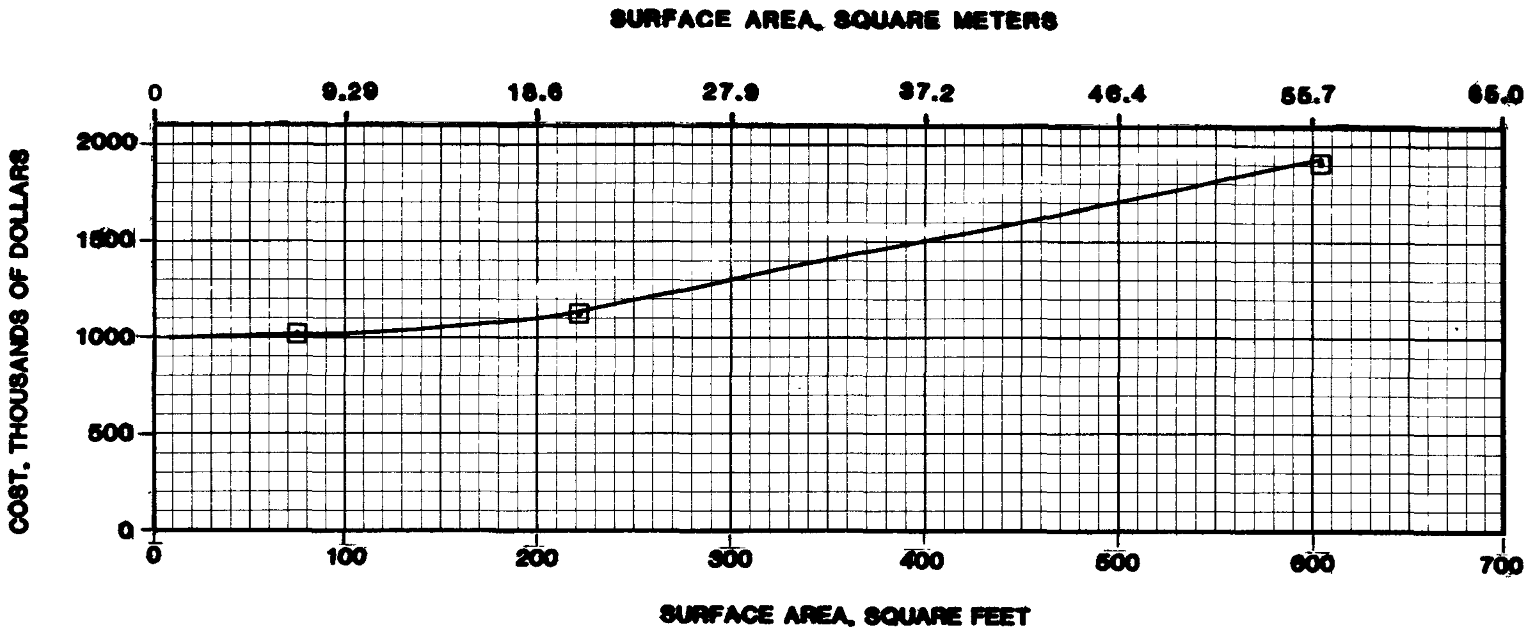


FIGURE IV.3.4.4-A2. CAPITAL COST ESTIMATE FOR THE SLUDGE INCINERATION [4-10]

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

where:
PC = power cost, \$/day
KW = power required, kilowatts
24 = hr/day
EC = electricity cost \$/Kw-hr

English

$$PC = HP \times 24 \times 0.746 \times EC$$

where:
PC = power cost, \$/day
HP = required horsepower, Hp
EC = electricity cost, \$/kw-hr
24 = hr/day
0.746 = kw-hr/Hp-hr

iii) Supplemental Fuel Requirements

Supplemental fuel requirements are determined after estimating the following: (1) the heat contribution from incoming biological and mixed sludges and residues; (2) the heat leaving the incinerator in the form of combustion gases; (3) the heat needed to evaporate water from the sludges; and (4) auxiliary heating needed to maintain an incinerator temperature of 982°C (1800°F).

Metric

$$FUEL = AUXHT \times 24 \div (41{,}900 \times 0.868)$$

where:
FUEL = supplemental fuel required, L/day
AUXHT = auxiliary heat required, KJ/hr
24 = hr/day
41,900 = heating value of No. 2 fuel oil, KJ/Kg
0.868 = Kg/L of No. 2 fuel oil

English

$$FUEL = AUXHT \times 24 \div (18000 \times 7.25)$$

where:
FUEL = supplemental fuel required, gal/day
AUXHT = auxiliary heat required, Btu/hr
24 = hr/day
18000 = heating value of No. 2 fuel oil, Btu/lb
7.25 = lb/gal of No. 2 fuel oil

The following steps are followed to determine the auxiliary heating requirements (AUXHT):

- Step 1: Determine the heat value of the sludges entering the incinerator.

Metric

$$HEATIN = \Sigma[Q(n) \times HV(n)] \div (120 \div 7)$$

where:
- HEATIN = heat value of wastes entering the multiple hearth incinerator, KJ/day
- Q(n) = dry or undiluted quantity of each type of biological sludge or liquid residue, Kg/day
- HV(n) = heating value of each sludge, KJ/Kg
- 120 ÷ 7 = 120 hours/7 days of operation

English

$$HEATIN = \Sigma[Q(n) \times HV(n)] \div (120 \div 7)$$

where:
- HEATIN = heat value of wastes entering the multiple hearth incinerator, Btu/day
- Q(n) = dry or undiluted quantity of each type of biological sludge or liquid residue, lb/day
- HV(n) = heating value of each sludge, Btu/lb (Table IV.3.4.4-A1)
- 120 ÷ 7 = 120 hours/7 days of operation

- Step 2: Determine the quantity of water which must be evaporated from the sludges and residues.

$$EVAP = WETWT - DRYWT$$

where:
- EVAP = total water to be evaporated, Kg/day or lb/day
- WETWT = total weight of wet sludge and diluted liquid residue, Kg/day or lb/day $= \Sigma[Q(n) \div SR(n)]$
- DRYWT = total dry weight of sludge and undiluted liquid residue, Kg/day or lb/day $= \Sigma[Q(n)]$
- Q(n) = dry weight of sludge or undiluted liquid residue, Kg/day or lb/day
- SR(n) = solids fraction of sludge or non-water fraction of liquid residue (Table IV.3.4.4-A1)

- Step 3: Determine the amount of heat leaving the incinerator in the combustion gases assuming 100% excess air.

Metric

$$HEATOUT = \Sigma[Q(n) \div 2 \times Fv(n) \times 2] \div (120 \div 7)$$

where:
HEATOUT = heat leaving the incinerator, KJ/hr
Q(n) = dry weight of sludge or undiluted liquid residue, Kg/day
Fv(n) = fuel value of sludge or liquid residue, KJ/Kg-mole
120 ÷ 7 = 120 hours/ 7 days of operation

English

$$HEATOUT = \Sigma[Q(n) \div 2 \times Fv(n) \times 2] \div (120 \div 7)$$

where:
HEATOUT = heat leaving the incinerator, Btu/hr
Q(n) = dry weight of sludge or undiluted liquid residue, lb/day
Fv(n) = fuel value of sludge or liquid residue, Btu/lb-mole (Table IV.3.4.4-A1)
120 ÷ 7 = 120 hours/7 days of operation

- Step 4: Determine the additional heat required to completely incinerate biological and mixed sludge and residue and maintain the incinerator at 982°C (1800°F).

$$COMHT = HEATOUT - HEATIN$$

where:
COMHT = additional heat required to incinerate wastes, KJ/hr or Btu/hr
HEATOUT = heat leaving the incinerator, KJ/hr or Btu/hr
HEATIN = heat value of waste entering the incinerator, KJ/hr or Btu/hr

- Step 5: Determine the total auxiliary heating requirement to burn wastes and evaporate water.

Metric

$$HTTOT = EVAP \times 4654 \div (120 \div 7) + COMHT$$

where: HTTOT = total heating required, KJ/hr
EVAP = water to be evaporated, Kg/day
4654 = heat required to evaporate water, KJ/Kg
COMHT = additional heat required to incinerate wastes, KJ/hr

English

$$HTTOT = EVAP \times 2000 \div (120 \div 7) + COMHT$$

where: HTTOT = total heating required, Btu/hr
EVAP = water to be evaporated, lb/day
2000 = heat required to evaporate water and bring the vapor to 1800°F [4-2], Btu/lb
COMHT = additional heat required to incinerate wastes, Btu/hr

- Step 6: The minimum auxiliary heating required to allow for start-up and backup is estimated as 10 percent of the heat needed to evaporate sludge water.

Metric

$$MINHT = 0.1 \times EVAP \times 4654 \div (120 \div 7)$$

where: MINHT = minimum auxiliary heating required, KJ/hr

English

$$MINHT = 0.1 \times EVAP \times 2000 \div (120 \div 7)$$

where: MINHT = minimum auxiliary heating required, Btu/hr

- Step 7: Determine the auxiliary heating requirement as follows:

  - If HTTOT > MINHT, then AUXHT = HTTOT

  - If MINHT > HTTOT, then AUXHT = MINHT

iv) Supplemental Fuel Cost

$$FC = UFC \times FUEL$$

where: FC = supplemental fuel cost, $/day
UFC = unit cost of supplemental fuel, $/L or $/gal
FUEL = supplemental fuel requirement, L/day or gal/day

v) Water Requirements

The total water requirement is the summation of quench water and scrubber water.

Metric

WATER = QW + SW

where: WATER = total water requirement, L/s

Quench Water

QW = quantity of quench water, L/s
= (HEAT ÷ 3600) ÷ (2398 × 1.0 × 0.5)
HEAT = total amount of heat released in the multiple hearth incinerator, KJ/hr
= (HEATIN + AUXHT)
HEATIN = heat value of wastes entering incinerator, KJ/hr (see Section A3, a, iii)
AUXHT = auxiliary heating required, KJ/hr
3600 = seconds per hour
2398 = heat removal value for kilogram of water, KJ/Kg
1.0 = kilograms per liter

Scrubber Water

SW = quantity of scrubber water, L/s
= FAN × 2.01 ÷ 60
FAN = size of fan required, m^3/min
= (WVVOL + EXSTVOL) × 10.8 × (367 ÷ 294) ÷ 60
WVVOL = water vapor volume moved by fan, Kg-mole/hr
= [(HEAT ÷ 2398) + EVAP] ÷ 18
EXSTVOL = volume of combustion gases, Kg-mole/hr
= HEATOUT ÷ FV
HEATOUT = (see Section A3, a, iii)
FV = fuel value of exhaust gases
10.8 = volume occupied by a kilogram mole of gas at standard temperature and pressure [4-1], m^3
367 = air temperature, °Kelvin [4-1]
294 = fuel temperature, °Kelvin [4-1]
60 = minute/hour
2.01 = water flow rate required per m^3 of air, L/m^3
EVAP = total quantity of water evaporated, Kg/hr
18 = molecular weight of water, Kg/mole
2398 = heat removed per pound of water, KJ/Kg

English

WATER = QW + SW

where: WATER = total water requirement, thou gal/day

Quench Water

QW = quantity of quench water, thou gal/day
= (HEAT × 10^6 × 24) ÷ (1030 × 8.34 × 0.5 × 1000)
HEAT = total amount of heat released in the multiple hearth incinerator, million Btu/hr
= (HEATIN + AUXHT) ÷ 10^6
10^6 = Btu/million Btu
HEATIN = heat value of wastes entering incinerator, Btu/hr (see Section A 3, a, iii)
AUXHT = auxiliary heating required, Btu/hr (see Section A 3, a, iii)
24 = hours per day
1030 = heat removal value for pound of water, Btu/lb
8.34 = pounds per gallon
1000 = gal/thou gal

Scrubber Water

SW = quantity of scrubber water, thou gal/day
= FAN × 0.015 × 1440 ÷ 1000
FAN = size of fan required, ft^3/min
= (WVVOL + EXSTVOL) × 387 × (660 ÷ 530) ÷ 60
WVVOL = water vapor volume, moved by fan, lb-mole/hr
= [(HEAT × 10^6 ÷ 1030) + EVAP] ÷ 18
EXSTVOL = volume of combustion gases, lb-mole/hr
= HEATOUT ÷ FV
HEATOUT = (see Section A 3, a, iii)
FV = fuel value of exhaust gases
387 = volume occupied by a pound mole of gas at standard temperature and pressure [4-1], ft^3
660 = air temperature, °Rankine [4-1]
530 = fuel temperature, °Rankine [4-1]
60 = minute/hr
0.015 = water flow rate required per ft^3 of air, gal/ft^3
1440 = minute/day
1000 = gal/thou gal

EVAP = total quantity of water evaporated, lb/hr
18 = molecular weight of water, lb/mole
1030 = heat removed per pound of water, Btu/lb

vi) Water Cost

Metric

$$W = WATER \times WC \times 86400$$

where:
W = water cost, \$/day
WATER = total water required, L/s
WC = unit cost of water, \$/L
86400 = s/day

English

$$W = WATER \times WC$$

where:
W = water cost, \$/day
WATER = total water required, thou gal/day
WC = unit cost of water, \$/thou gal

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.4.4-A2 including values for the cost basis and the unit costs [4-11].

A 4. Miscellaneous Costs

Cost for engineering, and other common plant items such as piping and buildings, are calculated after the completion of costing for individual units (See Section IV.3.5).

(a) Ash

The amount of ash resulting from the incineration of biological sludge or biological sludges mixed with liquid residues is determined as follows:

$$ASH = 0.7 \times \Sigma[Q(n) \times A(n)]$$

where:
ASH = total amount of ash, Kg/day or lb/day
Q(n) = quantity of sludge of type n, Kg/day or lb/day
A(n) = fraction ash content for sludge type n (Table IV.3.4.4-A1) [4-1]

A 5. Modifications

None required.

TABLE IV.3.4.4-A2. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR SLUDGE INCINERATION [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	(July 1977)
Labor (1)	0.71 Weeks (2) (24.0 hr/day, 5 days/week)	$ 9.80
Supervision	10% Labor (2.4 hr/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory	0.10 Shifts (3) (0.57 hr/day)	$10.70/hr
Maintenance	2.01% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.038 L/s (0.86 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

MULTIPLE HEARTH INCINERATOR
SUMMARY WORK SHEET REFERENCE: IV.3.4.4-A

I. DESIGN FACTOR

a. Hearth Surface AREA = ____________ ft^2

II. CAPITAL COST

Cost = ____________ (Cost from curve) × (____________ (current index) ÷ 204.7) $ ____________

III. VARIABLE O & M $/day

a. Power = ________ (Hp) × ________ (EC, $/Kw-hr) × 12.78 = ________

b. Supplemental Fuel = ________ (F, gals/day) × ________ (O, $/gal) = ________

c. Water = ________ (W,thou gals/day) × ________ (X,$/thou gal) = ________

IV. FIXED O & M $/day

a. Labor: ________ ($/day) = ________

b. Supervision: ________ (Labor, $/day) × ________% = ________

c. Overhead: ________ (Labor, $/day) × ________% = ________

d. Lab Labor: ________ (Labor, $/day) × ________% = ________

e. Maint, Service, I&T: ________ (capital, $) × ________% = ________

f. Service Water: ________ (thou gpd) × ________ ($/thou gal) = ________

V. YEARLY O & M 365 (day/yr) × ________ (sum, $/day) = ________ $/yr

VI. UNCOSTED ITEMS

ASH = ________ lb/day

MULTIPLE HEARTH INCINERATOR
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. EC: Electricity Cost = ________ $/Kw-hr

3. O = Supplemental Fuel Cost = ________ $/gal

4. X = Water Cost = ________ $/thou gal

5. Labor = ________ $/day

6. Supervision = % Labor
Overhead = % Labor
Lab Labor = ________ % Labor
Other Labor Factor = Sum Above

7. Maintenance = % Capital
Services = % Capital
Insurance/Taxes = ________ % Capital
Other O & M Factor = % ÷ 100 = ________ %/100

8. Service Water = ________ $/thou gal

I. DESIGN FACTOR

a. List quantities of dry sludge and mixed liquid wastes in Column B of Work Table 1.

b. Type of sludge dewatering device (vacuum or pressure filter) used prior to incineration = ________

c. If vacuum filter utilized before incineration, divide the quantity of dry sludge (from Column B) by the corresponding solid ratio (from Column C) and enter the results in Column E.

d. If pressure filter utilized before incineration, divide the quantity of dry sludge (from Column B) by the corresponding solid ratio (from Column D) and enter the results in Column E.

e. For liquid wastes which are to be incinerated along with the sludge, divide the quantities in Column C by the non-water fractions in Column D and enter the resulting wet weights in Column E.

WORK TABLE 1. CALCULATION TO DETERMINE THE AMOUNT OF WET SLUDGE

A Type of Sludge	B Quantity of Dry Sludge, Q(n) (lbs/day)	C Solid Ratio for Wet Sludge, SR (Vacuum)	D Solid Ratio for Wet Sludge, SR (Pressure)	E Quantity of Wet Sludge, Q (lbs/day)
Solid				
DAF Chemical Float		0.2	0.3	
DAF Oil/Solids		0.5	0.5	
Waste Activated Sludge		0.12	0.35	
Digested Sludge		0.12	0.35	
Filter Backwash (organic)		0.12	0.35	
Liquid		Quantity of Liquid Waste lbs/day	Non-Water Fraction lbs/day	
Oil			0.95	
Solvent Extraction Residue			0.65	
Stream Stripping Residue			0.95	
	Sum = ______ B, lbs/day		Sum =	______ E, lbs/day

f. Sum Column E to determine total quantity of wet sludge
Sum E = ________ lb/day

g. Required Hearth Area

AREA = $\frac{\rule{5cm}{0.4pt}}{\text{Sum Column E, lbs/day}}$ ÷ 8 = ________ ft^2.

II. CAPITAL COST

III. VARIABLE O & M

a. Power Requirements

HP = (0.225 × $\frac{\rule{3cm}{0.4pt}}{\text{AREA, } ft^2}$) + 25.9 = ________ Hp

b. Supplemental Fuel Requirement

1. Determine heat value of sludges entering the incinerator (See Table IV.3.4.4-A1).

- List the dry weights of sludges and the undiluted weights of liquid wastes entering the incinerator in Column B of Work Table 2.

- Multiply the dry weight of each waste in Column B by the corresponding heating value in Column C and enter the resulting heat value in Column D.

- Sum Column D.

- HEATIN = $\underset{\text{SUM D}}{\underline{\hspace{3em}}}$ × 0.058 = ________ Btu/hr

2. Determine the quantity of water to be evaporated from sludge and liquid waste (see Work Table 1)

- WETWT = $\underset{\text{SUM COLUMN E}}{\underline{\hspace{5em}}}$ lb/day

- DRYWT = $\underset{\text{SUM COLUMN B}}{\underline{\hspace{5em}}}$ lb/day

- EVAP = $\underset{\text{WETWT, lb/day}}{\underline{\hspace{5em}}}$ - $\underset{\text{DRYWT, lb/day}}{\underline{\hspace{5em}}}$ = ________ lb/day

3. Determine the amount of heat leaving the incinerator in the combustion gases (see Work Table 2).

- Multiply the dry weight of wastes from Column B by the fuel value of the wastes from Column E and enter the results in Column F.

- Sum Column F = ________ Btu

- HEATOUT = $\underset{\text{SUM F}}{\underline{\hspace{3em}}}$ × 0.058 = ________ Btu/hr

4. Determine the additional heat required to completely incinerate biological and mixed sludge and residues

COMHT = $\underset{\text{HEATOUT}}{\underline{\hspace{3em}}}$ - $\underset{\text{HEATIN}}{\underline{\hspace{3em}}}$ = ________ Btu/hr

5. Determine the total auxiliary heating requirement to burn wastes and evaporate water.

HTTOT = $\underset{\text{EVAP}}{\underline{\hspace{2em}}}$ × 116.667 + $\underset{\text{COMHT}}{\underline{\hspace{2em}}}$ = ________Btu/hr

6. Determine the minimum auxiliary backup heating requirement.

$$MINHT = \underline{\hspace{2em}}_{EVAP} \times 11.667 = \underline{\hspace{4em}} \text{ Btu/hr}$$

7. Determine the auxiliary heating requirement.

- If HTTOT > MINHT, AUXHT = $\underline{\hspace{3em}}_{HTTOT}$ Btu/hr

- If MINHT > HTTOT, AUXHT = $\underline{\hspace{3em}}_{MINHT}$ Btu/hr

8. Determine Supplemental Fuel Requirement

$$FUEL = \underline{\hspace{6em}}_{AUXHT,\ BTU/hr} \times 1.84 \times 10^{-4} = \underline{\hspace{4em}} \text{ gal/day}$$

c. Water Requirements

The total water requirement is the summation of quench water and scrubber water requirements

1. Determine quench water (QW) requirement.

- $HEAT = (\underline{\hspace{3em}}_{HEATIN} + \underline{\hspace{3em}}_{AUXHT}) \div 10^6 = \underline{\hspace{7em}}$ million Btu/hr

- $QW = \underline{\hspace{2em}}_{HEAT} \times 5.59 = \underline{\hspace{4em}}$ thou gal/day

2. Determine scrubber water requirement.

- Volume of water vapor in exhaust

  $WVVOL = (\underline{\hspace{2em}}_{HEAT} \times 971) + \underline{\hspace{2em}}_{EVAP} \div 18 = \underline{\hspace{4em}}$ lb-mole/hr

- Volume of combustion gases

  $EXSTVOL = \underline{\hspace{4em}}_{HEATOUT} \div 9700 = \underline{\hspace{4em}}$ lb-mole/hr

- Capacity of exhaust fan

  $FAN = (\underline{\hspace{3em}}_{WVVOL} + \underline{\hspace{4em}}_{EXSTVOL}) \times 8.03 = \underline{\hspace{4em}}$ cfm

- $SW = \underline{\hspace{2em}}_{FAN} \times 0.0216 = \underline{\hspace{4em}}$ thou gal/day

3. Total water requirement

WATER = $\underset{QW}{\_\_\_\_}$ + $\underset{SW}{\_\_\_\_}$ = ________ thou gal/day

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

a. Determine quantity of ash to be disposed of (see Work Table 3)

b. Enter quantity of each waste type in Column B

c. Multiply quantity of each waste type (from Column B) by the fractions in Column C and enter results in Column D

d. Sum Column D

e. ASH = ($\underset{\text{Sum D, lbs/day}}{\_\_\_\_\_\_\_\_\_\_\_\_}$) x 0.7 = _________ lbs/day

WORK TABLE 3.

A Waste Type	B Quantity of Waste lbs/day	C Ash Fraction of Waste	D Ash lbs/day
DAF Chemical Float		0.35	
Oil		0.05	
Oil & Solids (from DAF)		0.05	
Waste Activated Sludge		0.35	
Digested W.A.S.		0.35	
Solvent Extraction Residue		0.05	
Steam Stripping Residue		0.05	
Filter Backwash (organic)		0.35	

Sum = _________ lbs/day

IV.3.4.5 LANDFILL/OUTSIDE CONTRACTOR

Introduction

Landfill disposal is the most widely used method of final solid waste disposal. Factors considered in selecting a site for a landfill include zoning restrictions, public acceptance, accessibility, and size requirements. Because the waste operating facility is often a considerable distance from the landfill site, an important element of the total cost may be the transportation system. In order to function properly, a landfill must have proper geologic conditions and a suitable cover material. Landfill disposal is described in more detail in Volume III of the Treatability Manual, Section III.4.5. Costing methodologies and cost data for this technology are presented below.

IV.3.4.5-A. Landfill

A 1. Basis of Design

This presentation is for the disposal of wastewater sludge and incinerator ash in landfills. A landfill of the type considered is illustrated in Figure IV.3.4.5-A1. The principal design factor considered is the area required for the landfill and leachate collection and treatment facilities. The area required is determined from the sludge loading rate. Loading rates vary depending on the type of sludge and whether it has been dewatered by vacuum or pressure filtration (Table IV.3.4.5-A1). It is assumed that sludge is mixed with soil to achieve a final solids concentration of 80% for disposal. Because sludge handling and dewatering is uneconomical when sludge volumes are small, an outside contractor may be used to dispose of low volumes of sludge wastes.

The landfill is constructed as two-year capacity cells. If no depth is specified, a default value of three meters (ten feet) is assumed. Computed area requirements are increased by 25 percent, prior to costing, to allow for cell construction and access requirements. It is assumed that the landfill is constructed on a suitable site on company property away from the sludge production area and has a usable life of 20 years. The hauling distance to the landfill is assumed to be 5 miles unless otherwise specified.

a) Source

This cost estimate method was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

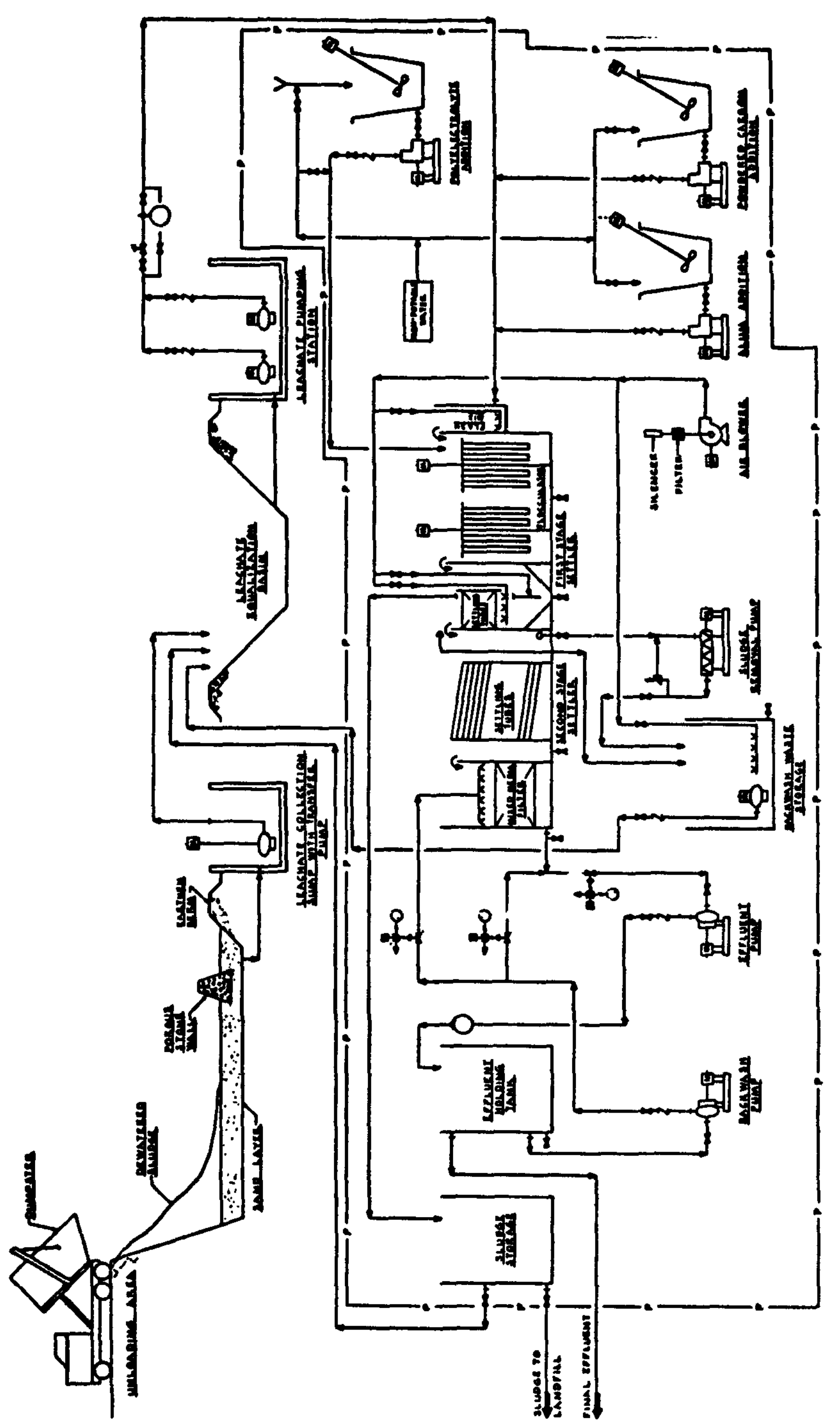


FIGURE IV.3.4.5-A1. PROCESS FLOW DIAGRAM FOR LANDFILL [4-1]

TABLE IV.3.4.5-A1. LANDFILL LOADING RATES AND WET SOLIDS RATIOS FOR VARIOUS TYPES OF SLUDGE [4-2]

Flag	Sludge	Loading Rates Mg/Hectare-m (Tons/Acre-ft) Vacuum	Loading Rates Mg/Hectare-m (Tons/Acre-ft) Pressure	Solids Ratio for Wet Sludge Vacuum	Solids Ratio for Wet Sludge Pressure
11	Lime Precipitate	1250 (170)	1980 (270)	0.40	0.50
12	Aluminum Precipitate	368 (50)	882 (120)	0.20	0.40
13	Iron Precipitate	368 (50)	882 (120)	0.20	0.40
14	Sulfide Precipitate	368 (50)	882 (120)	0.20	0.40
20	DAF Chemical Float	515 (70)	1250 (170)	0.25	0.45
50	Primary Solids	515 (70)	1250 (170)	0.25	0.45
51	Scrubber Sludge	515 (70)	1250 (170)	0.25	0.45
60	Waste Act. Sludge	184 (25)	735 (100)	0.12	0.35
*65	Digested Sludge	184 (25)	735 (100)	0.12	0.35
**72	Incinerator Ash (direct waste incineration)	2350 (320)	2350 (320)	0.60	0.60
75	Incinerator Ash (byproduct incineration)	2350 (320)	2350 (320)	0.60	0.60
80	Inorganic Filter Backwash	515 (70)	1250 (170)	0.25	0.45
81	Throwaway Act. Carbon (60% Solids)	2120 (289)	2120 (289)	0.60	0.60
90	Organic Filter Backwash	184 (25)	735 (100)	0.12	0.35

*If digested sludge (65) is present, the quantities of waste activated sludge (60) and organic filter backwash (90) are assumed to be zero.

**If ash from direct incineration of process waste (72) is present, its contributing wastes are assumed to be zero.

b) <u>Required Input Data</u>

Dry weight of incoming individual types of sludge solids Kg/day (lb/day)
Landfill haul distance (miles)
Depth of landfill meter (feet)

c) <u>Limitations</u>

None specified.

d) <u>Pretreatment</u>

Pretreatment consists of either vacuum or pressure filtration to dewater sludges.

e) <u>Design Equation</u>

The landfill design is based on the area required to dispose of sludges over a 20 year period. The required total area is computed based on the amount of incoming sludge as follows:

<u>Metric</u>

$$AREA = VOL \div DEPTH$$

where:
- AREA = Landfill area, hectares
- VOL = total volume of all sludges, hectare-meter
  $= \{\Sigma\ [DW(i) \div LR(i)]\} \times 365 \times 20 \times 1.25 \div 1000$
- DW(i) = dry weight of incoming sludge, Kg/day
- LR(i) = loading rate of sludge(i), Mg/hectare-meter
- 365 × 20 = days in design life (20 years), days
- 1.25 = factor adjustment to allow for area requirements for cell construction and access
- 1000 = Kg/Mg
- DEPTH = landfill depth, m

<u>English</u>

$$AREA = VOL \div DEPTH$$

where:
- AREA = landfill area, acres
- VOL = total volume of all sludges, acre feet
  $= \{\Sigma\ [DW(i) \div LR(i)]\} \times 365 \times 20 \times 1.25 \div 2000$
- DW(i) = dry weight of incoming sludge (i), lb/day

LR(i) = loading rate of sludge (i), ton/acre foot
365 × 20 = days in design life (20 years), days
1.25 = factor adjustment to allow for area requirements for cell construction and access
2000 = lb/ton
DEPTH = landfill depth, feet

f) Subsequent Treatment

Landfill leachate is collected and treated prior to discharge.

A 2. Capital Costs

The landfill area is the principal cost factor used in estimating capital cost. Costs for both single lined and double lined landfills may be estimated separately. The double lined landfill is included to represent the cost of disposing of sludges which may be of concern due to toxicity or other problems. The installed cost of a single lined landfill is represented in Figure IV.3.4.5-A2 while the cost for a double lined landfill is represented in Figure IV.3.4.5-A3. The capital cost estimate includes the first two year landfill cell. The cost of constructing additional cells is considered a maintenance item. Costs estimated using the cost curve must be adjusted to a current value using an appropriate cost index.

a) Cost Data

Items included in the capital cost estimate are as follows [4-2]:

i) Lined Landfills
   Rainfall runoff and leachate channeled to central drainage basin
   Package physical/chemical treatment facilities
   Underdrain system
   Plastic membrane liner covered with 0.61 meters (2 feet) of sand for the first two year landfill cell
   Monitoring wells

ii) Double Lined Landfills
   All equipment for single lined landfill plus following items:
   One additional sand/impermeable liner provided
   One additional leachate collection system

b) Capital Cost Curve

i) Lined Landfill
   Curve - see Figure IV.3.4.5-A2.
   - Cost (millions of dollars) vs. area (hectares or acres).

- Curve basis, cost estimate for four landfills of 1.09, 4.94, 15.7, and 52 hectares (2.7, 12.2, 38.7, and 128.6 acres).

ii) Double Lined Landfill

Curve - see Figure IV.3.4.5-A3.

- Cost (millions of dollars) vs. area (square kilometers or acres).
- Curve basis, cost estimate for four landfills of 1.09, 4.94, 15.7, and 52 hectares (2.7, 12.2, 38.7, and 128.6 acres).

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

A 3. Operation and Maintenance Costs

Operating costs include fixed and variable components. The variable component includes hauling costs. Fixed costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Costs

i) Hauling Cost

Metric

$$HC = HD \times WW \times CF$$

where: HC = hauling cost, \$/day
HD = hauling distance, kilometers
WW = wet weight of the sludge, Kg/day
$= \Sigma\,[DW(i) \div SR(i)]$
DW(i) = quantity of sludge type i, Kg/day dry
SR(i) = fraction of solids in cake after filtration for sludge type (i) (see Table IV.3.4.3-A1)
CF = hauling cost factor, \$/Kg-kilometer

English

$$HC = HD \times WW \times CF$$

where: HC = hauling cost, \$/day
HD = hauling distance, mi
WW = wet weight of the sludge, lb/day
$= \Sigma[DW(i) \div SR(i)]$
DW(i) = quantity of sludge type i, lb/day (dry)

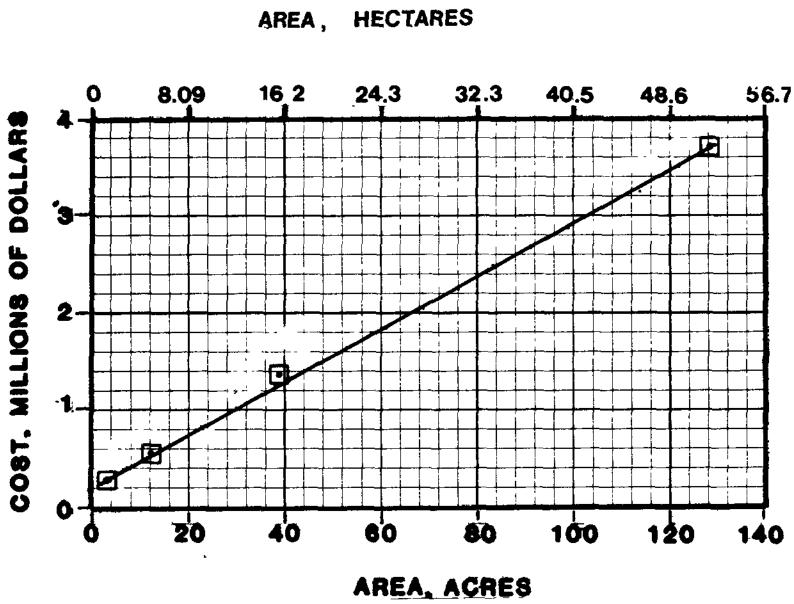


FIGURE IV.3.4.5-A2. CAPITAL COST ESTIMATE FOR LANDFILL (LINED) [4-10]

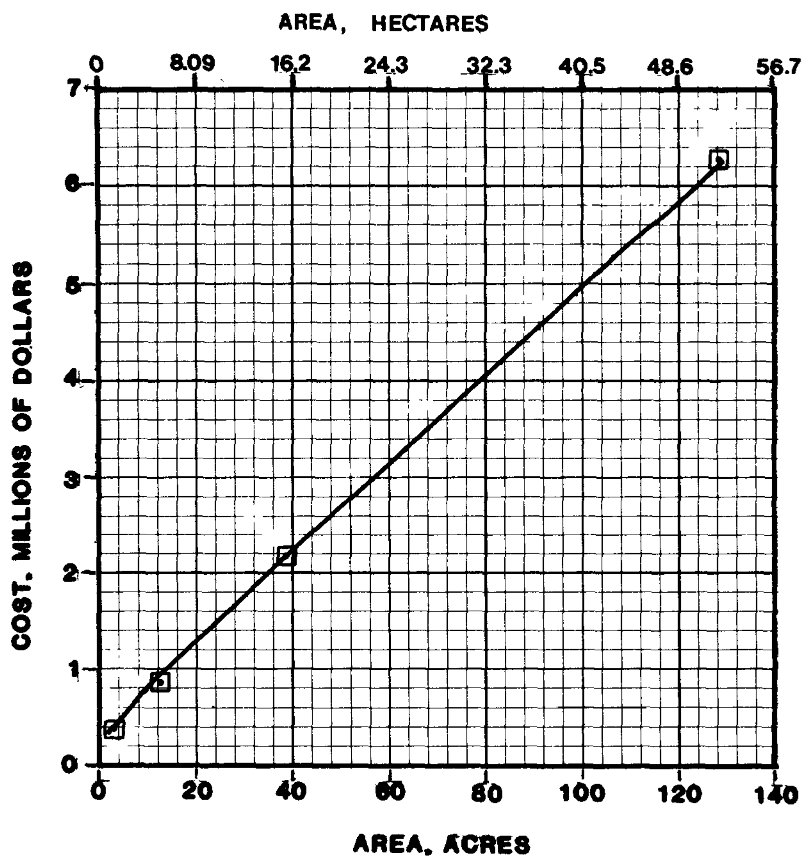


FIGURE IV.3.4.5-A3. CAPITAL COST ESTIMATE FOR LANDFILL (DOUBLE LINED) [4-10]

SR(i) = fraction of solids in cake after filtration for sludge type i (see Table IV.3.4.3-A1)

CF = hauling cost factor, \$/lb-mile (default value = 0.0004 \$/lb-mile) [4-2]

b) Fixed Costs

The fixed O & M components for this technology are listed in Table IV.3.4.5-A2, including the cost basis and the unit costs [4-11].

A.4 Miscellaneous Costs

Costs for engineering, and other common plant items such as land, piping, and buildings, are calculated after completion of costing for individual units (see Section IV.3.5).

A.5 Modifications

None required.

TABLE IV.3.4.5-A2. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR LANDFILL OPERATIONS [4-11]

Element	Cost Basis (Equivalent Unit Quantity)		Base Unit Cost (July 1977)
Labor (1,2)	0.83	Weeks (20.0 hrs/day)	$ 9.80/hr
Supervision (1)	10%	Labor (2.00 hrs/day)	$11.76/hr
Overhead (1)	75%	Labor Cost	NA
Laboratory	0.15	Shifts (3)(0.86 hrs/day)	$10.70/hr
Maintenance (4)	NA		NA
Services	0.40%	Capital	NA
Insurance & Taxes	2.50%	Capital	NA
Service Water	0.128 (2.93	L/s Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

(4) Annual maintenance cost for this technology includes the average annual cost of developing new 2-year landfill cells. Maintenance costs are calculated as a percentage of the capital costs. The percentage varies with the total landfill area as follows:

Landfill Area (acres)	% of Capital Cost for Maintenance
Area < 2.8	15.1
2.8 ≤ Area < 12.2	11.0 + (1.5 × Area)
12.2 ≤ Area < 38.7	27.0 + (0.25 × Area)
38.7 ≤ Area < 128.6	34.0 + (0.06 × Area)
128.6 ≤ Area	41.4

LANDFILL

SUMMARY WORK SHEET — REFERENCE: IV.3.4.5-A

I. DESIGN FACTOR		CAPITAL
Landfill Area = ______ acres		
II. CAPITAL COST		
Cost = ______ (Cost from curve) × (______ (current index) ÷ 204.7)		$ ______
III. VARIABLE O & M	$/day	O & M
a. Hauling Cost = ______ (Distance, Miles) × ______ (CF, $/lb-mile) × ______ (Wet weight, lb-day)	= ______	
IV. FIXED O & M		
a. Labor: ______ (hr/day) × ______ ($/hr)	= ______	
b. Supervision: ______ (hr/day) × ______ ($/hr)	= ______	
c. Overhead: ______ (Labor, $/day) × ______ (%/100)	= ______	
d. Lab Labor: ______ (hr/day) × ______ ($/hr)	= ______	
e. Maint, Service, I&T: ______ (capital, $) × ______ (%/100) ÷ 365 (day/yr)	= ______	
f. Service Water: ______ (thou gpd) × ______ ($/thou gal)	= ______	
V. YEARLY O & M 365 (day/yr) × ______ (sum, $/day)		= ______ ($/yr)
VI. UNCOSTED ITEMS		

LANDFILL
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. CF = Hauling Cost
   Factor = ________ \$/lb-mile

3. Labor = ________ \$/hr

4. Supervision = ________ \$/hr

5. Overhead = ________ % Labor ÷ 100 = ________%/100

6. Lab Labor = ________ \$/hr

7. Maintenance = % Capital (See Section IV)
   Services = % Capital
   Insurance/Taxes = ________ % Capital
   Other O & M Factor sum =________ ÷ 100 = %/100

8. Service Water = ________ \$/1000 gal

I. DESIGN FACTOR

a. For those sludges dewatered using vacuum filtration, use Work Table 1

   1. Enter incoming dry sludge weights (DW) by type in column C

   2. Divide dry sludge weights (DW) by loading rates (LR) from column A and enter the results (initial landfill volume) in column D.

   3. Sum column D

   4. To determine landfill area (AREA) for vacuum dewatered sludge enter the sum of column D (initial landfill volume) and the expected landfill depth (default value is 10 ft) in the following Equation.

$$\text{AREA} = \underset{\text{SUM D (VOL)}}{\underline{\hspace{3cm}}} \times 4.56 \div \underset{\text{DEPTH}}{\underline{\hspace{2cm}}} = \underline{\hspace{2cm}} \text{ acres}$$

b. For those sludges dewatered using pressure filtration, use Work Table 2. Follow the same procedure as described for Work Table I.

$$\text{AREA} = \underset{\text{SUM D (VOL)}}{\underline{\hspace{3cm}}} \times 4.56 \div \underset{\text{DEPTH}}{\underline{\hspace{2cm}}} = \underline{\hspace{2cm}} \text{ acres}$$

c. Total Basin Area = ______ + ______ = ______ acres

Area, acres Work Table I + Area, acres Work Table II

II. CAPITAL COST

III. VARIABLE O & M

a. For those sludges dewatered using vacuum filtration, use Work Table I.

1. To determine the wet weight of each sludge, divide dry weights (DW), Column C by the solids/moisture ratio (SR) from column B and enter the results in column E.

2. Sum column E and enter the results in the equation in Part III c below.

b. For those sludges dewatered using pressure filtration, use Work Table II. Follow the same procedure as described for Work Table I.

c. Total Weight Hauled = ______ + ______ = ______

Wet weight, lbs/day Work Table I + Wet weight, lbs/day Work Table II = Wet weight, lbs/day

IV. FIXED O & M

a. Determine maintenance cost factor (% capital) from the following table.

AREA (From Ic) (acres)	Factor Calculation		Maintenance % Capital
<2.8	15.1		= 15.1
2.8 to 12.2	11.0 + 1.526 ×	______ AREA, acres	= ______
12.2 to 38.7	27.0 + 0.249 ×	______ AREA, acres	= ______
38.7 to 128.6	34.0 + 0.0578 ×	______ AREA, acres	= ______
>128.6	41.4		= 41.4

V. YEARLY O & M

VI. UNCOSTED ITEMS

WORK TABLE 1. LANDFILL CALCULATIONS FOR VACUUM FILTRATION DEWATERED SLUDGE [4-2]

Flag	Sludge Type	A Loading Rate, (LR) (Tons/acre-ft)	B Solids:Moisture Ratio, (SR)	C Dry Weight, (DW) (lbs/day)	D Volume, (VOL) D = C/A	E Wet Weight, (WW) E = C/B
11	Lime Precipitate	170	0.40			
12	Aluminum Precipitate	50	0.20			
13	Iron Precipitate	50	0.20			
14	Sulfide Precipitate	50	0.20			
20	DAF Chemical Float	70	0.25			
50	Primary Solids	70	0.25			
51	Scrubber Sludge	70	0.25			
60	Waste Activated Sludge	25	0.12			
*65	Digested Sludge	25	0.12			
**72	Incinerator Ash (direct waste incineration)	320	0.60			
75	Incinerator Ash (byproduct incineration)	320	0.60			
80	Inorganic Filter Backwash	70	0.25			
81	Throwaway Activated Carbon (60% Solids)	289	0.60			
90	Organic Filter Backwash	25	0.60			
					Sum D = ____ (VOL)	Sum E = ____ (WW)

*If digested sludge (65) is present, the quantities of waste activated sludge (60) and organic filter backwash (90) are assumed to be zero.

**If ash from direct incineration of process waste (72) is present, its contributing wastes are assumed to be zero.

WORK TABLE 2. LANDFILL CALCULATIONS FOR PRESSURE FILTRATION DEWATERED SLUDGE [4-2]

Flag	Sludge Type	A Loading Rate, (LR) (Tons/acre-ft)	B Solids:Moisture Ratio, (SR)	C Dry Weight, (DW) (lbs/day)	D Volume, (VOL) D = C/A	E Wet Weight, (WW) E = C/B
11	Lime Precipitate	270	0.50			
12	Aluminum Precipitate	120	0.40			
13	Iron Precipitate	120	0.40			
14	Sulfide Precipitate	120	0.40			
20	DAF Chemical Float	170	0.45			
50	Primary Solids	170	0.45			
51	Scrubber Sludge	170	0.45			
60	Waste Activated Sludge	100	0.35			
*65	Digested Sludge	100	0.35			
**72	*Incinerator Ash (direct waste incineration)*	320	0.60			
75	Incinerator Ash (by product incineration)	320	0.60			
80	Inorganic Filter Backwash	170	0.45			
81	Throwaway Activated Carbon (60% Solids)	289	0.60			
90	Organic Filter Backwash	100	0.35			
					Sum D = ____ (VOL)	Sum E = ____ (WW)

*If digested sludge (65) is present, the quantities of waste activated sludge (60) and organic filter backwash (90) are assumed to be zero.

**If ash from direct incineration of process waste (72) is present, its contributing wastes are assumed to be zero.

IV.3.4.5-B. Outside Contractor

B 1. Basis of Design

This presentation is for the disposal of wastewater sludge and incinerator ash using an outside contractor. The principal design factor considered for this service is the volume required to store liquid residue and sludge generated over a 30-day period. The volume required is determined from the dry weight of incoming sludge solids, the ratio of dry sludge weight to wet sludge weight, and the density of the liquid sludge to be stored. Typical values for these factors are indicated in Table IV.3.4.5-B1. The design for the storage facility includes a concrete base, one or more storage tanks, centrifugal pumps, pipes, valves, and necessary instrumentation. The contractor hauling distance is assumed to be 10 miles if no other distance is specified.

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

Dry weight of each sludge type Kg/day (lb/day)
Total sludge weight Kg/day (lb/day)

c) Limitations

None specified.

d) Pretreatment

None required.

e) Design Equation

The design of storage facilities required for outside contractor hauling is based on the volume necessary to store liquid residue and sludge generated over a 30-day period. The required volume is computed from the amount of incoming sludge as follows:

Metric

$$VOL = 30 \times \Sigma\ [DW(i) \div SF(i) \div SD(i)]$$

TABLE IV.3.4.5-B1. SLUDGE FRACTION AND LIQUID SLUDGE DENSITY FOR VARIOUS TYPES OF SLUDGE [4-2].

Sludge Number	Sludge Type	SF Sludge Fraction, Kg or lb Dry Sludge/ Kg or lb Wet Sludge	SD Liquid Sludge Density lb/gal	SD Liquid Sludge Density Kg/L
**11	Lime Precipitate	0.100	8.34	1.0
**12	Aluminum Precipitate	0.015	8.34	1.0
**13	Iron Precipitate	0.030	8.34	1.0
**14	Sulfide Precipitate	0.015	8.34	1.0
20	DAF Chemical Float	0.200	8.50	1.02
*30	Oil	0.950	8.00	0.96
40	Oil plus Solids from DAF	0.500	8.34	1.0
**50	Primary Solids	0.030	8.34	1.0
**51	Scrubber Sludge	0.030	8.34	1.0
60	Waste Activated Sludge	0.010	8.34	1.0
*70	Solvent Extraction Residue	0.650	8.34	1.0
*71	Steam Stripping Residue	0.950	8.34	1.0
**72	Incinerator Ash (direct waste incineration)	0.600	8.34	1.0
**75	Incinerator Ash (byproduct incineration)	0.600	8.34	1.0
**80	Inorganic Filter Backwash	0.010	8.34	1.0
**81	Throwaway Activated Carbon	0.600	8.34	1.0
90	Organic Filter Backwash	0.010	8.34	1.0

*Liquid sludge residue
**Inorganic sludge

where: VOL = total storage volume, L/month
30 = days/month
DW(i) = dry weight of incoming sludge(i), Kg/day
SF(i) = solids fraction of incoming sludge(i), Kg dry sludge/Kg wet sludge
SD(i) = sludge density, Kg/L

English

$$VOL = 30 \times \Sigma\ [DW(i) \div SF(i) \div SD(i)]$$

where: VOL = total storage volume, gallon/month
30 = days/month
DW(i) = dry weight of incoming sludge(i), lb/day
SF(i) = solids fraction of incoming sludge(i), lb dry sludge/lb wet sludge
SD(i) = sludge density, lb/gallon (see Table IV.3.4.5-B1)

f) Subsequent Treatment

Treatment of sludges by contract hauler prior to disposal.

B 2. Capital Costs

On-site storage volume is the principal cost factor used in estimating capital cost. The cost of storage for either sludge or liquid wastes alone or sludge and liquid wastes combined may be estimated by this method. The cost of storing the combined wastes is assumed to be 1.3 times the standard cost for the combined waste. The additional cost reflects the cost of storage tank agitators necessary to produce a relatively homogeneous mixture. The installed cost of on-site waste storage vessels without agitators is represented in Figure IV.3.4.5-B1. Costs estimated using the cost curve must be adjusted to a current value using an appropriate cost index.

a) Cost Data

Items included in the capital cost estimate are as follows [4-2]:

Concrete base
Storage tanks
Centrifugal pumps
Pipes and valves
Instrumentation

b) Capital Cost Curve

i) Curve - see Figure IV.3.4.5-B1.
- Cost (thousands of dollars) vs. storage volume (thousand liters or thousand gallons)

- Curve basis, cost estimate for four storage vessel volumes 7570, 18,900, 56,800, and 98,400 liters (2,000, 5,000, 15,000, and 26,000 gallons).

ii) Scale Factor

If both liquid waste and sludge are stored together:

$$COST = \text{Standard Cost from Curve} \times 1.3$$

c) Cost Index

Base period, July 1977, St. Louis
Chemical Engineering (CE) Plant Index = 204.7

B 3. Operation and Maintenance Costs

Operating costs include both fixed and variable components. The variable component includes power, hauling, and disposal. Fixed costs include labor, supervision, overhead, laboratory labor, maintenance, services, insurance and taxes, and service water. All fixed and variable operating costs should be adjusted to current levels using an appropriate index or unit cost factor.

a) Variable Cost

i) Power Requirements [4-1]. The following equations were developed using regression analysis procedures.

Metric

$$KW = (VOL \times 5.48 \times 10^{-5}) + 0.356$$

where: KW = power, kilowatts
VOL = storage vessel volume, liter

English

$$HP = (VOL \times 2.78 \times 10^{-4}) + 0.474$$

where: HP = power, Hp
VOL = storage vessel volume, gallons

ii) Power Cost

Metric

$$PC = KW \times 24 \times EC$$

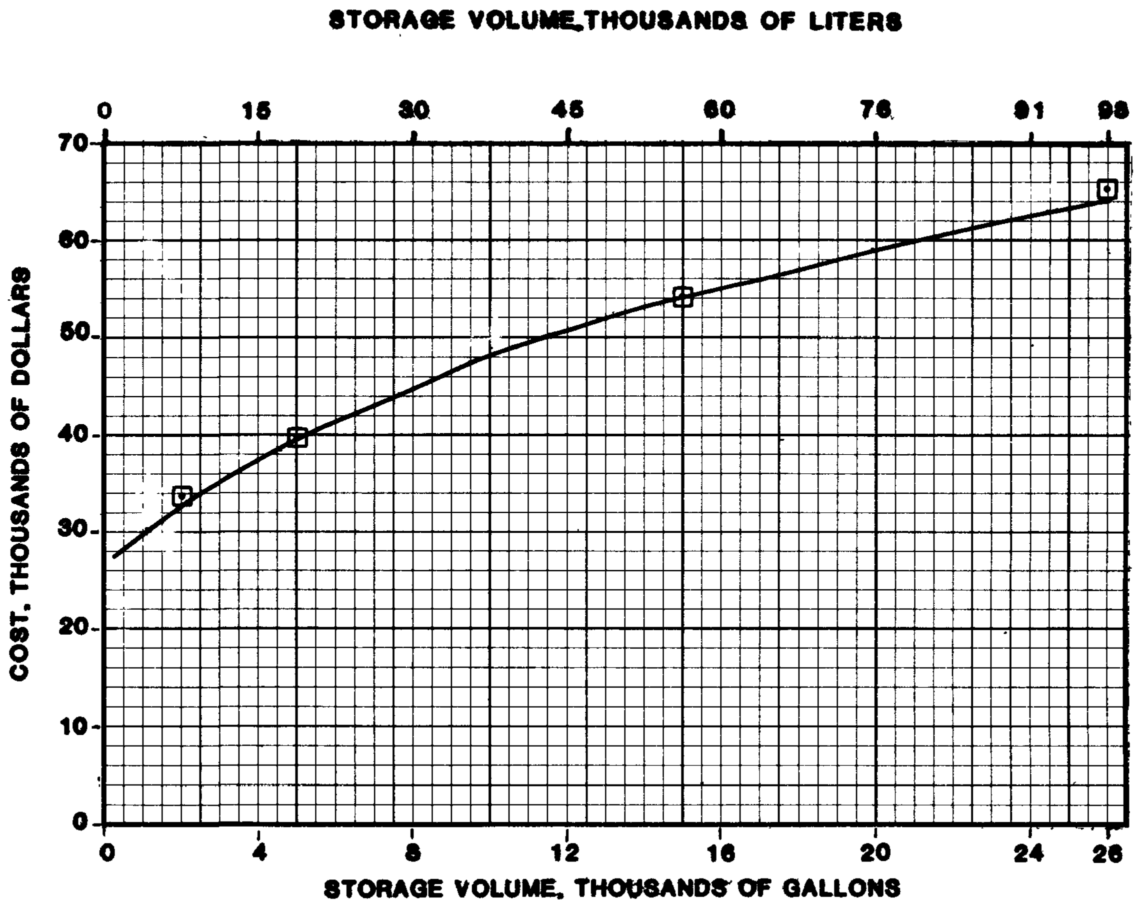


FIGURE IV.3.4.5-B1. CAPITAL COST ESTIMATE FOR OUTSIDE CONTRACTOR [4-10]

where: PC = power cost, \$/day
KW = power, kilowatts
24 = hr/day
EC = electricity cost \$/Kw-hr

English

$$PC = HP \times EC \times 24 \times 0.746$$

where: PC = power cost, \$/day
EC = electricity cost, \$/Kw-hr
24 = hr/day
0.746 = Kw-hr/Hp-hr

iii) Hauling Cost

Metric

$$HC = HCF \times WW \times HD$$

where: HC = hauling cost, \$/day
HCF = hauling cost factor, \$/Kg-kilometer (factor = 0.0005 \$/Kg-kilometer unless otherwise specified)
WW = wet weight of sludge and residue to be hauled, Kg/day
$= \Sigma[DW(i) \div SF(i)]$
DW(i) = dry weight of sludge and residue to be hauled, Kg/day
SF(i) = solids fraction of the wet weight of sludge, Kg dry solids/Kg wet solids
HD = hauling distance, kilometer (assumed to be 16.1 kilometers)

English

$$HC = HCF \times WW \times HD$$

where: HC = hauling cost, \$/day
HCF = hauling cost factor, \$/lb-mile (factor = 0.0004 \$/lb-mile unless otherwise specified) [4-2]
WW = wet weight of sludge and residue to be hauled, lb/day
$= \Sigma[DW(i) \div SF(i)]$
DW(i) = dry weight of sludge and residue to be hauled, lb/day
SF(i) = solids fraction of the wet weight of sludge, lbs dry solids/lbs wet sludge
HD = hauling distance, miles (assumed to be 10 miles unless otherwise specified) [4-2]

(iv) Disposal Cost - regular wastes with no toxicity or other problems

Metric

$$DC = DCF \times XWW \div 1000$$

where: DC = disposal cost, \$/day
DCF = disposal cost factor, \$/Mg (factor = 39.7 \$/Mg unless otherwise specified)
WW = wet weight of sludge and residue to be hauled, Kg/day
= $\Sigma[DW(i) \div SF(i)]$
DW(i) = dry weight of sludge and residue to be hauled, Kg/day
SF(i) = solids fraction of the wet weight of sludge, Kg dry solids/Kg wet sludge
1000 = Kg/Mg

English

$$DC = DCF \times WW \div 2000$$

where: DC = disposal cost, \$/day
DCF = disposal cost factor, \$/ton (factor = 36 \$/ton unless otherwise specified) [4-2]
WW = wet weight of sludge and residue to be hauled, lb/day
= $\Sigma[DW(i) \div SF(i)]$
DW(i) = dry weight of sludge and residue to be hauled, lb/day
SF(i) = solids fraction of the wet weight of sludge, lbs dry solids/lbs wet sludge
2000 = lb/ton

v) Disposal Cost - combustible and inorganic sludges with toxicity or other problems

Metric

$$DC = [(DCFI \times IWW) + (DCFC \times CWW)] \div 1000$$

where: DC = disposal cost, \$/day
DCFI = inorganic sludge disposal cost factor, \$/Mg (factor = 230 \$/Mg unless otherwise specified)
IWW = inorganic sludge wet weight, Kg/day
= $\Sigma[DW(j) \div SF(j)]$
DW(j) = dry weight of inorganic sludges(j), Kg/day

$SF(j)$ = solids fraction of the wet weight of sludge, Kg dry solids/Kg wet sludge
$DCFC$ = combustible sludge disposal cost factor, \$/Mg (factor = 314 \$/Mg unless otherwise specified)
CWW = combustible sludge wet weight, Kg/day
$= \Sigma[DW(K) \div SF(K)]$
$DW(K)$ = dry weight of combustible sludges (K), Kg/day
$SF(K)$ = solids fraction of the wet weight of sludge, Kg dry solids/Kg wet sludge
1000 = Kg/Mg

English

$$DC = [(DCFI \times IWW) + (DCFC \times CWW)] \div 2000$$

where: DC = disposal cost, \$/day
$DCFI$ = inorganic sludge disposal cost factor, \$/ton (factor = 209 \$/ton unless otherwise specified) [4-2]
IWW = inorganic sludge wet weight, lb/day
$= \Sigma[DW(j) \div SF(j)]$
$DW(j)$ = dry weight of inorganic sludges(j), lb/day
$SF(j)$ = solids fraction of the wet weight of sludge, lb dry solids/lb wet sludge
$DCFC$ = combustible sludge disposal cost factor, \$/ton (factor = 285 \$/ton unless otherwise specified) [4-2]
CWW = combustible sludge wet weight, lb/day
$= \Sigma[DW(k) \div SF(k)]$
$DW(k)$ = dry weight of combustible sludges(k), lb/day
$SF(k)$ = solids fraction of the wet weight of sludge, lbs dry solids/lbs wet sludge
2000 = lbs/ton

b) Fixed Costs

The fixed O & M components of this technology are listed in Table IV.3.4.5-B2, including the cost basis and the unit costs [4-11].

B 4. Miscellaneous Costs

Costs for engineering, and other common plant items such as land, piping, and buildings, are calculated after completion of costing for individual units (see Section IV.3.5).

B 5. Modifications

None required.

Table IV.3.4.5-B2. FIXED O & M COST BASIS AND UNIT COST FACTORS FOR OUTSIDE CONTRACTOR WASTE DISPOSAL [4-11]

Element	Cost Basis (Equivalent Unit Quantity)	Base Unit Cost (July 1977)
Labor (1,2)	0.036 Weeks (0.86 hrs/day)	$ 9.80/hr
Supervision (1)	10% Labor (0.09 hrs/day)	$11.76/hr
Overhead (1)	75% Labor Cost	NA
Laboratory (3)	0.036 Shifts (0.21 hrs/day)	$10.70/hr
Maintenance	5.60% Capital	NA
Services	0.40% Capital	NA
Insurance & Taxes	2.50% Capital	NA
Service Water	0.001 L/s (0.02 Thou gpd)	$ 0.13/thou L ($ 0.50/thou gal)

NA - not applicable

(1) Labor may vary from 0.7 to 1.2 times the standard amount indicated depending on the overall scale of the plant. Labor, Supervision, and Overhead may be adjusted for the scale of the plant as indicated in Miscellaneous Costs (Section IV.3.5).

(2) One week = 7 days = 168 hours = 4.2 shifts

(3) One shift = 40 hours

OUTSIDE CONTRACTOR
SUMMARY WORK SHEET

REFERENCE: IV.3.4.5-B

I. DESIGN FACTOR — CAPITAL

a. Storage Vessel Volume = ____________ gallons

II. CAPITAL COST

Cost = ____________ (Cost from curve) × (____________ (current index) ÷ 204.7) — $ ________

III. VARIABLE O & M — $/day — O & M

a. Power = ________ (Hp) × ________ (EC, $/Kw-hr) × 17.9 = ________

b. Hauling = ________ (Wet Weight, lb/day) × ________ (HCF, $/lb-mile) × 10 (distance, miles) = ________

c. Disposal (sludge, no toxicity or other problems)

= ____________ (Total Wet Weight, lb/day) × ____________ (Disposal Cost Factor, DCF, $/ton) ÷ 2000 lb/ton = ________

d. Disposal (sludge with toxicity problems)

= [(________ (DCFI, $/ton) × ____________ (Inorganic Wet weight, lb/day)) + (________ (DCFC, $/ton)

× ________ (Combustible WW, lb/day))] ÷ 2000 = ____________ = $ ________

IV. FIXED O & M

a. Labor: ________ (hr/day) × ________ ($/hr) = ________

b. Supervision: ________ (hr/day) × ________ ($/hr) = ________

c. Overhead: ________ (Labor, $/day) × ________ (%/100) = ________

d. Maint, Service, I&T: ________ (capital, $) × ________ (%/100) ÷ 365 day/yr = ________

e. Service Water: ________ (thou gpd) × ________ ($/thou gal) = ________

V. YEARLY O & M — 365 day/yr × ________ (sum, $/day) = ________ $/yr

VI. UNCOSTED ITEMS

OUTSIDE CONTRACTOR
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Current Index = ________ Capital Cost Index

2. HCF = Hauling Cost Factor = ________ \$/lb-mile

3. DCF = Disposal Cost Factor (Non-toxics) = ________ \$/ton

4. DCFI = Inorganics Disposal Cost Factor (Toxics) = ________ \$/ton

5. DCFC = Combustibles Disposal Cost Factor (Toxics) = ________ \$/ton

6. Labor = ________ \$/hr

7. Supervision = ________ \$/hr

8. Overhead = ________ % Labor ÷ 100 = ________ %/100

9. Laboratory Labor = ________ \$/hr

10. Maintenance = ________ % Capital
    Services = ________ % Capital
    Insurance/Taxes = ________ % Capital
    Other O & M Factor Sum = ________ ÷ 100 = ________ %/100

11. Service Water = ________ \$/1000 gal

I. DESIGN FACTOR

a. To determine storage vessel volume use Work Table I.

   1. To determine the volume of each sludge, divide dry weights (DW) from Column A by the sludge fraction (SF) from Column B, and divide this by liquid sludge density (SD) from Column C. Enter the result in Column D.

   2. Sum the items in Column D and enter the results in the equation below.

   3. Total storage vessel volume (VOL) = 30 × ________ = ________ gallons
      SUM D

II. CAPITAL COST

III. VARIABLE COST

a. Power requirements

HP = (_____________________ $\times$ 2.78 $\times$ 10^{-4})
Storage Vessel Volume,

+ 0.474 = __________ Hp

b. To determine wet weight of sludge to use in calculating hauling costs use Work Table II

1. To determine wet weight of inorganic and combustible sludges, divide dry weights (DW) from Colume A by the sludge factor (SF) from Column B. Enter the results in the inorganics (Column C) or combustible sludge (Column D) as appropriate.

2. Total weight hauled = ____________________ (Inorganics Wet weight, Work Table II, Sum Column C) + ____________________ (Combustible Wet weight, Work Table II, Sum Column D)

= _____________ (Wet weight lb/day)

c. To determine disposal costs for sludges without toxicity or other problems

Total Wet weight (From III b 4) = ___________ lb/day

d. To determine disposal costs for sludges with toxicity or other problems

1. Inorganic sludge wet weight (Work Table II, sum of column C) = _________ lb/day

2. Combustible sludge wetweight (Work Table II, sum of column D) = _________ lb/day

IV. FIXED O & M

V. YEARLY O & M

VI. UNCOSTED ITEMS

WORK TABLE I. STORAGE VESSEL VOLUME CALCULATIONS FOR OUTSIDE CONTRACTOR

Flag	Sludge	A Dry Weight, DW (lb/day)	B Sludge Fraction, SF (lb day/lb wet)	C Liquid Sludge Density, SD (lb/gal)	D = A / B / C Sludge Volume (gal/day)
11	Lime Precipitate		0.100	8.34	
12	Aluminum Precipitate		0.015	8.34	
13	Iron Precipitate		0.030	8.34	
14	Sulfide Precipitate		0.015	8.34	
20	DAF Chemical Float		0.200	8.50	
30	Oil		0.950	8.00	
40	Oil plus Solids from DAF		0.500	8.34	
50	Primary Solids		0.030	8.34	
51	Scrubber Sludge		0.030	8.34	
60	Waste Activated Sludge		0.010	8.34	
70	Solvent Extraction Residue		0.650	8.34	
71	Steam Stripping Residue		0.950	8.34	
72	Incinerator Ash (direct waste incin.)		0.600	8.34	
75	Incinerator Ash (byproduct incin.)		0.600	8.34	
80	Inorganic Filter Backwash		0.010	8.34	
81	Throwaway Activated Carbon		0.600	8.34	
90	Organic Filter Backwash		0.010	8.34	
					SUM D (VOL) = ________

WORK TABLE II. INORGANIC AND COMBUSTIBLE SLUDGE WEIGHT CALCULATIONS FOR OUTSIDE CONTRACTOR

Flag	Sludge	A Dry Weight, DW (lb/day)	B Sludge Fraction, SF (lb day/lb wet)	C = A / B Inorganic Sludge (lb/day)	D = A / B Combustible Sludge (lb/day)
11	Lime Precipitate		0.100		xxxxx
12	Aluminum Precipitate		0.015		xxxxx
13	Iron Precipitate		0.030		xxxxx
14	Sulfide Precipitate		0.015		xxxxx
20	DAF Chemical Float		0.200	xxxxx	
30	Oil		0.950	xxxxx	
40	Oil plus Solids from DAF		0.500	xxxxx	
50	Primary Solids		0.030		xxxxx
51	Scrubber Sludge		0.030		xxxxx
60	Waste Activated Sludge		0.010	xxxxx	
70	Solvent Extraction Residue		0.650	xxxxx	
71	Steam Stripping Residue		0.950	xxxxx	
72	Incinerator Ash (direct waste incin.)		0.600		xxxxx
75	Incinerator Ash (byproduct incin.)		0.600		xxxxx
80	Inorganic Filter Backwash		0.010		xxxxx
81	Throwaway Activated Carbon		0.600		xxxxx
90	Organic Filter Backwash		0.010	xxxxx	
				SUM C = ______ lb/day	SUM D ______ lb/day

IV.3.5 MISCELLANEOUS COSTS AND TOTAL PLANT COSTS

Introduction

There are certain costs associated with building a treatment plant which cannot be directly attributed to any particular unit process. Transformers, area lighting, offices, laboratories, and other such general facilities are partly a function of the size of the plant, and partly fixed in cost since there are certain minimum sizes mandatory for facilities. Costing methodologies for these common, miscellaneous facilities are presented below.

A. Miscellaneous Direct Costs and Total Plant Costs

A 1. General

This presentation is for determination of miscellaneous costs associated with construction of industrial wastewater treatment facilities. This method requires that adjustments be made to the amounts of labor, supervision, overhead, laboratory labor, and service water to account for the relative size of the plant and associated services. The sums of the capital costs, power requirements, and total number of unit processes serve as the basis for estimating costs for yard piping, buildings, transformers, yard lighting, motor controls, a sanitary waste pumping station, and engineering services. Total land requirements are also determined for all unit processes as well as ancillary facilities. Finally, the total capital cost and total annual operation and maintenance cost for the entire wastewater treatment facility are calculated from the component costs.

a) Source

The unit cost information in this section was derived from the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industries [4-2]. The method for developing the design factor is based on assumptions and procedures in the Contractor Developed Design and Cost Model [4-1].

b) Required Input Data

- Total number of unit processes
- Total adjusted capital cost of unit processes, \$(current)
- Total power requirements of all unit processes, Kw or Hp
- Total labor requirements of all unit processes, hr/day
- Total supervision requirements for all unit processes, hr/day
- Total laboratory labor requirements for all unit processes, hr/day
- Total labor, supervision, and laboratory labor requirements for "in-plant" processes, hr/day

Total number of unit processes for which land requirements have been previously calculated
Total land requirements of unit processes for which land requirements had been calculated, m^2 or ft^2

A 2. Miscellaneous Direct Costs [4-11]

There is the need to include several cost items for the entire treatment facility that are not included in the individual unit process cost estimates.

a) General Yard Piping

The cost of general yard piping is computed as a fraction of the total capital cost of the unit processes to be constructed.

$$YP = 0.0875 \times TCUP$$

where: YP = yard piping cost, $
TCUP = total capital cost (adjusted to current dollars) for all unit process, $

b) Laboratory and Office Building

The cost of the necessary laboratory and office facilities are computed on the basis of the total number of unit processes to be constructed.

If $TNUP \leq 10$

$$BLDG = \$78,000$$

If $TNUP > 10$

$$BLDG = [1,200 + (100 \times (TNUP - 10))] \times 65$$

where: TNUP = total number of unit processes
BLDG = building cost, 1977 dollars

This cost must be updated to a current level using an appropriate cost index or factor.

c) Sanitary Waste Pumping Station

A sanitary waste pumping station is generally provided for a new plant.

$$PS = \$5,000$$

This facility is estimated at a fixed cost of $5,000 in 1977 but must be adjusted to a current cost using an appropriate cost index or factor.

d) Transformer Cost

The cost of transformers for the plant is estimated on the basis of total power demand. Total power for all unit processes is first converted to power demand and appropriate size transformers are matched and costed according to the following schedule:

i) Total Power Demand [4-11]

Metric

$$KVA = TKW \times 1.16$$

where: KVA = total power demand, kilovolt-ampere
TKW = total power requirements, kilowatts

English

$$KVA = THP \times 0.866$$

where: KVA = total power demand, kilovolt-ampere
THP = total horsepower requirements, Hp

ii) Transformer Cost

KVA Range	Transformer Cost (TC) (1977 dollars)
KVA < 500	0
500 < KVA < 1000	59400
1000 < KVA < 1500	74600
1500 < KVA < 2000	74600 + 42900
2000 < KVA < 2500	74600 + 59400
2500 < KVA < 3000	74600 + 74600

The cost of transformers estimated using this schedule must be updated to a current level using an appropriate cost index or factor.

e) Motor Control Center

The cost of the motor control center for the plant is based on the total power requirements of the individual unit processes.

Metric

$$MOCONC = TKW \times 80.4$$

where: MONCONC = cost of motor control center, 1977 dollars
TKW = total power requirements of plant, kilowatts

English

$$MOCONC = THP \times 60$$

where: MOCONC = cost of motor control center, 1977 dollars
THP = total horsepower requirement of the plant, Hp

This cost must be updated from 1977 dollars to a current level using an appropriate cost index or factor.

f) Yard Lighting

The cost of yard lighting is computed on the basis of the number of unit processes to be considered.

$$YLIGHT = (3 \times TNUP + 6) \times 770$$

where: YLIGHT = cost of yard lighting, 1977 dollars
TNUP = total number of unit processes to be constructed

This cost must be updated to a current level using an appropriate cost index or factor.

A 3. Engineering Services [4-11]

The cost of engineering services is based on the total capital cost of the facilities to be constructed, adjusted to current dollars.

$$ECOST = FACTOR \times (TCUP + TMISC)$$

where: ECOST = engineering cost, \$
FACTOR = fraction of total capital costs charged for engineering
= $(-7.3 \times 10^{-9}) \times (TCUP + TMISC) + 0.182$ or a minimum of 0.06
TCUP = total capital cost of unit processes, \$
TMISC = total capital cost of miscellaneous items, \$
= YP + BLDG + PS + TC + MOCONC + YLIGHT
YP = yard piping cost, \$
BLDG = building cost, \$
PS = pump station, \$
TC = transformer cost, \$
MOCONC = cost of motor control center, \$
YLIGHT = cost of yard lighting, \$

The estimates for the TMISC components are developed as described in Part A2.

A 4. Labor Adjustments [4-1, 4-2]

The labor, overhead, and service water estimates presented for the individual unit processes were based on a typical plant. Adjustments may be made to the total labor, supervision, overhead, laboratory labor, and service water estimates to account for the relative scale of the facilities to be constructed. It is assumed that if the treatment plant is small, it will probably be operated on a part-time basis by other existing operators and receive incremental supervision. On the other hand, if the plant is very large, it will probably require extra environmental attention by virtue of its potential impact on any receiving body of water, and will be set up as a self-sufficient operation. This would require more labor than normal. To account for relative scale labor, costs are adjusted as follows:

TABLE IV.3.5-A1. LABOR ADJUSTMENT FACTORS [4-2].

Capital Cost* of Plant	Factor to Adjust "Normal" Labor
Less than $500,000	0.7
$500,000 to $1,500,000	0.9
$1,500,000 to $20,000,000	1.0
Over $20,000,000	1.2

*All of these capital cost ranges are based on 1977 capital costs (Chemical Engineering (CE) Plant Index = 204.7). They should be adjusted to a current price index prior to use.

The plant labor adjustment is performed as follows:

The total labor requirements of the primary and end-of-pipe unit processes are totaled and the number of people adjusted to remove any "fractional" people. This final labor count is used to adjust all labor accounts (labor, supervision, overhead, laboratory labor) for pretreatment and end-of-pipe treatment processes. Water use is also adjusted by this same factor on the basis that clean-up, washdowns, miscellaneous services such as shops, and other service water using activities would be modified approximately in proportion to the labor staff.

In these labor adjustments, only primary treatment and end-of-pipe treatment labor items are evaluated and adjusted. In-plant unit processes such as steam stripping, solvent extraction, and in-process incineration are not included since it is assumed that they are attached to a product/process, and therefore need no adjustment. (Note all terms are defined after part e, below).

a) Labor

$$ADJLABOR = [(TOTLABOR - IPLABOR) \times NFACTOR + IPLABOR] \times LPAY$$

b) Supervision

$$ADJSUPER = 0.1 \times ADJLABOR \times (SPAY \div LPAY)$$

c) Overhead

$$ADJOH = 0.75 \times ADJLABOR$$

d) Laboratory Labor

$$ADJLAB = [(TOTLAB - IPLAB) \times NFACTOR + IPLAB] \times LABPAY$$

e) Service Water

$$ADJSW = (TOTSW - IPSW) \times NFACTOR + IPSW$$

where:
- ADJLABOR = total adjusted labor cost, \$/day
- TOTLABOR = total unadjusted labor, hr/day
- IPLABOR = total labor for in-plant processes, hr/day
- NFACTOR = labor adjustment factor (see Table IV.3.5-A1)
- LPAY = pay rate for labor, \$/hr
- ADJSUPER = total adjusted supervision cost, \$/day
- SPAY = pay rate for supervision, \$/hr
- ADJOH = total adjusted overhead, \$/day
- ADJLAB = total adjusted laboratory labor cost, \$/day
- TOTLAB = total unadjusted laboratory labor, hr/day
- IPLAB = total laboratory labor for in-plant processes, hr/day
- LABPAY = pay rate for laboratory labor, \$/hr
- ADJSW = total adjusted service water cost, \$/day
- TOTSW = total service water cost, unadjusted, \$/day
- IPSW = total in-plant service water cost, \$/day

A 5. Land Requirements [4-1]

The cost of land is highly variable depending on location and other factors. Total land requirements for a plant may be estimated using guidelines outlined below. Costs may be estimated if information on local conditions can be obtained.

a) Land Requirements Previously Calculated

Sum the land requirements for the unit processes (UP) for which land requirements were calculated independently. Do not include landfill areas.

UPLAND = ______________ m^2 or ft^2
sum of land for unit processes

b) Land Requirements Not Previously Calculated

Sum the number of unit processes to be constructed for which land requirements were not previously calculated and select an appropriate land allowance from the following table:

NLUP = ______________
number of UP's with no land estimates

Number of Unit Processes Without Land Estimates (NLUP)	Land Allowance per Unit Process (ALLOW)	
	m^2	ft^2
Greater than 10	232	2,500
5 to 9	325	3,500
3 or 4	418	4,500
1 or 2	465	5,000

c) Total Land Requirement

Metric

$$LAND = [UPLAND + (NLUP \times ALLOW)] \div 10{,}000$$

where:
LAND = total land requirement, hectares
UPLAND = total land requirement for unit processes (UP's) previously calculated, m^2
NLUP = number of UP's without previous land requirements
ALLOW = land allowance per UP, m^2
10,000 = m^2/hectare

English

$$LAND = [UPLAND + (NLUP \times ALLOW)] \div 43560$$

where:
LAND = total land requirements, acres
UPLAND = total land requirements for unit processes (UP's) previously calculated, ft^2
NLUP = number of UP's without previous land requirements

ALLOW = land allowance per UP, ft^2
43560 = ft^2/acre

A 6. Total Capital and O & M Costs [4-1]

After any necessary miscellaneous costs have been calculated and necessary adjustments have been made, the final estimates are prepared for total capital cost and O & M.

a) Capital Costs

Total capital costs are the sum of all unit process costs, all miscellaneous direct costs, and engineering costs. Note that land is not included, but may be if land costs can be estimated:

$$CAPCOST = TCUP + TMISC + ECOST$$

where: CAPCOST = total adjusted capital cost for all facilities, current $
TCUP = total adjusted capital cost for all unit processes, current $
TMISC = total adjusted miscellaneous cost, current $
ECOST = total engineering cost, current $

b) Operation and Maintenance Costs

Total O & M costs for the whole plant are the sum of all adjusted and unadjusted variable and fixed O & M elements for the unit processes.

i) Variable O & M

$$TVOM = TPC + TCC + TSC + TWC + TFC + TLHC + OCHC + OCDC$$

where: TVOM = total variable O & M cost, current $/day
TPC = total power cost, current $/day
TCC = total chemical cost, current $/day
= Σ cost of all chemicals used by unit processes including lime, current $/day
TSC = total steam costs, current $/day
TWC = total process/cooling water cost, $/day
TFC = total fuel cost, current $/day
TLHC = total landfill hauling cost, current $/day
OCHC = outside contractor hauling cost, current $/day
OCDC = outside contractor disposal cost, current $/day

ii) Fixed O & M

$$TFOM = ADJLABOR + ADJSUPER + ADJOH + ADJLAB + ADJSW + TIAT + TMAINT + TSER$$

where: TFOM = total fixed O & M cost, current $/day
ADJLABOR = total adjusted labor, current $/day
ADJSUPER = total adjusted supervision, current $/day
ADJOH = total adjusted overhead, current $/day
ADJLAB = total adjusted laboratory labor, current $/day
ADJSW = total adjusted service water, current $/day
TIAT = total insurance and taxes, current $/day
TMAINT = total maintenance cost, current $/day
TSER = total plant services, current $/day

iii) Total Annual O & M

$$TAOM = 365 \times (TVOM + TFOM)$$

where: TAOM = total annual O & M, current $/yr
TVOM = total variable O & M, current $/day
TFOM = total fixed O & M, current $/day
365 = day/year

A 7. Modifications

All of the miscellaneous direct costs and adjustments described in this section may not be applicable in every case, and some may be deleted or modified at the discretion of the user. Also, the financial, legal, and administrative costs of constructing new wastewater treatment facilities have not been included in this cost estimate. Although these are not considered capital cost items in this analysis, they can have a significant effect on the cost of the plant.

MISCELLANEOUS AND TOTAL PLANT COSTS
SUMMARY WORK SHEET

REFERENCE IV.3.5-A

I. UNIT PROCESS CAPITAL COST	$	CAPITAL

a. Total Adjusted Capital Cost for Unit Processes (TCUP) = ________

II. TOTAL MISCELLANEOUS DIRECT COSTS

a. Yard Piping (YP) = ________
b. Laboratory, Office Building (BLDG) = ________
c. Sanitary Waste Pump Station (PS) = ________
d. Transformer (ATC) = ________
e. Motor Control Center (MOCONC) = ________
f. Yard Lighting Y(LIGHT) = ________

g. Total Miscellaneous Direct Costs (TMISC) = ________

III. ENGINEERING COSTS

Engineering fee (ECOST) = ________

IV. TOTAL DIRECT CAPITAL COSTS (LESS LAND)

Total Direct Capital Cost (TCUP + TMISC + ECOST) = $________

V. ADJUSTED O & M	$/day	O & M

a. Total Power Cost = ________
b. Total Chemical Cost = ________
c. Total Steam Cost = ________
d. Process Water Cost = ________
e. Fuel Cost = ________
f. Total Hauling/Disposal Cost = ________
g. Adjusted Labor Cost (ADJLABOR) = ________
h. Adjusted Supervision Cost (ADJSUPER) = ________
i. Adjusted Overhead Cost (ADJOH) = ________
j. Adjusted Laboratory Labor Cost (ADJLAB) = ________
k. Adjusted Service Water = ________
l. Maintenance, Insurance, Taxes, and Services = ________

m. Total O & M 365 × ________ (SUM) = $________

VI. LAND REQUIREMENTS

LAND = ________ acres

MISCELLANEOUS AND TOTAL PLANT COSTS
WORK SHEET

REQUIRED COST FACTORS AND UNIT COSTS

1. Labor, LPAY = __________ \$/hr

2. Supervision Labor, SPAY = __________ \$/hr

3. Lab Labor, LABPAY = __________ \$/hr

I. TOTAL CAPITAL COSTS FOR UNIT PROCESSES

a. Prepare a summary of costs by unit process using Work Table 1.

   1. Enter the name of the unit process and indicate by a mark whether it is used as an in-plant or end-of-pipe treatment technology. The in-plant distinction generally has to do with whether the unit process is used to treat a segregated waste stream with the object of recovering or reusing the stream.

   2. Fill in the rest of the table from the summary work sheets which were prepared for each of the unit processes previously.

   3. Sum all of the columns for all unit processes. Separately sum the labor, supervision, overhead, laboratory labor, and service water requirements for those unit processes which have been designated as "in-plant" and enter the sums in the indicated spaces.

   4. From Work Table I

      Total number of unit processes (B + C) = __________ TNUP

      Total number of in-plant processes (B) = __________

      Total number of unit processes with land requirements = __________

      Total capital cost for all unit processes (D) = __________ \$ TCUP

      Total horsepower requirements (E) = __________ Hp THP

II. TOTAL MISCELLANEOUS DIRECT COSTS

a. General Yard Piping

$$YP = 0.0875 \times \underset{TCUP(D)}{\underline{\qquad\qquad}} = \$\underline{\qquad\qquad}$$

b. Laboratory and Office Building

<u>If</u> TNUP (B + C) ≤ 10

$$BLDG = 78000 \times (\underset{\text{current index}}{\underline{\qquad\qquad\qquad}} \div 204.7) = \$\underline{\qquad\qquad\qquad}$$

<u>If</u> TNUP (B + C) > 10

$$BLDG = [1200 + (100 \times (\underset{TNUP}{\underline{\qquad}} - 10))] \times 65$$

$$\times (\underset{\text{current index}}{\underline{\qquad\qquad\qquad}} \div 204.7) = \$\underline{\qquad\qquad\qquad}$$

c. Sanitary Waste Pumping Station

$$PS = 5000 \times (\underset{\text{current index}}{\underline{\qquad\qquad\qquad}} \div 204.7) = \$\underline{\qquad\qquad\qquad}$$

d. Transformer

1. $KVA = \underset{THP(E),\ Hp}{\underline{\qquad\qquad\qquad}} \times 0.866 = \underline{\qquad\qquad\qquad}$

2. Determine Transformer Cost from following table:

KVA Range	Transformer Cost (TC) (1977 dollars)
KVA < 500	0
500 < KVA < 1000	59400
1000 < KVA < 1500	74600
1500 < KVA < 2000	74600 + 42900
2000 < KVA < 2500	74600 + 59400
2500 < KVA < 3000	74600 + 74600

3. $ATC = \underset{TC,\ \$}{\underline{\qquad\qquad\qquad}} \times (\underset{\text{current index}}{\underline{\qquad\qquad\qquad}} \div 204.7) = \$\underline{\qquad\qquad\qquad}$

e. Motor Control Center

$$MOCONC = \underset{THP(E),\ Hp}{\underline{\qquad\qquad\qquad}} \times 60 \times (\underset{\text{current index}}{\underline{\qquad\qquad\qquad}} \div 204.7) = \$\underline{\qquad\qquad\qquad}$$

f. Yard Lighting

$$YLIGHT = [(3 \times \underset{TNUP(B + C)}{\underline{\qquad\qquad}}) + 6] \times 770 \times (\underset{current\ index}{\underline{\qquad\qquad\qquad}} \div 204.7)$$

$$= \$\underline{\qquad\qquad}$$

g. Total Miscellaneous Direct Costs (Sum of steps a to f)

$$TMISC = \underset{YP(Ia)}{\underline{\qquad\qquad}} + \underset{BLDG(Ib)}{\underline{\qquad\qquad}} + \underset{PS(Ic)}{\underline{\qquad\qquad}} + \underset{ATC(Id)}{\underline{\qquad\qquad}} + \underset{MOCONC(Ie)}{\underline{\qquad\qquad}}$$

$$+ \underset{YLIGHT(If)}{\underline{\qquad\qquad}} = \$\underline{\qquad\qquad\qquad}$$

III. ENGINEERING COSTS

a. Determine fee basis

$$FACTOR = [-7.3 \times 10^{-9} \times (\underset{TCUP(D),\ \$}{\underline{\qquad\qquad}} + \underset{TMISC(IIg),\ \$}{\underline{\qquad\qquad}})] + 0.182$$

$$= \underline{\qquad\qquad}$$ or minimum of 0.06

b. $ECOST = \underset{FACTOR}{\underline{\qquad\qquad}} \times (\underset{TCUP(D),\ \$}{\underline{\qquad\qquad}} + \underset{TMISC(IIg),\ \$}{\underline{\qquad\qquad}}) = \$\underline{\qquad\qquad\qquad}$

IV. TOTAL CAPITAL COSTS

SUM OF PARTS I, II, AND III

V. ADJUSTED O & M

a. Total Power Cost
Work Table I, sum of column F = __________ \$/day

b. Total Chemical Cost
Work Table I, sum of column G = __________ \$/day

c. Total Steam Cost
Work Table I, sum of column H = __________ \$/day

d. Process Water Cost
Work Table I, sum of column I = __________ \$/day

e. Fuel Cost
Work Table I, sum of column J = __________ \$/day

f. Total Hauling/Disposal Cost
Work Table I, sum of column K = ________ \$/day

g. Adjusted Labor Cost

1. Capital Cost of Plant Facilities (excluding land)

$$CAPCOST = \underset{TCUP(D)}{\underline{\qquad\qquad}} + \underset{TMISC(IIg)}{\underline{\qquad\qquad}} + \underset{ECOST(IIIb)}{\underline{\qquad\qquad}} = \$\underline{\qquad\qquad}$$

2. Adjust the range of labor, overhead, and service water adjustment factors as follows:

Adjust Capital Cost Ranges to Current Level	If CAPCOST	Adjustment Factor (NFACTOR)
	less than (1)	0.7
(1) 500,000 × (_______ index) ÷ 204.7 = \$_______		
	(1) to (2)	0.9
(2) 1,500,000 × (_______ index) ÷ 204.7 = \$_______		
	(2) to (3)	1.0
(3) 20,000,000 × (_______ index) ÷ 204.7 = \$_______		
	greater than (3)	1.2

3. Adjustment Factor = $\underset{NFACTOR(Vb)}{\underline{\qquad\qquad}}$

4. From Work Table 1

Total Labor Hours = $\underset{TOTLABOR(Li)}{\underline{\qquad\qquad}}$ hr/day

In-Plant Labor Hours = $\underset{IPLABOR(Lii)}{\underline{\qquad\qquad}}$ hr/day

5. Adjusted Labor

$$ADJLABOR = [(\underset{TOTLABOR}{\underline{\qquad\qquad}} - \underset{IPLABOR}{\underline{\qquad\qquad}}) \times \underset{NFACTOR(Vg3)}{\underline{\qquad\qquad}} + \underset{IPLABOR}{\underline{\qquad\qquad}}],\ hr/day$$

$$\times \underset{LPAY,\ \$/hr}{\underline{\qquad\qquad}} = \underline{\qquad\qquad}\ \$/day$$

h. Adjusted Supervision Cost

$$ADJSUPER = 0.1 \times \underset{ADJLABOR(Vg5)}{\underline{\qquad\qquad}} \times (\underset{SPAY,\$/hr}{\underline{\qquad\qquad}} \div \underset{LPAY,\ \$/hr}{\underline{\qquad\qquad}})$$

$$= \underline{\qquad\qquad}\ \$/day$$

i. Adjusted Overhead

$$ADJOH = 0.75 \times \underset{ADJLABOR(Vg5)}{\underline{\hspace{3cm}}} = \underline{\hspace{3cm}} \ \$/day$$

j. Adjusted Laboratory Labor Cost

1. From Work Table 1

$$\text{Total Lab Labor Hours} = \underset{TOTLAB(Qi)}{\underline{\hspace{2.5cm}}} \ hr/day$$

$$\text{In-Plant Lab Labor Hours} = \underset{IPLAB(Qii)}{\underline{\hspace{2.5cm}}} \ hr/day$$

2. Adjusted Lab Labor

$$ADJLAB = [(\underset{TOTLAB}{\underline{\hspace{2cm}}} - \underset{IPLAB}{\underline{\hspace{2cm}}}) \times \underset{NFACTOR(Vg3)}{\underline{\hspace{2.5cm}}} + \underset{IPLAB}{\underline{\hspace{2cm}}}],\ hr/day$$

$$\times \underset{LABPAY,\ \$/hr}{\underline{\hspace{3cm}}} = \underline{\hspace{3cm}} \ \$/day$$

k. Adjusted Service Water Cost

1. From Work Table 1

$$\text{Total Service Water} = \underset{TOTSW(Vi)}{\underline{\hspace{2.5cm}}} \ \$/day$$

$$\text{In-Plant Service Water} = \underset{IPSW(Vii)}{\underline{\hspace{2.5cm}}} \ \$/day$$

2. Adjusted Service Water

$$ADJSW = (\underset{TOTSW}{\underline{\hspace{2cm}}} - \underset{IPSW}{\underline{\hspace{2cm}}}) \times \underset{NFACTOR(Vg3)}{\underline{\hspace{2.5cm}}} + \underset{IPSW}{\underline{\hspace{2cm}}} = \underline{\hspace{2.5cm}} \ \$/day$$

l. Maintenance, Insurance, Taxes, and Services Cost
Work Table I, sum of column S = ____________ $/day

m. Total Operation and Maintenance
sum of a to f = Total O & M

VI. LAND REQUIREMENTS

a. From Work Table 1

1. Sum of land for UP's with land (column V) = $\underset{UPLAND}{\underline{\hspace{3cm}}}$ ft^2

2. Number of unit processes without land estimates = ____________
NLUP

b. Land Requirements Not Previously Calculated

Number of UP's Without Land Estimates (NLUP)	Square Feet Allowance per Unit Process (ALLOW)
> 10	2500
5 to 9	3500
3 or 4	4500
1 or 2	5000

ALLOW = ____________

c. Total Land Requirement

LAND = [$\underset{\text{UPLAND}}{\underline{\qquad\qquad}}$ + ($\underset{\text{NLUP}}{\underline{\qquad\qquad}}$ × $\underset{\text{ALLOW}}{\underline{\qquad\qquad}}$)] ÷ 43,560 = ________ acres

WORK TABLE 1. SUM OF CAPITAL AND UNADJUSTED O & M COSTS FOR UNIT PROCESSES (PART 1 of 2)

A UNIT PROCESS	B TYPE IN-PLANT	C TYPE END OF PIPE	D CAPITAL COST CURRENT $	E POWER REQUIRED Hp	F POWER REQUIRED $/day	G CHEMICAL COST $/day	H STEAM COST $/day	I PROCESS WATER COST $/day	J FUEL COST $/day
TOTALS	No.	No.	(TCUP)$	Hp	$/day	$/day	$/day	$/day	$/day

WORK TABLE 1. SUM OF CAPITAL AND UNADJUSTED O & M COSTS FOR UNIT PROCESSES (PART 2 of 2)

A	K	L	M	N	O	P	Q	R	S	T	U	V
UNIT PROCESS	LANDFILL HAULING OR CONTRACTOR COST	LABOR		SUPERVISION		OVERHEAD	LABORATORY LABOR		MAINTENANCE, SERVICE, INSURANCE & TAX	SERVICE WATER		LAND
	$/day	hr/day	$/day	hr/day	$/day	$/day	hr/day	$/day	$/day	thou gal/day	$/day	sq ft
Totals	$/day	Total(i) (TOTLABOR) In-Plant(ii) (IPLABOR)		Total(i) (TOTLABOR) In-Plant(ii) (IPLABOR)		Total(i)	Total(i) (TOTLAB) In-Plant(ii) (IPLAB)		$/day	Total(i) (TOTSW) In-Plant(ii) (TOTSW)		Total (UPLAND)

IV.4 INDUSTRY COST DATA

Chapter 4 is reserved for possible future inclusion of industry specific wastewater treatment cost data in Volume IV of the Treatability Manual.

IV.5. COMPUTER COST MODELS

IV.5.1 GENERAL DISCUSSION

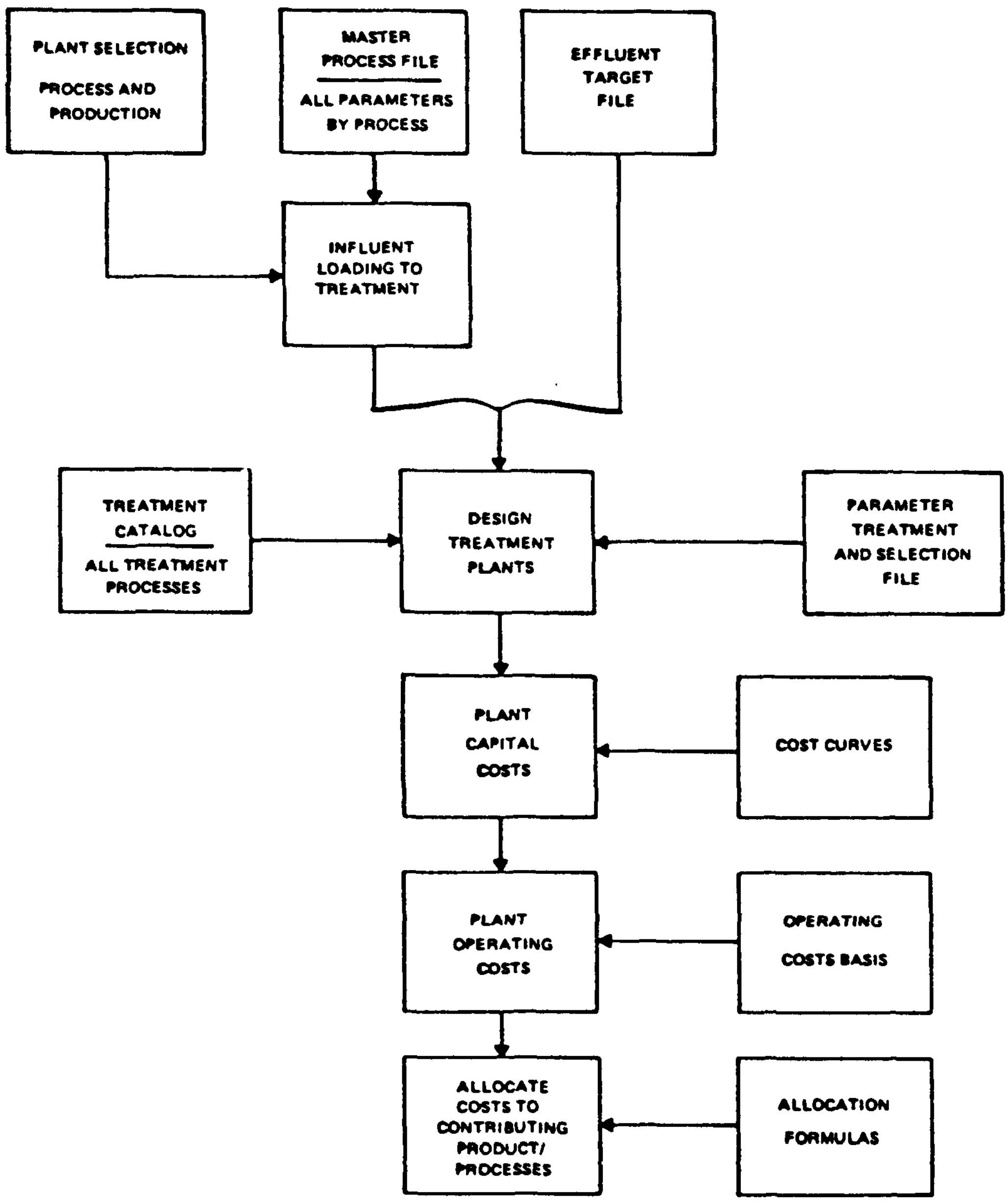
The cost estimating methods presented in Chapter 3 of this volume are applicable for non-computer applications. The USEPA and others have developed computerized cost estimating methods that can be used for more complex and more comprehensive evaluations. These vary in their application to industrial wastewater treatment systems.

IV.5.2 CONTRACTOR DEVELOPED DESIGN AND COST MODEL - OVERVIEW

The Contractor Developed Design and Cost Model is a computerized design, performance, and cost allocation model developed for the BAT Effluent Limitations Guidelines engineering study for the Organic Chemicals/Plastics and Synthetic Fibers Industry [4-1]. The Model is composed of a group of inter-related programs which will design, cost, and predict performance of a wastewater treatment plant (including by-product handling systems) given the characteristics of the raw wastewater and the desired effluent characteristics. It is driven by a group of files which include waste stream and pollutant specific data and unit process costing data used in the design and costing of the wastewater treatment systems. A generalized flow diagram of the Model design process is presented in Figure IV.5-1.

The Model can operate in two primary modes. In the Treatment Unit Process Trail (TUPT) mode it will select the unit processes needed to treat a user specified raw waste load, order the unit processes in an initial sequence, and develop performance and cost predictions on the system. The initial sequence may then be refined and adjusted by the user as necessary and the Model will recalculate the performance and cost predictions. The second major operation mode is the Specified Unit Process Trail (SUPT) in which the selection and sequence of unit processes are specified by the user and the Model performs only the performance and cost predictions. In either mode, the user can specify certain design parameters for the unit operations/processes (fixed design parameters) which then will be used during treatment performance calculations. This enables the user to incorporate existing units into the design of the Model. The user also can specify special requirements for the design (e.g., haul distance for land disposal of sludge, temperature of cooling water) or for the costing (e.g., labor rates, utility and chemical unit costs, capital cost index). The user is required to provide waste specific treatability parameters for the design of certain unit processes (e.g., reaction rate coefficient for activated sludge, adsorbability coefficient for activated carbon).

FIGURE IV.5-1. SIMPLIFIED LOGIC FLOW DIAGRAM OF THE CONTRACTOR DEVELOPED DESIGN AND COST MODEL [4-2]



IV.5.2.1 Model Operating Sequence

The Model operates as a series of programs called and executed under the control of a master program. These programs use information in working files set up from information in the main files or from input by the user. The master program function is to call the various operating programs into the computer. The operating programs access the necessary input data from the files, operate on these data, generate required output, write the output into appropriate working files, and then returns control to the master program. The next appropriate operating program is then called into the computer by the master program.

The sequence of operation for the Model generally follows the order:

(1) Pre-Edit. Input data are verified to confirm all required data are present and in proper order.

(2) Edit. Input is verified to confirm that the proper format is used for all data fields, and the data are consistent with the run mode selected.

(3) Selected Treatment System and Data Required for Model Run. When the Model Select option is used (TUPT), this step involves the Model selecting and sequencing a treatment system based on the pollutant parameters in each waste stream. When the SUPT option with a raw waste load is specified, this operating step is replaced by the user supplied input. (For the Organic Chemicals/Plastics and Synthetic Fibers Industry, there is another option where the Model can access file data for specific types of facilities.)

(4) Treatment System Performance Calculations. Each unit process specified for the treatment system is called in proper sequence and executed as a separate program. Each unit process is represented by a program that sizes the required equipment, calculates the effluent from the unit process (i.e., performance of the process in removing the wastewater pollutants), calculates byproducts generated by the process, calculates the basis for operating and maintenance costs (e.g., unit quantities), and defines the basis for the capital cost estimate (e.g., the surface area of a clarifier).

(5) Compare and Resequence Evaluation. The effluent from each unit process is checked against the target discharge level to determine if treatment is complete. This step also will address any problems that occur when the treatment system performance calculations are being performed. For example, when the Model Select

option is used to design a treatment system, the Model will resequence the selected order of unit processes in this step if it is required to meet treatment objectives. This may include adding or deleting unit processes as well as reordering their occurrence in the treatment system.

(6) Byproduct System Design and Performance. The Model addresses byproduct treatment after all of the forward flow treatment system calculations are completed. When the SUPT option is being used, the byproduct system design step will involve executing the appropriate unit process programs in the specified sequence. When the Model Select (TUPT) option is being used, the appropriate byproduct treatment system unit processes will be selected, and the unit process programs executed in the proper sequence. The Model has an option that will allow input of a byproduct system and waste load directly for evaluation, which operates similar to the SUPT option. The byproduct unit process programs operate similar to the treatment system unit processes.

(7) Cost Calculation, Allocation, and Reporting. The final operating step in the Model is the development of the system cost estimate. The capital cost and operation and maintenance costs for each unit process in the treatment and byproduct systems are calculated using results from the unit process programs and file data on unit costs (these are digital cost curves for capital costs and unit cost factors for operation and maintenance costs). The cost calculation also will develop system costs not computed in any unit process program (e.g., lime handling system, yard piping) and will adjust some costs according to the total size of the system (e.g., labor, laboratory cost). The Model will allocate costs according to the contributing source, if this is desired (e.g., to determine treatment cost for each input waste stream). The Model reports are generated in this step.

IV.5.2.2 Major Files

The Model is "file-driven" which means that all important data are stored in various permanent files. For each run the master program sets up working files by selecting applicable data from the permanent files or using data input by the user. These working files are then used to supply the information specifically required for executing the run and to record the results. The permanent files accessed by the model to develop the working files include the following:

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4-2. U.S. Environmental Protection Agency. Public Record Information. Detailed cost documentation for the contractor developed design and cost model. Prepared for USEPA Effluent Guidelines Division, Washington, D.C. by Catalytic, Inc. This reference includes the following files from the Public Record for the Organic Chemicals/Plastic and Synthetic Fibers Effluent Guidelines Rulemaking: Book I. Equipment Sizing Calculations, 1978/1979. pp. 60800-609309. Book III, Part I. Equipment Sizing/Costs. pp. 608697-609083. Book IV, Part II. Equipment Sizing/Costs. pp. 609090-609171. Book V, Part III. Equipment Sizing/Costs. pp. 609172-609309. USEPA Guidelines Cost Estimates SES. pp. 616001-616467. Backup for Unit Operations Costs, Parts I and II. pp. 616468-617183.

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☆U.S. GOVERNMENT PRINTING OFFICE : 1984 O - 432-455 (Vol. 4)