AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523
BIBLIOGRAPHIC INPUT SHEET

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Batch 53

1. SUBJECT CLASSIFICATION
A. PRIMARY: TEMPORARY
B. SECONDARY:

2. TITLE AND SUBTITLE
Industrial pollutants,methods and costs of control

3. AUTHOR(S)
(101) Stone,Ralph & Co.,Los Angeles

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1977	174p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Stone

8. SUPPLEMENTARY NOTES (*Sponsoring Organization, Publishers, Availability*)
(In Industrial pollution control,technological strategies,chapt.3,p.23-171)

9. ABSTRACT
(ENVIRONMENTAL ENGINEERING R&D)

A pollutant is considered of major concern if it has had a significant environmental impact in one or more regions, or is known to have serious effects in virtually any concentration. This chapter identifies major industrial pollutants, their possible effects on human health and the natural environment, and methods of controlling their generation, emission, and impact. It describes briefly the most important and widely used pollution control methods and facilities, and discusses industrial solid waste management. The publication from which this third chapter is taken, "Industrial Pollution Control, Technological Strategies," presents the effects and controls of industrial discharge, and technologies for reducing the environmental impact of pollutants.

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAD- 346	
12. DESCRIPTORS	13. PROJECT NUMBER
	14. CONTRACT NUMBER: AID/ta-C-1091 GTS
	15. TYPE OF DOCUMENT

AID 590-1 (4-74)

AID/ta-C-1091 GTS
PN-AAD-346

INDUSTRIAL POLLUTION CONTROL

TECHNOLOGICAL STRATEGIES

APRIL 1977

BY

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PREFACE

A two-volume study was prepared to provide information relating to the impact and control of environmental pollution from industrial sources. It is intended for the use of government leaders, industrialists, and other concerned individuals who may have widely differing technical and national backgrounds.

Volume I provides background information and reference sources to facilitate general policy decisions relating to the control of industrial pollutants.* Volume II is concerned with the technical application and comparative costs of pollution abatement in manufacturing operations.

Although the purpose of the report is to describe the effects of industrial discharges and their control, it is recognized that other sources of pollution contribute to environmental problems. The problems of pollution abatement, however, are similar wherever they originate. The general principles and control methods discussed in the report will therefore usually be applicable to pollutants from both industrial and non-industrial sources.

* See inside back cover for information on ordering Volume I.

ACKNOWLEDGMENTS

We gratefully acknowledge the assistance of many individuals in the following agencies and institutions: Instituto Centro Americano de Investigacion y Technologia Industrial (ICAITI); Organization of American States; Pan American Health Organization; United Nations Development Program; United Nations Industrial Development Organization; United Nations Information Center; The World Bank; World Health Organization; Companhia Estadual de Tecnologia de Saneamento Basico (CETESB), Sao Paulo, Confederacao Nacional da Industria, Rio de Janeiro, Soc. Civil de Planejanento e Consultas Tecnicas Ltda. (CONSULTEC), Rio de Janeiro, Departmento de Limpes Publica, Grupo Executivo da Grande Sao Paulo, Instituto Engenharia Sanitaria, Rio de Janeiro, Ministerio da Industria e do Comercio, Brasilia, NGK do Brasil S. A., Mogidas Cruzes, Secretaria de Planejamento Ciencia e Technologia, Salvador, Bahia, and Superintendencia de Saneamento Ambiental (SUSAM), Sao Paulo, Brazil; Environmental Protection Council, Accra, Ghana; Camara Nacional de la Industria del Hierro y del Acero, Comision Federal de Electricidad, Confederacion de Camaras Industriales, Direcion General de Usos del Agua y Prevencion de la Contaminacion, Subsecretaria de Mejoramiento del Ambiente, and Tubos de Acero de Mexico, Mexico; Department of Science and Technology, Tandogan-Ankarra, Turkey; Council on Environmental Quality, United States Embassy to Brazil, United States Embassy to Mexico, and U. S. Environmental Protection Agency, United States; Universidade de Sao Paulo, Brazil; Syracuse University, University of Denver, and University of North Carolina, United States; Companhia Suzano de Papel e Cellulose, Brazil; and HYSLA, Mexico.

This study was prepared by Ralph Stone and Company, Inc., for the Agency for International Development under AID contract ta-C-1091. Ralph Stone and Company, Inc., is grateful for the assistance extended by AID, Department of State; Department of Commerce; Environmental Protection Agency; and Council on Environmental Quality personnel.

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CHAPTER 1

INTRODUCTION

The primary purpose of this volume is to provide information on commonly used technologies for reducing the environmental impact of industrial air and water pollutants, and to indicate their relative costs for removing different quantities of pollutants from industrial waste streams.

The topics discussed include:

- Pollution abatement approaches which may supplement, facilitate, or replace end-of-pipe treatment processes.
- The potential adverse effects of major air and water pollutants generated by industrial sources.
- Available techniques, processes, and equipment which may be used separately or as parts of a system for removing or reducing pollutants in industrial discharges to the air and water environment.
- Pollutants generated by selected basic industries, and examples of suitable treatment systems for their control.
- Actual pollution abatement practices used by specific industrial plants in three case study industries.
- Related economic data and cost curves.

MINIMIZING POLLUTION CONTROL COSTS

A major objective of industry is to maximize profits. Industrial firms will therefore usually seek the most cost-efficient method of achieving desired or required levels of pollution control. Two related factors should be considered: the need to comply with both present and anticipated future control requirements, and the alternative means by which pollution abatement may be achieved.

The first factor is important because retrofitting can be excessively difficult and costly. Industrial planners should therefore consider the advisability of installing at least the basic fittings for future control devices during initial construction of new plants or additions to existing plants. The actual control devices can then be attached later at minimum cost whenever stricter pollution control programs require their installation.

The second factor is important because consideration of alternative options for pollution control will help in the selection of the most suitable and least costly system of control for an individual industrial plant or operation. Approaches which can advantageously supplement, and sometimes replace, end-of-pipe treatment include: substituting

alternative non-polluting manufacturing processes, modifying existing processes to reduce their polluting effects, substituting less-polluting raw materials, preventing pollution through the recycling and by-product recovery of waste discharges, and appropriate land use and plant siting--especially industrial parks which permit comprehensive, multi-plant pollution control treatment and waste reuse methods.

NATURAL PURIFICATION--PROS AND CONS

Natural cycles involve a combination of physical, chemical, and biological processes which maintain a dynamic equilibrium among organic and inorganic matter, living organisms, and inanimate objects. Major natural self-purification processes include the mixing and dilution of wastes, absorption of particulates and gases by rainfall, adsorption of gases by plants, settling of particulates discharged into the air onto the ground and surface water, precipitation of suspended solids discharged into water bodies onto the bottoms, biological decomposition of organic matter, and chemical conversion of organic and inorganic matter.

Industrial and other pollutants enter natural cycles when discharged into the environment. In most developed regions, however, self-purification processes cannot eliminate all the potential harmful effects of untreated industrial discharges. Some pollutants are generated and released into the environment more quickly than the natural processes can reduce their harmful effects; others interfere with desirable ecological relationships, or have toxic effects which resist or interfere with self-purification processes.

The full impact of some toxic substances may be delayed for years. Certain pollutants, for example, may be concentrated in the food chain by plants and animals, and in their higher forms become highly toxic; or the effects may become evident later or in succeeding generations as a cause of cancer, failure to reproduce, or genetic damage. Other pollutants, such as nutrients (organic carbon or carbon dioxide, nitrogen and phosphorus compounds), may cause an over-development of particular links in natural food chains, with secondary effects which cause environmental degradation. Even small nutrient discharges into a water body may stimulate excessive algal growth and, as a consequence, contribute to eutrophication and resulting damage to fish and other desirable aquatic life. In addition, since even effective self-purification processes generally require considerable time to restore environmental quality, they are of little value in reducing the immediate local harmful impacts of industrial pollutants on nearby human, animal, and plant life.

There has been an optomistic tendency to overestimate the capacity of environmental self-purification mechanisms, and to perceive actual or potential damage as insignificant when compared with the benefits of industrial development. The subsequent damage to important natural systems, however, has pointed up the limitations of natural purification processes, the costs of environmental pollution, and the need to weigh these costs against the costs and benefits of controlling pollution from industrial sources. In general,

therefore, natural self-purification processes cannot be relied upon to control the potential adverse effects of industrial pollutants. Photographs 1-3, 1-4 , and 1-5 show three examples where natural purification failed to make polluted lake water safe for drinking, fishing or recreation.

TYPES OF INDUSTRIAL POLLUTION CONTROL OPTIONS

Figure 1-1 summarizes the basic types of industrial pollution control measures which can be used to protect the environment. A pollution control program may combine all or several. For each basic type of strategy, the report will describe commonly used methods with broad industrial applications. Technological process changes which are very specific to individual industries are multitudinous and beyond the scope of this book.

MEETING POLLUTION ABATEMENT OBJECTIVES

In most countries, protecting the natural environment is either a current objective or is being reviewed as a future national objective. The information provided in this volume can assist industrial planners to develop pollution abatement programs which meet present or anticipated discharge standards. Further helpful information can be secured from appropriate government, industry, and institutional agencies in countries and regions where programs to control industrial discharges are already in effect. Direct observation, personal contacts, and a search of available literature may all be useful. The last chapter of Volume I offers further suggestions on possible sources of information. *

Although the scope of this guidebook is limited to industrial pollutants, most of the discussion and control methods will apply equally well to polluting discharges from other commercial and municipal sources.

* See inside back cover for information on ordering Volume I.

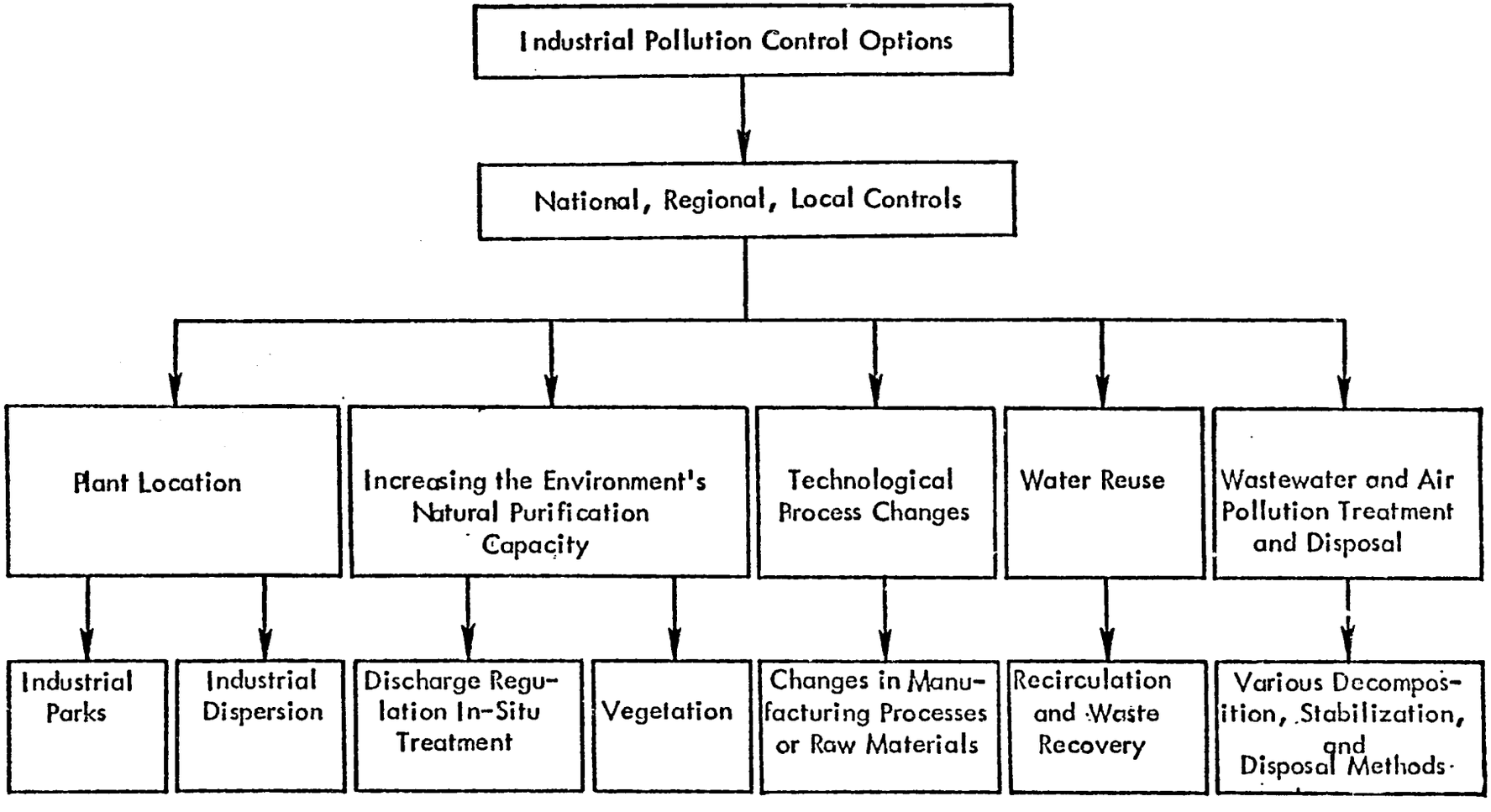

FIGURE 1-1
INDUSTRIAL POLLUTION CONTROL OPTIONS

INDUSTRIAL POLLUTANTS, METHODS AND COSTS OF CONTROL

April 1977

(Chapt. 3 of Industrial Pollution Control, Technological Strategies)

by

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CHAPTER 3
INDUSTRIAL POLLUTANTS, METHODS AND COSTS OF CONTROL

This chapter identifies the major pollutants; their possible effects on human health and the natural environment, and available methods for controlling their generation, emission, and impact. It includes brief descriptions of the most important and widely used pollution control methods and facilities and a discussion of industrial solid waste management. A final section of the chapter provides cost estimating curves for selected control equipment and processes.

Pollutants may be divided into categories of "major" and "minor"concern. The division is only a rough approximation, since the impact of a given pollutant will in general depend on its concentration in a specific environment. A pollutant is considered of major concern if it has had a significant environmental impact in one or more regions or is known to have serious effects in virtually any concentration. Only major pollutants whose primary impact is on the general environment are considered; this excludes their identification with occupational diseases from in-plant exposure to toxic substances.

AIR POLLUTION

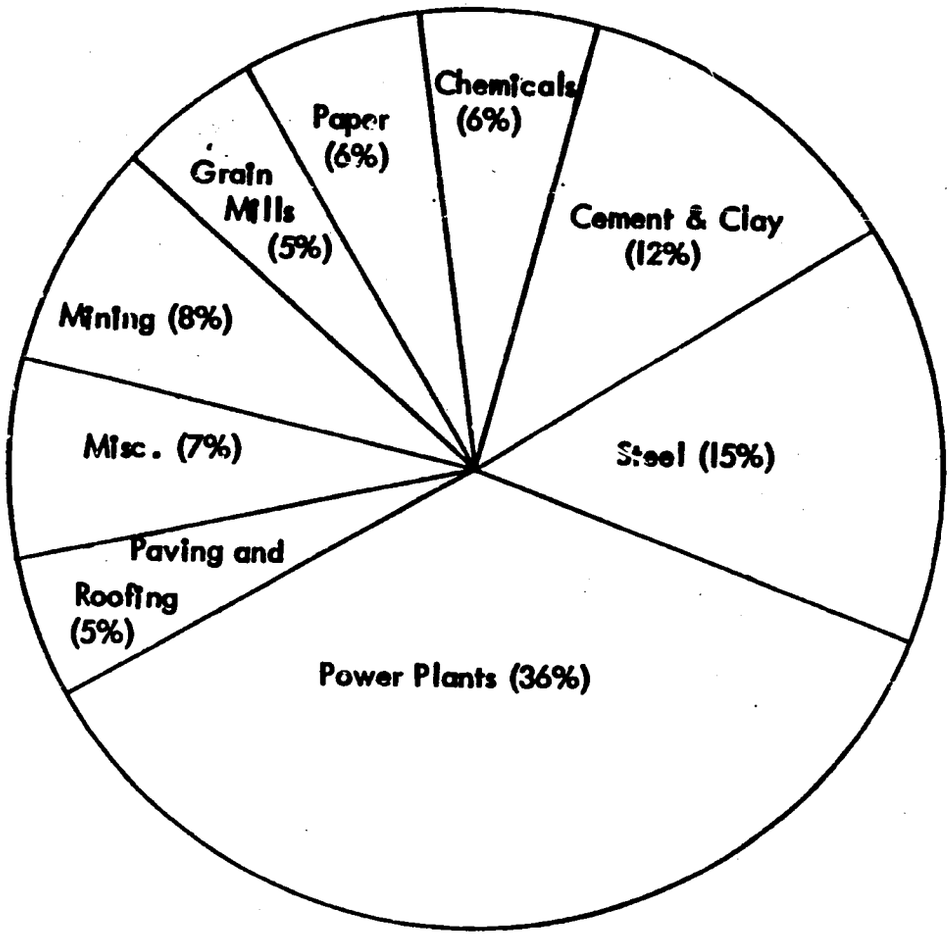
MAJOR AIR POLLUTANTS

Air pollutants may be in the form of particulates (solid or liquid), gases, or vapors. Pollutants in air emissions may be hazardous to human, animal, or plant life; cause corrosion or other deterioration of materials; and be responsible for offensive odors, reduced visibility, and other aesthetic nuisances.

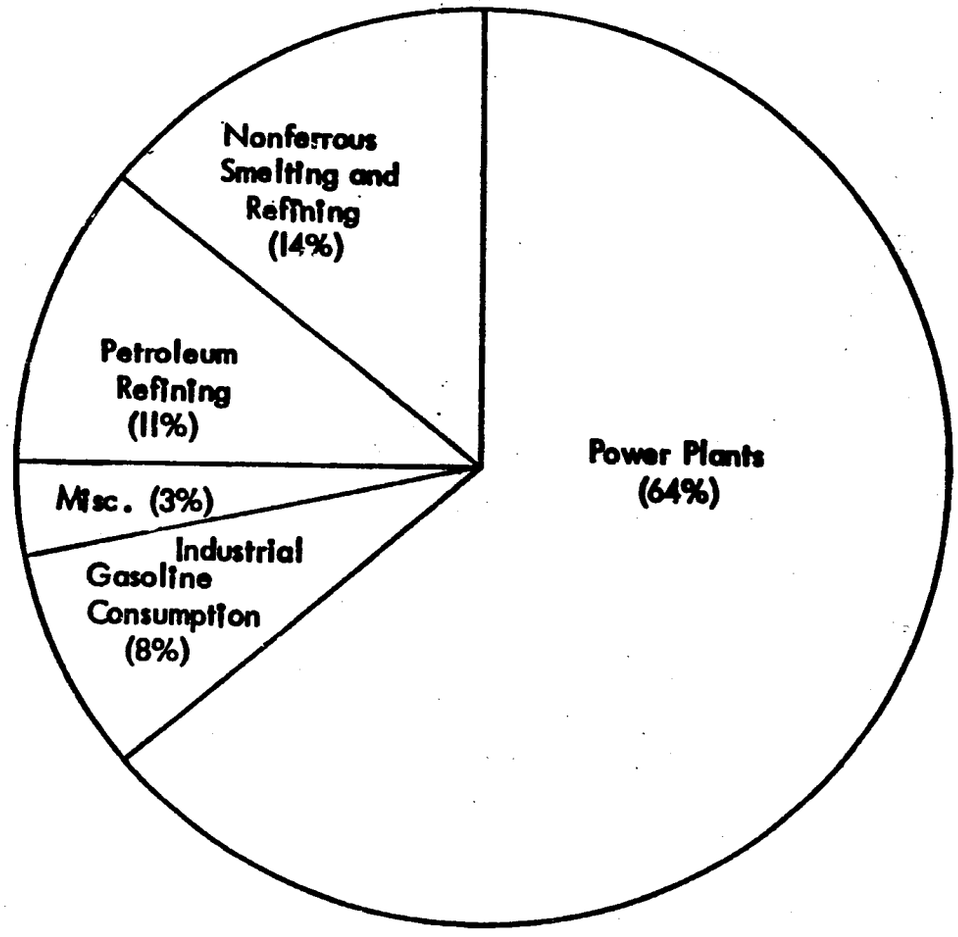
Particulates.

Particulates are small particles suspended in the air; they normally enter the environment as solids (although occasionally in liquid form) entrained in gaseous discharges. They may remain in the air for long periods of time and travel considerable distances. Particulates may be composed of any of a large variety of substances. They range in size from microscopic (0-1 μ diameter) to visible smoke and soot. The smaller sized particles are the most hazardous and also the most difficult to remove. Primary sources of particulates are fuel combustion (primarily coal), cement plants, grain mills, the iron and steel industry, and the paper and allied products industry. Figure 3-1 shows, for the United States, the major industrial sources of particulate emissions and their relative quantitative contributions.

The adverse impacts of a given concentration of particulates will depend on the specific chemical and physical nature of that type of particulate. Since highly diverse substances are classified as particulates, they have a wide diversity of impacts. Particulates known to be highly toxic to man include asbestos and compounds of lead, fluorine, beryllium, and arsenic; some tars which may appear as hydrocarbon particulates are carcinogenic. Deposits of any type of fine particulates in lung tissue can aggravate respiratory illness. In addition to health effects, particulates may cause corrosion to materials, damage or destroy plant and animal life, reduce visibility, change weather patterns, and increase maintenance and cleaning costs.



PARTICULATES



SULFUR OXIDES

FIGURE 3-1
INDUSTRIAL SECTORS CONTRIBUTING TO NATIONAL DISCHARGES OF THE TWO MAJOR INDUSTRIAL AIR POLLUTANTS IN THE UNITED STATES: 1971

Carbon Monoxide (CO).

Carbon monoxide is a colorless, odorless, tasteless gas produced by incomplete combustion of carbon in fuels. By weight, carbon monoxide is the most widely distributed and common air pollutant. The most important sources of carbon monoxide are gasoline-burning vehicles; important industrial contributors are combustion sources in the paper and allied products, petroleum, and power generation industries. Carbon monoxide is extremely toxic. It is lethal at concentrations of 1,000 ppm (0.1 percent on a volume basis) and causes dizziness, headaches, and lassitude at concentrations of over 100 ppm (0.1 percent).[16]

Sulfur Oxides (SO_x).

Sulfur oxides, principally sulfur dioxide (SO_2), are acrid, corrosive gases produced when sulfur-containing fuels are burned. In the atmosphere, SO_2 is converted to sulfur trioxide or sulfuric acid. Oxidation in the atmosphere is highly dependent on atmospheric conditions including residence time, moisture, sunlight, and the presence of catalysts. Major industrial sources of sulfur oxides are power generation, smelting and refining of nonferrous metal (mainly copper), and petroleum refining. Figure 3-1 shows the major United States manufacturing plant sources of sulfur oxides and their relative importance.

The health effects of sulfur oxides are considerable. In high concentrations (attainable under certain atmospheric conditions) they can help cause deaths, as illustrated by recent "smog disasters" such as those in Donora, Pennsylvania and New York City, in the United States, and London, England. Lower concentrations may result in respiratory tract irritation and diseases. A second major effect of sulfur dioxides (in the form of sulfuric acid) is injury to plant life; this may occur with concentrations as low as 0.2 ppm.[16] Sulfur oxides are also a major contributor to reduced visibility in urban areas.

Sulfur oxide air pollution may contribute to the production of "acid rain." In some industrial areas in the United States, rainfall with a pH of 4.0 is not uncommon. Sulfur oxides are relatively easily washed from the atmosphere, usually in the form of sulfates. The washed-out compounds are not easily degraded and can damage plant life and eventually contaminate surface and groundwater supplies. Sulfur oxides can also cause significant damage to agriculture. In excessive concentrations, these compounds can destroy paint pigments; corrode metals; and disintegrate textiles, paper, limestone, and other materials.

Nitrogen Oxides (NO_x).

These compounds are produced when fuel is burned at high temperatures. Normally inert atmospheric nitrogen combines with oxygen in high temperature flames, and the compounds remain stable if the exhaust gases are quickly cooled. Important contributors to atmospheric nitrous oxides are gasoline-burning vehicles, iron and steel production, petroleum refining, and power generation.

Concentrations of nitrous oxides as low as 64 ppm by volume have been linked to pulmonary fibrosis in humans; concentrations of NO_2 above 25 ppm can result in plant damage. Corrosion of materials results when nitrous oxides are converted to nitric acid. NO_x alone reduces visibility, imparting a brownish-red color to the atmosphere when present in excessive concentrations. The presence of nitrous oxides in the atmosphere is necessary for the formation of other toxic photochemical oxidants such as peroxyacetylnitrate (PAN).

Hydrocarbons.

Hydrocarbons, like carbon monoxide, are produced by the incomplete combustion of fuel. Most hydrocarbons result from the operation of gasoline-burning vehicles; other major contributors are petroleum refining, power generation, and the manufacture of chemical and allied products. Excessive amounts of hydrocarbons have been linked to plant damage and possible carcinogenic effects in man. Under the influence of the ultraviolet in sunlight, hydrocarbons combine with nitrogen oxides to form photochemical oxidants. The smog commonly encountered over major metropolitan areas is a combination of photochemical oxidants together with solid and liquid particulates in the air. The most common photochemical oxidants are PAN and ozone (O_3). Photochemical oxidants can result in reduced atmospheric visibility, damage to plants, decomposition of rubber and textiles, eye and lung irritation, and disease.

Fluorides.

Fluorides may occur in the atmosphere as solids (sodium and calcium fluoride) or as irritating gases and fumes (e.g., hydrofluoric acid). Ambient concentrations are generally extremely low. Some major industrial sources of fluorides are the manufacture of phosphate fertilizer, aluminum, brick and tile, iron and steel, employing relatively low-temperature combustion.

Fluorides are physiologically very active, resulting in eye and respiratory tract irritation. Where fluoride emissions settle and accumulate on pastureland, cattle can develop fluorosis, a disease characterized by crippling skeletal changes. Fluorides can also damage certain types of crops and other vegetation.

Odorous Compounds.

A primary odorous compound in industrial areas is hydrogen sulfide. Others include methane, mercaptans, hydrocarbons, and ammonia. Major industrial sources of odorous compounds are kraft paper mills, animal rendering, production of certain types of chemicals, iron and steel mills, and municipal sewage treatment plants. To the extent that the component odor compounds are toxic, they present a health hazard. (Hydrogen sulfide, for example, has caused many deaths at sewage treatment and handling facilities.) But even if they are not toxic, odorous substances can cause discomfort to those exposed.

Heavy Metals.

Heavy metals are an important class of air pollutants. Those emitted to the air include lead, mercury, beryllium, arsenic, cadmium, vanadium, nickel, manganese, zinc, copper, silenium, and chromium. In excessive concentrations, these metals are toxic to man and generally cause plant and animal damage; these adverse effects occur with relatively small concentrations of particular metals.

Summary of Air Pollutant Impacts

Table 3-1 summarizes the major and minor impact areas of the above and other important air pollutants.

AIR POLLUTION TREATMENT METHODS

The appropriate air pollution treatment system for a specific industrial application will depend on the gas flow rate, the type and concentration of impurities in the gas, and the desired removal efficiency (or discharge limit) for each impurity. In the simplest case, a control system may include a single treatment process (a scrubber, fabric filter, or mechanical collector, for example) intended to remove particulate pollutants. Where the gas stream contains several impurities (particulates plus several gaseous pollutants, for example), and/or a high level of removal is desired, the system will usually contain several unit treatment processes. Major air pollution control processes are discussed below organized by type of pollutant treated.

Control of Particulate Emissions.

Particulate collection devices can use several types of process: gravity; sedimentation or deposition of dust particles on a collecting surface via the application of directional forces other than that of the motion of the gas stream; retention of the particles on the collecting surface; and removal of the particles from the collecting surface by cleaning mechanisms, either intermittently or continuously. Table 3-2 summarizes advantages and disadvantages of some particulate control devices.

Gravity Particulate Settling Chambers are used to remove coarse particulates. The gas stream is passed slowly through the gravity chamber, allowing particulates to settle and collect in hoppers, from which they are periodically emptied. Figure 3-2 presents a schematic of this device.

Cyclones are mechanical collectors where the gas stream is forced into a circular motion creating a vacuum in the center of the stream and forcing particulates towards the collector wall. The trapped particulates are removed from the wall by gravity or secondary currents. Wet cyclones are often used to treat polluting gases and particulates. Cyclones may be employed singly or in banks. They are recommended for situations where concentrations of large-diameter particulates are high and high removal efficiencies are not critical. Their advantages include: low initial cost, simple construction

TABLE 3-1

DETRIMENTAL EFFECTS OF SELECTED AIR POLLUTANTS

Air Pollutant	Human Health Hazards	Material Deterioration	Aesthetics	Vegetation	Animal Health Hazards
Particulates	Major	Minor	Major	Major	Minor
Sulfur oxides	Major	Major	Major	Major	Major
Oxidants	Major	Major	Major	Major	
Carbon monoxide	Major				
Hydrocarbons	Major		Major	Minor	
Nitrogen oxides	Major	Major	Major	Major	
Fluorides	Major			Major	Major
Lead	Major			Minor	Major
Polycyclic organics	Major				Major
Odors			Major		
Asbestos	Major				
Beryllium	Major			Minor	Major
Hydrogen chloride	Major	Major		Major	
Chlorine	Major	Major		Major	Major
Arsenic	Major			Minor	Major
Cadmium	Major				Major
Vanadium	Minor				
Nickel	Minor				
Manganese	Minor				
Zinc	Minor				Minor
Copper	Minor				
Barium	Minor				
Boron	Minor				
Mercury	Major	Minor		Minor	Major
Selenium	Major				Major
Chromium	Minor	Minor			
Pesticides	Major			Major	Major
Radioactivity	Major			Major	Major
Aeroallergens	Major				

Major concern

Minor concern

TABLE 3-2

ADVANTAGES AND DISADVANTAGES OF PARTICULATE CONTROL DEVICES

Device	Advantages	Disadvantages
Cyclones	Low initial cost Simple construction and operation Little efficiency drop over a wide temperature range	Relatively low maximum efficiency Poor removal of small particles
Filters	High efficiency over a wide flow rate Can operate at high temperatures with special filter median	High maintenance cost Require highly controlled operating conditions Large space requirements
Electrostatic precipitators	High efficiency Can operate at high temperatures	Require highly controlled operating conditions High initial and maintenance costs Large space requirements Power requirements may increase overtime
Scrubbers	May be used for cooling Remove both particulates and some gaseous pollutants High efficiency Applicable over a wide range of operating parameters Most effective option for removing fine particulates	High initial cost High operating cost High rate of operating problems Large volume of sludge produced

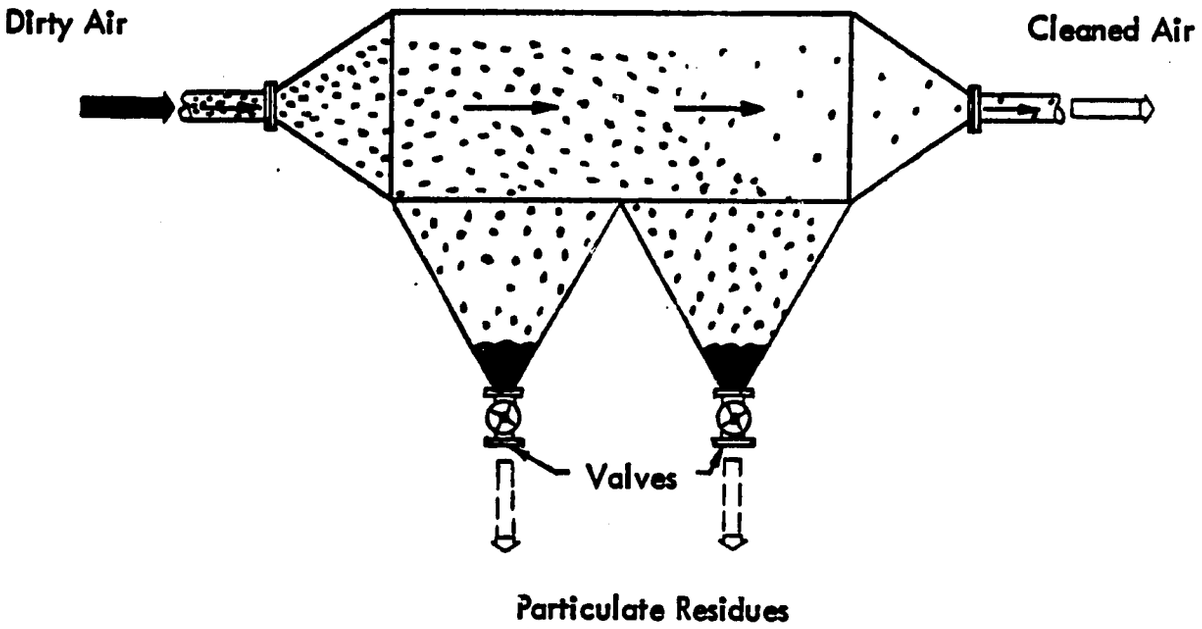


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FIGURE 3-2
GRAVITY PARTICULATE
SETTLING CHAMBER

and operation, small area and volume space use, and applicability to gas streams over a wide temperature range. Disadvantages include inability to remove particulates smaller than 10 microns, the possibility that power requirements for maintaining velocities may increase with time, and lower removal efficiencies than certain other methods. Figure 3-3 illustrates a mechanical cyclone.

In filtration systems, the gas stream is passed through a porous medium which retains particulates. The most commonly employed filters use fabric (such as cotton, nylon, fiberglass, or teflon) as a medium. Figure 3-4 illustrates one type of fabric filter. Other types of mechanical filters include a fibrous bed and a granular bed. Panel-type filters are generally used only for light loadings and have considerable cleaning requirements, whereas baghouse filters can be used with heavy loadings and may be cleaned automatically. An advantage of fabric filters is their relatively high efficiency; disadvantages include high maintenance costs, relatively large space requirements, and the need for highly controlled operating conditions. In general, fabric filters become inefficient when collecting hygroscopic dust or stringy fibers. When operating temperatures are above 300 C, special bag materials (such as teflon or stainless steel) must be employed.

Electrostatic precipitators operate by electrically charging particulates and removing these charged pollutants from gas streams by attracting them to oppositely charged collecting electrodes (Figure 3-5). Particles may be removed from the electrodes by either dry methods (rapping or vibration) or wet methods. High efficiency and tolerance of high temperatures are the major advantages of electrostatic precipitators. Disadvantages include sensitivity to variations in operating parameters, high initial and maintenance costs, frequent maintenance required to keep up their operating efficiency (removal effectiveness tends to decline between cleanings), large volumes of sludge for disposal when wet removal methods are employed, and limited effectiveness in removing fine particles. Photograph 3-1 illustrates an electrostatic precipitator's reduction of emissions from a power plant.

Scrubbers employ a fluid stream, generally water, to remove gases and suspended particles. Contact between liquid droplets and particles forms an agglomerate which is easily removed from the gas stream. The end result is a sludge containing water, sulfur oxides (where present in the gas stream), suspended solids (particulates),and often lime or limestone (where this is used to improve scrubber performance). The several types of existing scrubbers vary in their operation; spray chamber, cyclonic, venturi, and submerged orifice are common types. Scrubbers are particularly appropriate for small-volume gas streams when cooling is desired, and when simultaneous removal of sulfur oxides and particulates is needed. Advantages include high efficiencies and applicability for a wide range of operating conditions. Scrubbers are also fairly effective in removing fine particulates. Disadvantages include high operating costs (due in part to high power requirements), large volume of residual sludge that must ultimately be disposed of, and high potential for operating problems such as corrosion. These latter two problems can be reduced by carefully controlling the chemical reaction so that a soluble salt (calcium bisulfite), rather than a solid (calcium sulfate), is

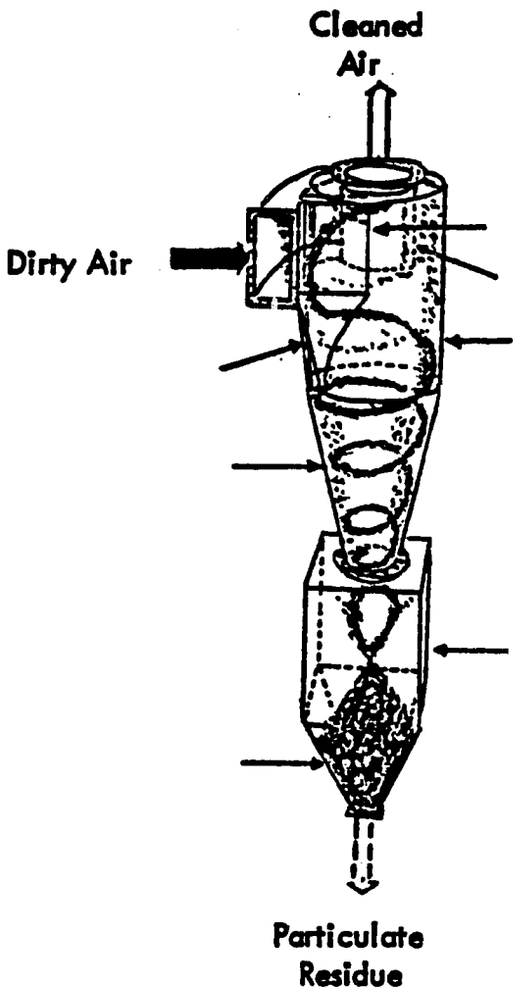

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FIGURE 3-3
MECHANICAL CYCLONE

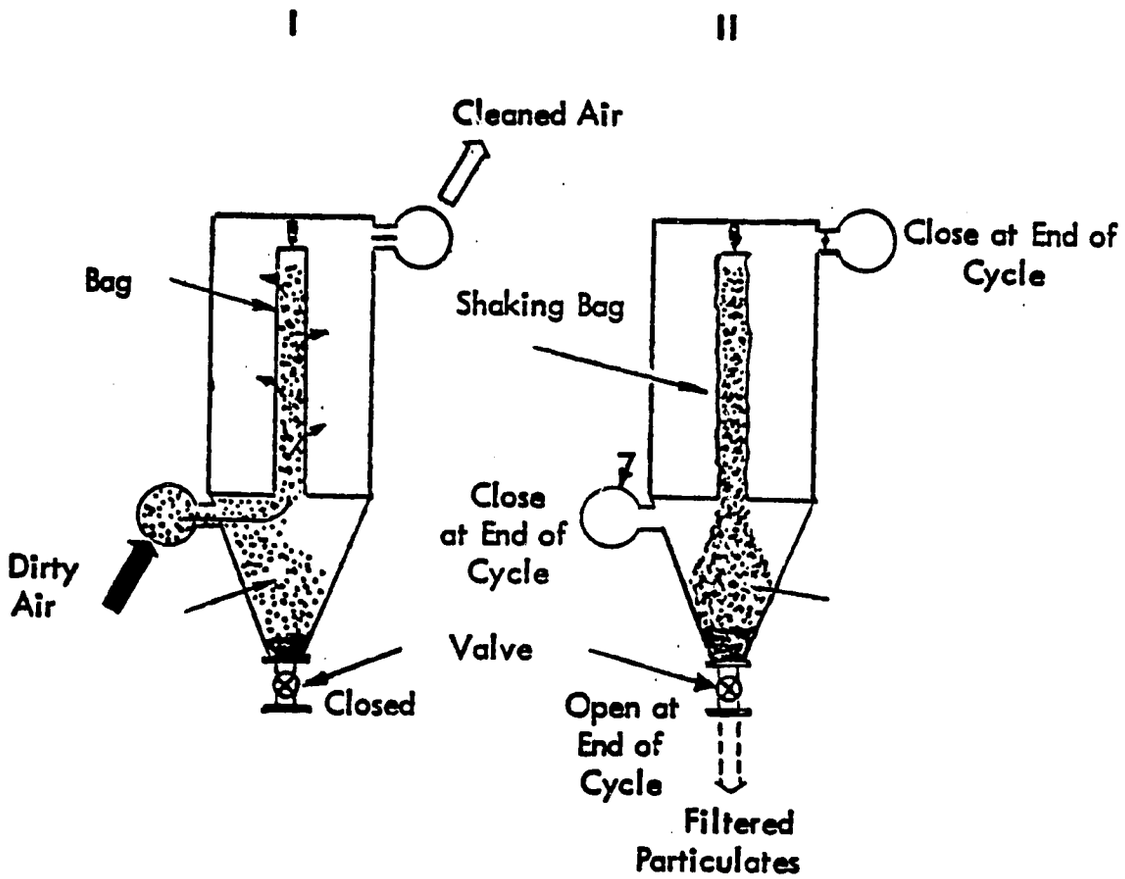

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FIGURE 3-4
BAGHOUSE FILTER

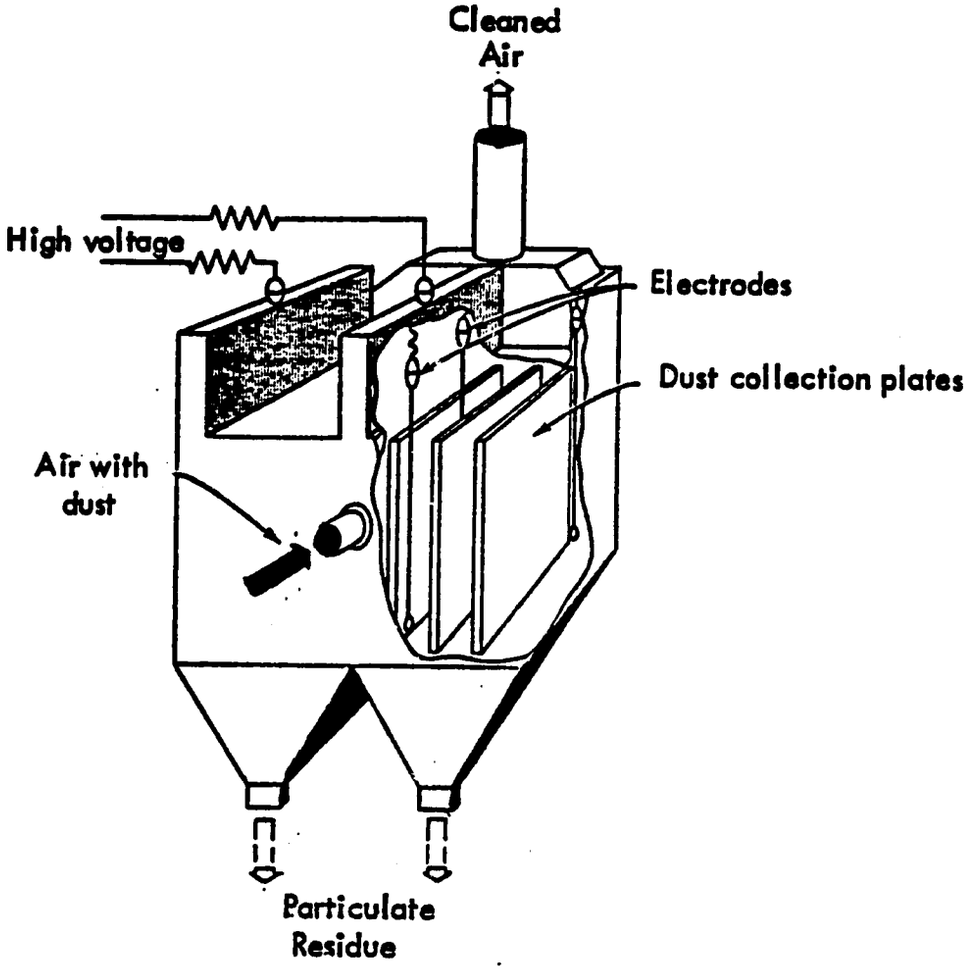

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FIGURE 3-5
ELECTROSTATIC PRECIPITATOR

Photograph 3-1

Operating power plant smokestack photographed before and after installation of an electrostatic precipitator.

produced. An example of a venturi type scrubber is shown in Figure 3-6.

Control of Gaseous Pollutants.

These pollutants can be controlled by a variety of processes: adsorption, absorption, combustion, and catalytic reactions. Table 3-3 summarizes their advantages and disadvantages.

Adsorption processes involve the attraction of molecules in a gas (or liquid) stream to a solid surface. Activated carbon is the most commonly used adsorbent material; activated carbon adsorption is capable of removing odors as well as many types of gaseous pollutants. Once the adsorbing medium becomes saturated with pollutants, it is cleaned by superheated steam. Adsorbers may be of the fixed bed, dynamic bed, or dispersed type. Advantages of using adsorption include high efficiencies and removal of a variety of selected air pollutants by appropriate choice of adsorbent medium. Disadvantages include high initial cost and requirements for special safety precautions. Figure 3-7 shows an example of an adsorber.

The absorption process involves attraction of pollutants in a gas stream to liquid droplets or films.

Wet scrubbing, discussed previously, is a commonly used absorption process for sulfur oxides removal. Removal of pollutants may be accomplished by either direct dissolving in the liquid or by reaction with chemical additives in the liquid. Lime and limestone are often employed as additives in scrubbing; reaction with sulfur oxides forms sulfate salts retained in sludges which may be saleable. The absorption tower (Figure 3-8) is another common absorption device.

Combustion is typically employed where the gaseous pollutants cannot be economically recovered. Combustion is usually performed in incinerators; often natural gas must be added to the gas stream to achieve flammability. Incineration may be of the direct thermal or catalytic type. Combustion is effective in reducing odors, eliminating hazards of explosions, and removing paint solvents and hydrocarbons. Figure 3-9 is a schematic of one type of afterburner.

Advantages of incineration of air pollutants include simple operation, small space requirements, and high efficiency in removing selected contaminants. Disadvantages include requirements for high temperature, and sensitivity to atmospheric conditions. Certain atmospheric conditions virtually prohibit the use of incineration because the exhaust gases will not disperse. Atmospheric conditions must be such that exhaust carbon dioxide, carbon monoxide, nitrogen oxides, and sulfur oxides can be readily dispersed.

Power Requirements.

There is an inverse relationship between the smallest size of particle that a control device can remove and its power requirements: devices that can remove smaller-sized

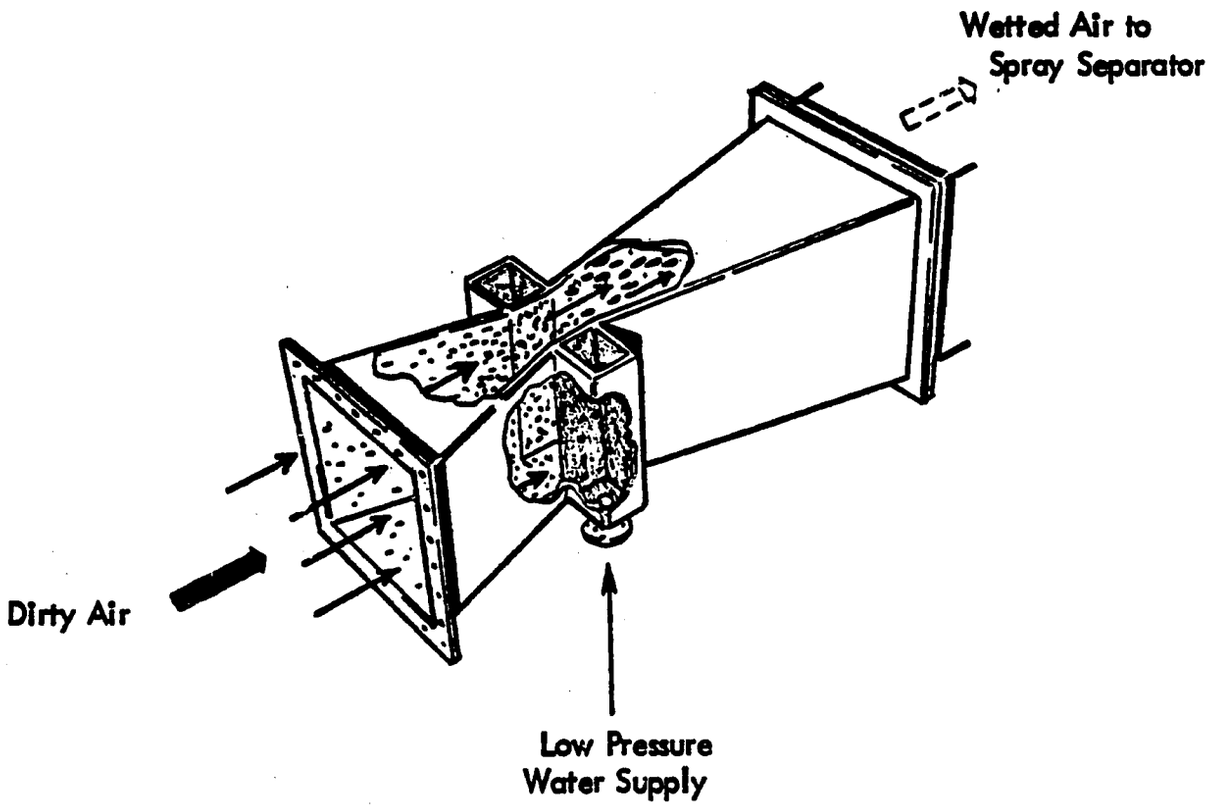

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FIGURE 3-6
VENTURI SCRUBBER

TABLE 3-3

ADVANTAGES AND DISADVANTAGES OF GASEOUS POLLUTANT CONTROL PROCESSES

Process	Advantages	Disadvantages
Adsorption	High efficiency Gases can be selectively removed by choice of adsorbents. Possible by-product recovery.	High initial cost Special safety procedures required
Absorption	Can be used for cooling By-product recovery possible Can remove both gaseous pollutants and particulates High efficiency Applicable over a wide range of operating parameters	High initial cost High operating cost Technically complex to operate Produces large volume of sludge
Combustion	Simple operation High efficiency Compact Heat recovery	Operates at high temperature Sensitive to atmospheric conditions
Catalysts	Simple operation High efficiency Compact Low energy	High initial costs May be easily contaminated Require constant operating supervision Only work on certain types of gases Catalysts and gases may cause new toxic products.

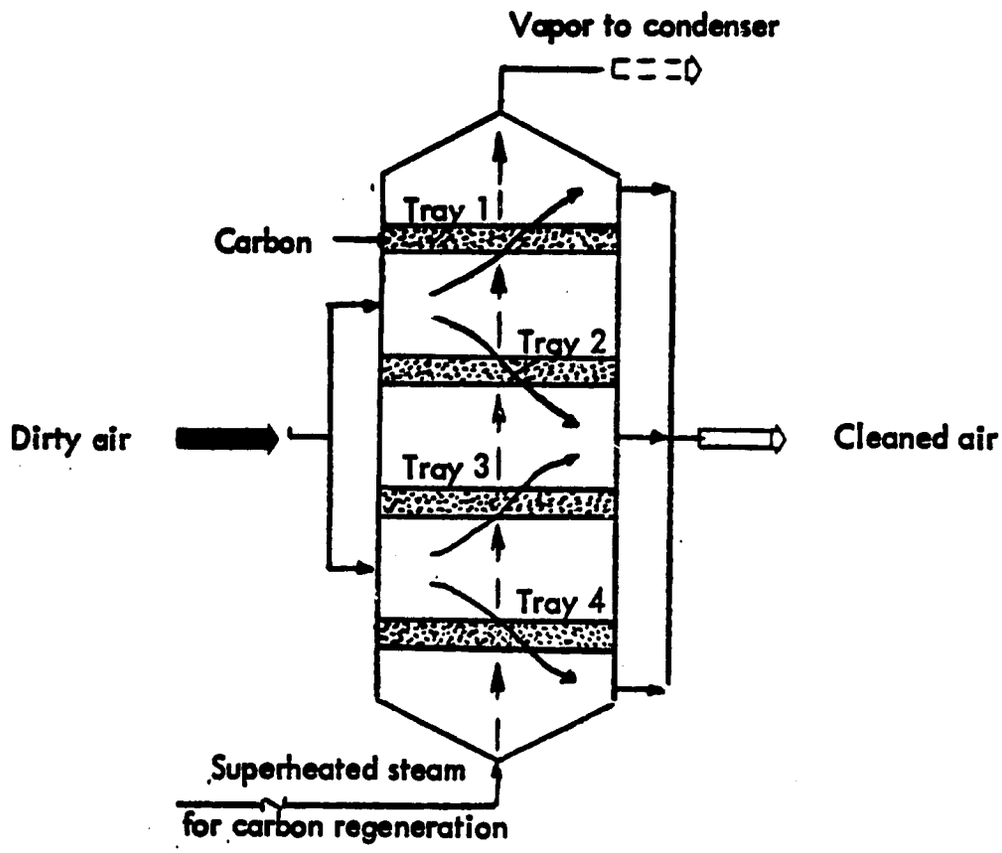

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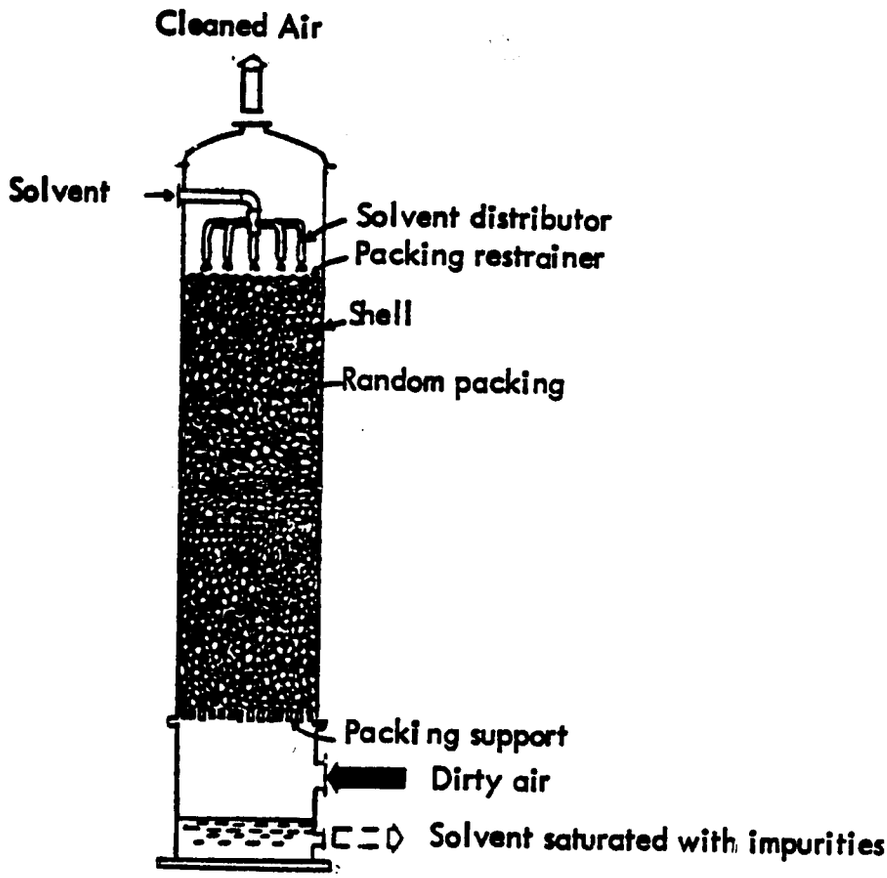
FIGURE 3-7
ACTIVATED CARBON
ADSORBER (FIXED BED)



No scale.

Source: 85.

FIGURE 3-8
PACKED ABSORPTION TOWER

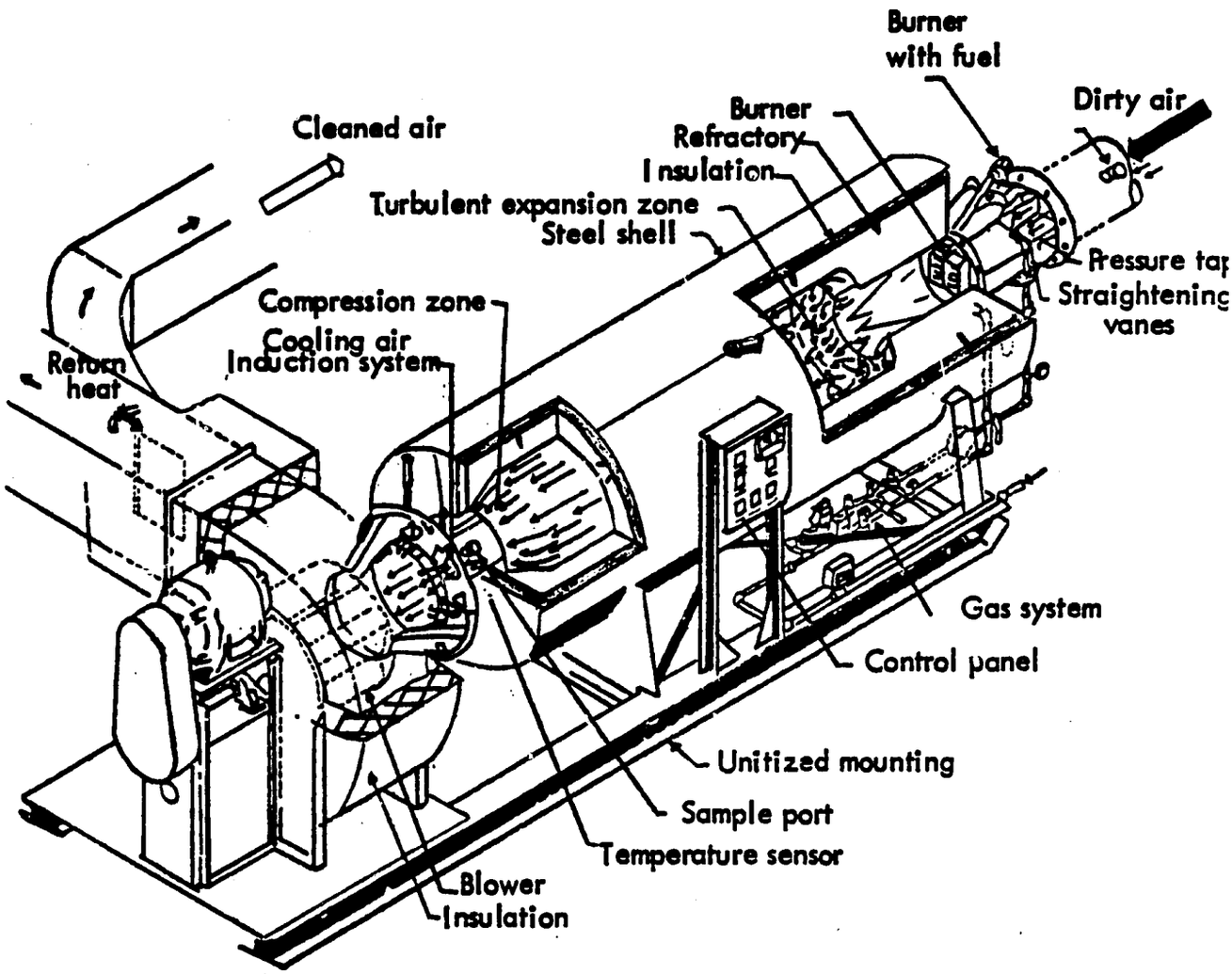


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FIGURE 3-9
AFTERBURNER
(DIRECT FLAME)

particles generally require more power. This relationship is strong for dry collection devices, but is less apparent for wet devices. Also, wet devices generally have higher power requirements than dry devices. Figure 3-10 illustrates these relationships for selected wet and dry treatment processes.

Choice of Alternative Options.

Table 3-4 suggests possible treatment methods for five classes of air pollutants. Many factors (including desired treatment level and pollutant concentration) would have to be considered in designing an appropriate treatment system for a given application. To design a control system for a specific plant and site, a worksheet similar to Table 3-5 may be used to assemble data relating to manufacturing processes, pollution generation, regional factors, and applicable control methods. The final selection of a control system is a matter for plant management to decide based on engineering evaluation of available control technologies and costs in relation to the specific plant's productive activities. Their objective will be to develop a final pollution control plan and specifications which meet required discharge standards at the least total cost.

WATER POLLUTION

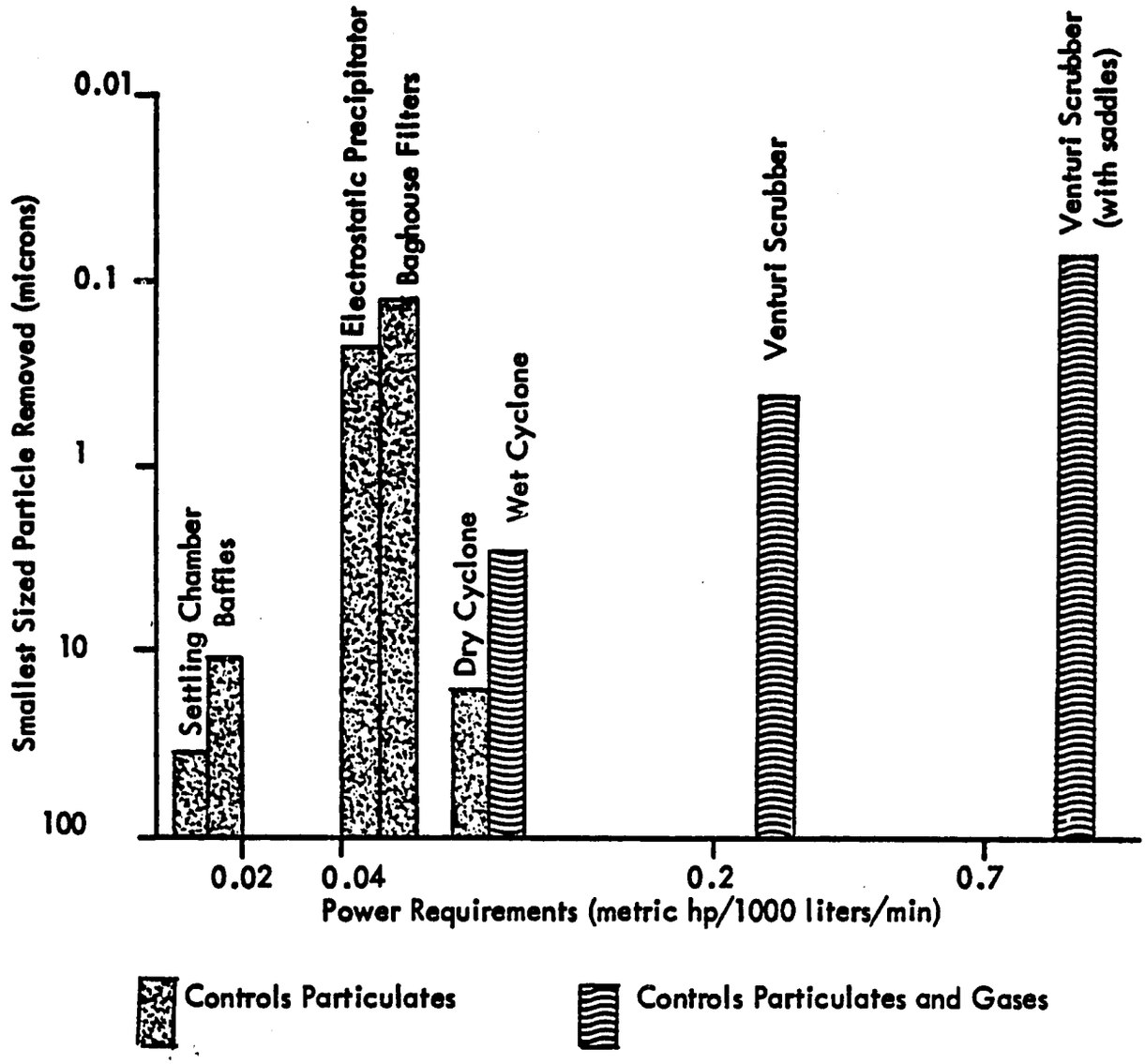
MAJOR WATER POLLUTANTS AND THEIR INDICATORS

Industrial water pollutants may be classified by environmental impact or type of contaminant. Pollutants discharged to receiving waters may present a disease or toxicity hazard; create aesthetic nuisances such as of taste, odor, and color; damage aquatic flora and fauna; and have other harmful effects. A specific pollutant may have several impacts. Phenolic compounds, for example, may have all of the impacts listed above, and, in addition, may limit industrial or other water uses.

Wastewater impurities are usually present as suspended or dissolved solids and may be either organic or inorganic. The presence and quantity of pollutants in wastewater are determined based on: 1) the wastewater flow rate; 2) representative samples of the wastewater; and 3) laboratory analysis of constituents in the samples. Since it is seldom practical to analyze for all the constituents which may be present in a given waste stream, several indicators are used to evaluate wastewater quality. These include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), suspended solids (SS), oil and grease, and toxicity to fish or other animals. Certain contaminants with high potentials for environmental damage cannot be adequately evaluated with a general index and require individual analysis. They include toxic and carcinogenic organic and inorganic compounds, such as heavy metals, nutrients, and radioactive materials. The main types of pollutant indicators and pollutants are described below.

Biochemical Oxygen Demand.

BOD is an indirect measure of the amount of organic compounds contained in wastewater; it is computed from the quantity of oxygen used under standard conditions by aerobic microorganisms in oxidizing the organics in the wastewater in a specified period of time. Traditionally, five-day oxygen demand (BOD_5) has been used as the indicator, although sometimes twenty-day or total BOD is preferable.



Source: 74.

FIGURE 3-10

RELATIONSHIP BETWEEN POWER INPUT AND PARTICLE SIZE FOR SELECTED PARTICULATE COLLECTING DEVICES

TABLE 3-4
AIR POLLUTANT CONTROL OPTIONS

Type of Pollutant	Treatment Installations
Abrasive dust, mineral salts, metallic salts	Mechanical dust collectors, wet dust collectors, filters, and electrofilters
Wood, tobacco, coal, and flour dust	Mechanical dust collectors, absorbers, incinerators.
Hydrogen fluoride, hydrogen chloride, hydrogen bromide, fluorine, chlorine, bromine, iodine, sulfur dioxide, sulfur trioxide, nitrogen oxide, nitrogen dioxide, phosphorous pentoxide, hydrogen iodide	Absorbers, chemosorbers, electrofilters
Organic acids, aldehydes, ketonic types, hydrocarbons, alcohols, benzol, etc.	Adsorbers with vapor burners, condensers, catalytic afterburners, incinerators
Freons, amines, pyridines, mercaptans, etc.	Adsorbers, catalytic or noncatalytic burners with adsorbers

TABLE 3-5
AIR POLLUTION WORKSHEET

1. Plant Site
   A. Description of Manufacturing Process

   B. Products Manufactured:

   C. Plant Capacity _____

   D. Plant Operation: _____ hr/day _____ days/wk

   E. Pollution Sources:

Source	Process	Exhaust Rate	Frequency of Release	Duration of Release	Pollutants				Stack Height + Plume Rise	Product Recovery	Type Treatment
					Gaseous		Particulates				
					Type	Kg/hr	Type	Kg/hr			

   F. Raw Materials Requirements:

Mat'l	Quantity	Storage		Pollution Potential				
	Kg/day	Type	Capacity	Volatile	Dust	Toxicity	Odor	Hazard

   G. Treatment
      1. Segregation or Elimination of Pollutants by Process Change
      2. Substitution of Raw Materials
      3. Value of Recovered Pollutants
      4. Possible Improvements to Existing Exhaust Systems

   H. Existing or Planned Pollution Control Equipment
      1. Type
      2. Description
      3. Supplier
      4. Design capacity for Specified Pollutants
      5. Standby Facilities

TABLE 3-5 (Cont.)

1. Plant Site (Cont.)

I. Available Plant Facilities
   1. Area and Location Available for Control System
   2. Utilities
      Air: _____ l/min. @ _____ Kg/cm^2
      Steam: _____ Kg/hr @ _____ Kg/cm^2
      Condensate Return Unit:
      Gas: _____ l/hr of _____
      Oil: _____ l/hr of _____
      Process Water: _____ l/min. @ _____ Kg/cm^2, _____ °C
      Cooling Water: _____ l/min. @ _____ Kg/cm^2, _____ °C
      Electricity: _____ Kw/hr
   3. Waste Treatment
      Plant Facilities
      Municipal Facilities
      Other Facilities

Sample Point	Sampling Methods	Required Tests	Sampling Frequency	Stability of Pollutants	Shipping Requirements

2. Site Restrictions

A. Meteorology
   1. Wind Direction and Variation (Wind Rose)
   2. Wind Speed and Variation
   3. Atmospheric Temperature: Max., Min., Rate of Change
   4. Precipitation: Seasonal Amounts
   5. Frequency of Fog, Inversions, etc.
   6. Nearest Weather Data Collection Office
   7. Existing Ambient Air Quality

B. Topography
   1. Map
   2. Nearest Building or Natural Obstruction

C. Community
   1. Type of Region Around Plant
   2. Surrounding Vegetation or Farm Crops
   3. Neighboring Plants, Including Emissions

The BOD index is used to evaluate the practicability of biological wastewater treatment and the potential reduction in receiving water oxygen concentration which the effluent could cause. Plentiful dissolved oxygen is necessary for a healthy aquatic environment. In addition, high concentrations of organics in wastewater deplete the receiving water oxygen content and encourage the eutrophication of water bodies, which is characterized by rapid growth of generally undesirable algae and bacteria and disruption of the ecology. Figure 3-11 gives the major sources of BOD in the United States for 1971.

Chemical Oxygen Demand.

COD is another indirect measure of the quantity of organic compounds in wastewater; it is calculated from the amount of a chemical oxidant, usually $K_2 Cr_2 O_7$, which is used to oxidize the organic compounds in the wastewater. COD is the equivalent quantity of oxygen required for this oxidation. For a given wastewater sample, the COD value will always be higher than the BOD value and can be determined much more quickly than BOD_5. Since the two indices are correlated, COD can be used as a rapid check on wastewater or treatment system effluent and then later compared with BOD results. The comparison between BOD and COD will indicate the potential effectiveness of biological treatment in removing organics.

Total Dissolved Solids.

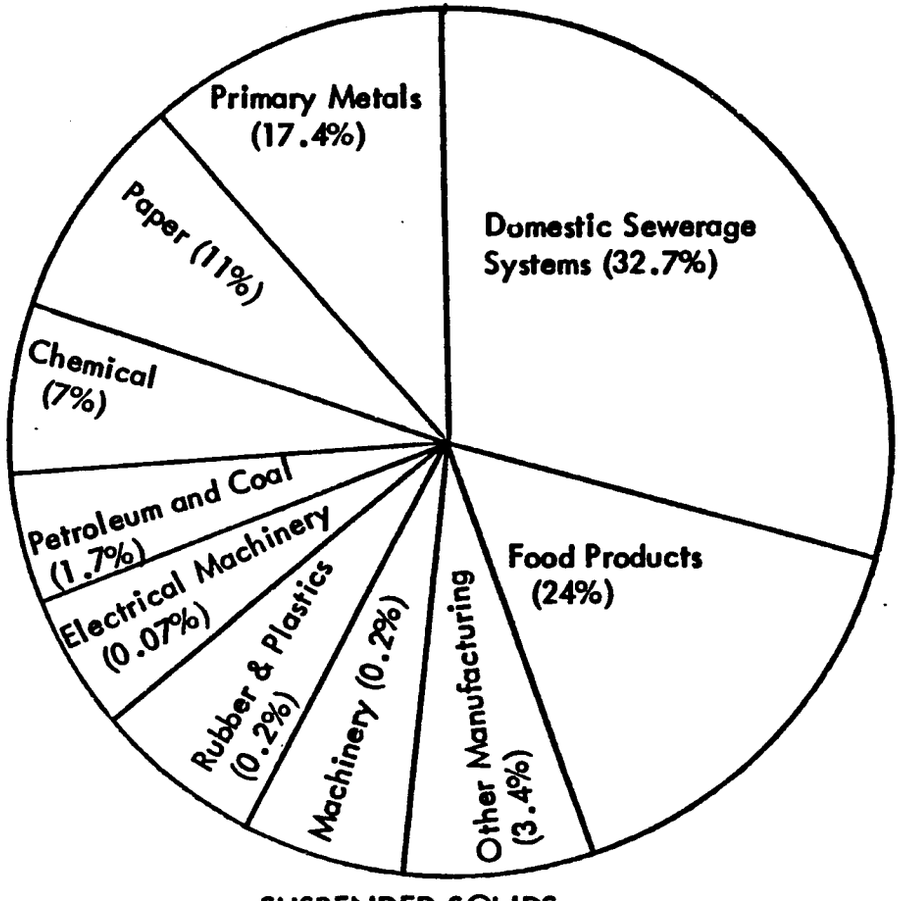
TDS is a measure of the concentration of dissolved matter, both organic and inorganic, in the wastewater, exclusive of that which is volatilized when the sample is dried. Further analysis can then determine the organic and inorganic fractions of TDS. Knowledge of these fractions is important in determining the feasibility of water reuse and the probable impact of the wastewater on receiving waters. High dissolved salt content can cause equipment corrosion and scaling problems if the wastewater is reclaimed and harm aquatic life or affect potability if discharged.

Oil and Grease.

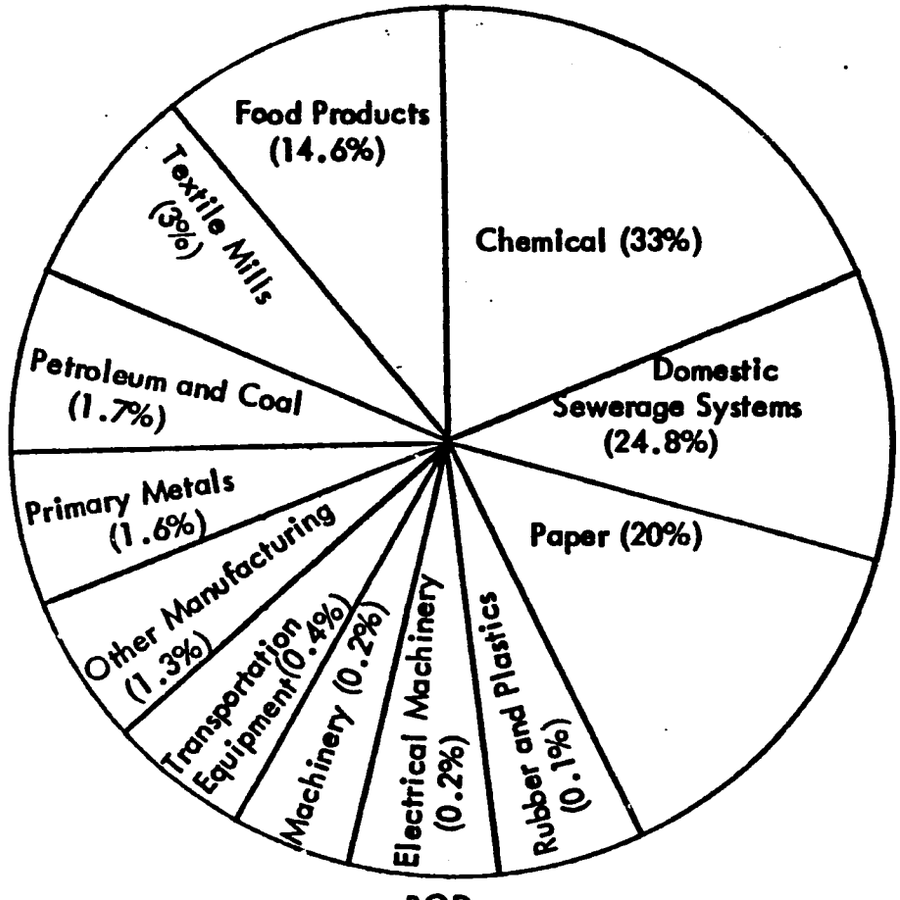
Oil in wastewater may be dissolved, emulsified, or in a surface film. Regardless of state, oil and grease promote biological processes which can deplete oxygen. Also, a surface film will block the natural reaeration process, thus encouraging anaerobic conditions.

Suspended Solids.

As with particulates released to the air, suspended solids released to water are composed of materials which differ greatly in their physical-chemical natures. Suspended solids are defined as those pollutants that can be removed from water by settling, filtration, or screening. Virtually all industries release some form of suspended solids in their wastewater. Those contributing particularly large amounts are iron and steel production, the smelting and refining of nonferrous metals, and pulp and paper manufacture. (See Figure 3-11 for major industrial contributors to suspended solids and BOD_5



SUSPENDED SOLIDS
(Mining excluded)



BOD_5

Source: 77.

FIGURE 3-11

MAJOR UNITED STATES CONTRIBUTORS TO SUSPENDED SOLIDS AND BOD_5: 1964

emissions in the United States.)

Suspended solids have several adverse effects on the aquatic environment. The organic fraction of suspended solids leads to increased oxygen demand (BOD) of the receiving water. In addition, high concentrations of suspended solids cause water murkiness and turbidity, making it aesthetically unattractive and less desirable to consume. Suspended solids may destroy aquatic life through oxygen depletion, toxicity, and abrasive injuries, by clogging respiration, and by destroying spawning beds.

Phosphorus and Nitrogen Compounds.

Organic or inorganic phosphorus, potash, and nitrogen compounds are the major nutrients. In high concentrations they promote excessive algal and plant growth. When these growths die, their decomposition creates a substantial oxygen demand which may seriously reduce dissolved oxygen levels, possibly leading to fish kills. In addition, high nitrate concentrations in drinking water can lead to the serious and sometimes fatal infant disease known as methemoglobinemia. Large quantities of nutrients are released by the food processing, chemical, and agricultural industries.

Toxic Pollutants.

The release of heavy metals into water poses a greater environmental threat than their release into air. These metals are released in relatively high concentrations by the ferrous and non-ferrous metals industries and by the manufacture of chemicals. Heavy metals released to water include aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, tin, titanium, vanadium, and zinc. Of these, cadmium, mercury, and lead are of considerable concern. High levels of cadmium are present in treatment plant sludges and some chemical industrial wastes. Sources of mercury include fossil fuel combustion, the chlorine-alkali industry, electrical power generation, paint manufacture, mining activities, and the paper industry. Lead smelting and the manufacture of chemicals are important industrial sources of lead. Most heavy metals are toxic to aquatic life in relatively low concentrations. Many of these compounds become concentrated in edible fish and shellfish through accumulation in the food chain, cadmium and mercury being examples of current concern.

Other toxic industrial pollutants include pesticides, fluorides, cyanides, sulfides, asbestos, phenols, and acrylics. Some of these compounds have cumulative, long-term effects; diseases they cause may not appear until many years after the period of initial exposure. Major sources of toxic pollutants are the metallurgical, mining, chemical, agricultural, textile, and leather industries. Photograph 3-2 illustrates the problem of hazardous pollutants in surface water.

Aesthetic Quality Pollutants.

Several contaminants can impart color, odor, and bad taste to receiving waters. Even

Photograph 3-2

Hazardous wastes accumulate in receiving body of water. Safe disposal of hazardous toxic wastes from new industrial processes is now recognized as a serious problem.

if these pollutants do not destroy aquatic life or have other obvious deleterious effects because their concentrations are relatively low, the worsened aesthetic properties of the water may limit its use for many purposes. Major industrial dischargers of wastes which can harm the aesthetic properties of the receiving water include the pulp and paper, chemical, and textile industries.

Undesirable Acidity or Alkalinity.

Excessively acid or alkaline industrial discharges can have harmful effects on aquatic life if the pH of the receiving water is significantly changed. The pH of receiving waters generally ranges from 6.5 to 8; a pH below 5 or above 9 in the receiving water may have harmful consequences.

Pathogens.

Pathogenic microorganisms may be discharged with sewage and from food, leather, and other industrial plants. Pathogens may be responsible for common fecal type diseases in humans and other organisms.

Radioactivity.

Radioactive wastes are produced almost solely from nuclear power or munitions plants; although the control systems of such plants are usually nearly 100 percent effective, the storage and ultimate disposal of these wastes is a pressing problem.

Thermal Pollution.

Heat generated during industrial processes is typically removed by water cooling. Coolant water released to the environment causes thermal pollution if the temperature of the receiving water is raised abnormally high. It has been estimated that approximately three-fourths of the water used in industrial nations for manufacturing is used for cooling water; electric power plants are especially heavy users. Thermal pollution of receiving water can upset the aquatic ecology through effects which include reduced incubation times, increased oxygen consumption, decreased oxygen storage capability, and increased susceptibility of organisms to other pollutants.

Summary of Water Pollutant Impacts.

Table 3-6 summarizes the impact area and level of potential harm of selected water pollutants.

TABLE 3-6

DETRIMENTAL EFFECTS OF SELECTED WATER POLLUTANTS

Water Pollutants	Health Hazard	Property Values	Recreational Water Use	Flora and Fauna	Aesthetics
Suspended Solids		Major	Major	Major	Minor
BOD		Minor	Minor	Minor	Major
Nutrients		Major	Minor	Minor	Major
Heavy Metals	Major		Major	Major	
Heat			Minor	Major	
Floating Debris		Major	Major	Minor	Major
Pesticides	Major		Minor	Major	
Radioactivity	Major		Major	Major	
Acidity/Alkalinity			Minor	Major	
Oil and Grease		Major	Major	Major	Major
Pathogens	Major		Major	Minor	

Major concern

Minor concern

WATER REUSE AS CONTROL METHOD

One means for controlling water pollution is the reuse of industrial and municipal wastewater. The development and application of water reuse systems has been stimulated by the availability of improved treatment methods, water shortages in arid regions, and increasingly stringent pollution control requirements. Wastewater reuse can reduce pollutant discharges to the environment; it can also reduce fresh water requirements, an advantage for regions with limited water supplies, and may reduce water treatment costs as well. Depending on its final quality, treated effluent may be used for irrigation, industrial water supply, recreational purposes, fish propagation, groundwater recharge, or potable supply.

Water reuse and recycling often have the effect of reducing or concentrating the eventual waste stream. Control costs per unit of pollutant will tend to fall as the pollutant's concentration increases. As illustrated in the case study of Kaiser Steel Corporation's Fontana, California, plant (Chapter 4), wastewater reuse may be associated with higher wastewater treatment efficiencies and lower water supply and pollution control costs.

The technical and economic feasibility of reusing an industrial waste stream will depend on the effluent quality, the water quality requirements of the specific use intended, and the extent of pretreatment required to make effluent quality compatible with disposal requirements.

Wastewater Reuse for Irrigation.

Potential Advantages. Irrigating with wastewater is both a treatment and a disposal method. The soil mantle is a massive filter capable of removing or breaking down many of the pollutants in wastewater. Some of the applied effluent is lost to the atmosphere due to transpiration. Part of the remainder is used by plants growing in the soil, part filters through the soil to return to the surface water bodies, and the rest passes through and enters the groundwater. The soil, its microbes, and other living organisms play vital roles in the renovation process. Soil microbes help convert organic materials into useful soil conditioners. Use of treated effluent may increase yield (or cut fertilizer requirements) more than the use of normal irrigation water. Because of the treatment afforded by the soil, wastewater used for irrigation may also require less pretreatment (therefore reducing cost) than if discharged directly. Table 3-7 shows recommended limits for pollutants in irrigation water.

Potential Adverse Effects. The widespread application of wastewater for irrigation has been limited primarily by certain technical and public health uncertainties relating to its environmental impacts. There is concern that the quality of foodstuffs, land resources, and water resources may be partially impaired by residual contaminants present in the treated effluent. For instance, the salinity of irrigation water may greatly affect crop yield. The salt content of the soil strongly affects the osmotic relationships within plants, working against their uptake of water. Saline irrigation water may also

TABLE 3-7

LIMITS OF POLLUTANTS FOR IRRIGATION WATER[a]

Constituents	For Water Used Continuously On All Soils (mg/l)	For Short-Term Use[b] On Fine Textured Neutral and Alkaline Soils (mg/l)
Heavy Metals		
Aluminum	5.0	20.0
Arsenic	2.0	10.0
Beryllium	0.1	0.5
Boron	0.75	2.0
Cadmium	0.01	0.05
Chromium	0.1	1.0
Cobalt	0.05	5.0
Copper	0.2	5.0
Fluoride	2.0	15.0
Iron	5.0	20.0
Lead	5.0	10.0
Lithium	2.5	-
Manganese	0.2	10.0
Molybdenum	0.01	0.05
Nickel	0.2	2.0
Selenium	0.02	-
Bacterial		
Coliform dens	1,000/100 ml	
Chemical		
pH	4.5-9.0	
TDS	5,000	
Herbicides		
Dalapon	0.2 μg/l	
TCA	0.2 μg/l	
2,4-D	0.1 μg/l	

[a] Developed by U. S. Environmental Protection Agency.
[b] "Short-term" as used here means a period of time less than 20 years.

Source: 89.

create an unfavorable nutrient balance in the soil.

Undesirable concentrations of toxic or heavy metal salts in treated effluent may be caused by discharges from manufacturing plants or domestic sources using zeolite water softeners. In irrigation water, salts may be harmful in at least two ways. Many trace metals, such as aluminum, boron, copper, manganese, selenium, and silver are phytotoxic. Phytotoxins may kill a plant outright, but more often they inhibit and weaken growth, thus reducing yield or causing inferior quality. Also many plants and animals absorb and concentrate some toxic substances ("biomagnification"). This tendency is most pronounced in the case of the absorption of mercury by aquatic algae, but similar problems may occur to a lesser extent in terrestrial plants and animals. Some of the toxic substances subject to biomagnification are cadmium, molybdenum, selenium, and fluoride. In food crops, these may present a hazard to human health. The long-term significance of heavy metal accumulation in agricultural soils due to wastewater application will depend on whether these metals ultimately assume chemical forms that cannot be absorbed by plants, or are leached into the groundwater.

Pathogens can also be a problem when irrigating with sewage effluent. Pathogens (bacteria, protozoa, nematodes, viruses) can enter plant tissues in a variety of ways and may contaminate edible crops. The problem is intensified when the plant is consumed raw. One solution is to irrigate with fresh water for one month before harvesting. Some pathogens may also damage the plants themselves and severely affect their yield, or harm animals which feed on them.

Dissolved salts, heavy metals, pathogens, and toxic constituents are potential pollutants of useable groundwater supplies. They may move through the soil and contaminate groundwater if conditions such as soil permeability, distance to aquifer, or pH are favorable. This possibility should be evaluated for each proposed use of effluent as irrigation water.

Choice of Irrigation Method and Site. Irrigation may be done by spraying, ridge and furrow, or flooding methods. Irrigation is in general a reliable method for direct wastewater recycling, renovation, long-term use, and minimization of adverse environmental effects. Factors to be considered in selecting the site and the wastewater application method include economic and land use planning, and such technical factors as soil type and permeability, topography, groundwater levels and quality, underlying geologic formations, wastewater characteristics, and pretreatment. The existing data on quality requirements for a given land application vary widely.

Water Reuse for Industrial Water Supply

Water Quality Classifications. Water quality requirements for wastewater to be reused as industrial water supply are generally similar to those for water from traditional sources. Water quality requirements for all types of industrial use (such as washing raw material, solvent, sorption, transportation or heat-carrying transfer, etc.) may be classified as follows:

- Water which needs no treatment (some well waters)
- Water commonly used with minimal treatment (disinfection)
- Water treated to be potable (clarified and disinfected)
- Thoroughly treated water (softened or demineralized plus above)

This classification is arbitrary; however, it allows consideration of general requirements which are typical for many water users, such as the range of total salinity, total organic content, hardness, alkalinity, suspended solids, pathogens etc. Individual requirements can be given for specific water use processes. Variations in water requirements for different plants in the same industry and between various processes within a single plant can be taken into account in the design of their water supply systems. There may be as many as four separate sources in one plant: potable, demineralized, cooling, and softened waters. The classification may also be useful for the selection of wastewater treatment methods. Wide ranges in industrial wastewater quality necessitate specific analysis of each application of this water before reuse.

Types of Industrial Uses.

Cooling Water. Cooling water systems may be classified as "once through" or recirculating. "Once through" systems use water for only one cycle and then discharge it. There is no significant evaporation or concentration of constituents; therefore water may have a relatively low quality. For example, the Bethlehem Steel Company has successfully reused secondary treated municipal effluent for over 20 years.

Recirculating cooling systems have more stringent requirements because of possible corrosion, scaling, and biological sliming of apparatus and installations. Examples of recirculating water quality requirements are given in Table 3-8 . The quality of water required is comparable to that of many river waters, and may be achieved by conventional secondary treatment of municipal wastes plus additional filtration through sand or a mixed media bed, sometimes accompanied by coagulation. Typical water quality for municipal treated effluent is given in Table 3-9. BOD and SS after filtration are respectively from 2 to 8 and from 1 to 7 mg/l.[36]

Cooling water makeup may be treated by shock chlorination, lime clarification, recarbonation, or other pH adjustment. Lime clarification in combination with recarbonation and filtration provides softening of water and some removal of bacteria and virus contaminants, heavy metals, organic compounds, and foam-producing detergents. Also, some treated industrial wastewater coming from refinery, chemical, metallurgical, and other plants, may be reused as cooling water, although the additional physical-chemical treatment for softening, stabilization, and hydrocarbon removal may be required.[36]

Cleanup Water. Water used for equipment and other cleanup operations will usually have requirements similar to those for cooling water. For example, for mining and enrichment processes, secondary treated water may be reclaimed.

TABLE 3-8
COOLING WATER QUALITY
REQUIREMENTS FOR MAKEUP WATER
TO RECIRCULATING SYSTEMS

Parameter	Concentration (mg/l)		
Cl	500		150-300
TDS	500	--	500
Hardness ($CaCO_3$)	130	50	60
Alkalinity ($CaCO_3$)	20	--	--
pH	aar[a]	6.9-9.0	6.5-8.5
COD	75	--	--
TSS	100	25	20-30
Turbidity	--	50	--
BOD	--	25	15-20
MBAS	--	2	--
NH_3	--	4	2
PO_4	--	1	2
SiO_2	50	--	--
Al	0.1	--	--
Fe	0.5	0.5	0.5
Mn	0.5	--	--
Ca	50	--	--
Mg	aar	0.5	--
HCO_3	24	--	--
SO_4	200	--	350-500

[a] aar = accepted as received.

Source: 37, 89.

TABLE 3-9
TYPICAL QUALITY OF SECONDARY
TREATED MUNICIPAL WASTEWATER

Index	Concentration (mg/l)
Mg	5-20
Ca	10-50
SiO_2	10-20
PO_4	15-50
NO_3 as N	1-20
NH_3 as N	2-20
Cl	25-125
SO_4	10-40
Alkalinity	30-100
Dissolved organic compounds	10-50
TDS	150-500
BOD	15-30
SS	15-30

Boiler Feed Water - This water should be of high purity. Allowable concentrations of dissolved salts, hardness, etc., are dependent on the pressure under which the boiler is operated. There are several examples of municipal wastewater reclaimed for boiler feed.[89] Low pressure boiler installations usually require lime clarification, granular filtration, zeolite softening, and deaeration. Medium and high pressure boilers require, in addition, demineralization and organics removal by methods such as ion exchange, reverse osmosis, and carbon adsorption. Condensates which may occur as waste products in some industrial processes are a suitable source for reuse as boiler makeup, although they sometimes require pH adjustment, and further salt and organic removals.

Preparing high quality water, such as boiler feed water from treated wastewater, although technically possible, is often not economical. Since as a rule the quantity of demineralized water required is not significant, fresh water is generally used. For users with special water requirements (such as distilled water) special treatment methods may be required.

Use of industrial wastewater for industrial water supply has several advantages over municipal wastewater for reuse as industrial water supply. Industrial wastewater may contain highly toxic components. Although the allowable concentrations of these substances in rivers, lakes and the ocean are very low and treatment methods can be ineffective and costly, these constituents may be easy to recycle for industrial water use. Sometimes water is saturated with raw materials or manufactured products and their discharge causes loss of valuable resources. In-plant recirculation and reuse of water diminishes this loss. Therefore water reuse may be profitable for the plant, as well as protecting the environment from pollution.

Water Supply/Reuse/Treatment System.

Today specialists consider industrial water supply and wastewater disposal as one unit. The first step in designing the system for a plant or group of plants is to collect pertinent data on the quality and quantity of consumed and discharged waters. The second step is to calculate water and pollution mass balances. Next, the system of water supply and sewerage systems can be evaluated and a selected optimum alternative system designed. An example of such a general system is given in Figure 3-12 . All water users in the plant are classified according to the four categories of water quality, and four respective networks of water supply are provided. Some processes use circulating subsystems; others are "once through" consumers. Several users may have local treatment installations for the removal of undesirable constituents, the recovery of valuable products, or the purification of water recycled for subsequent reuse. Several types of systems can be provided for different types of wastewater, such as: high organics concentration, medium organics concentration, and different mineral salt contents.

The specific water quality classification will depend on the types of available wastewater, the treatment methods used, and existing water quality supply requirements.

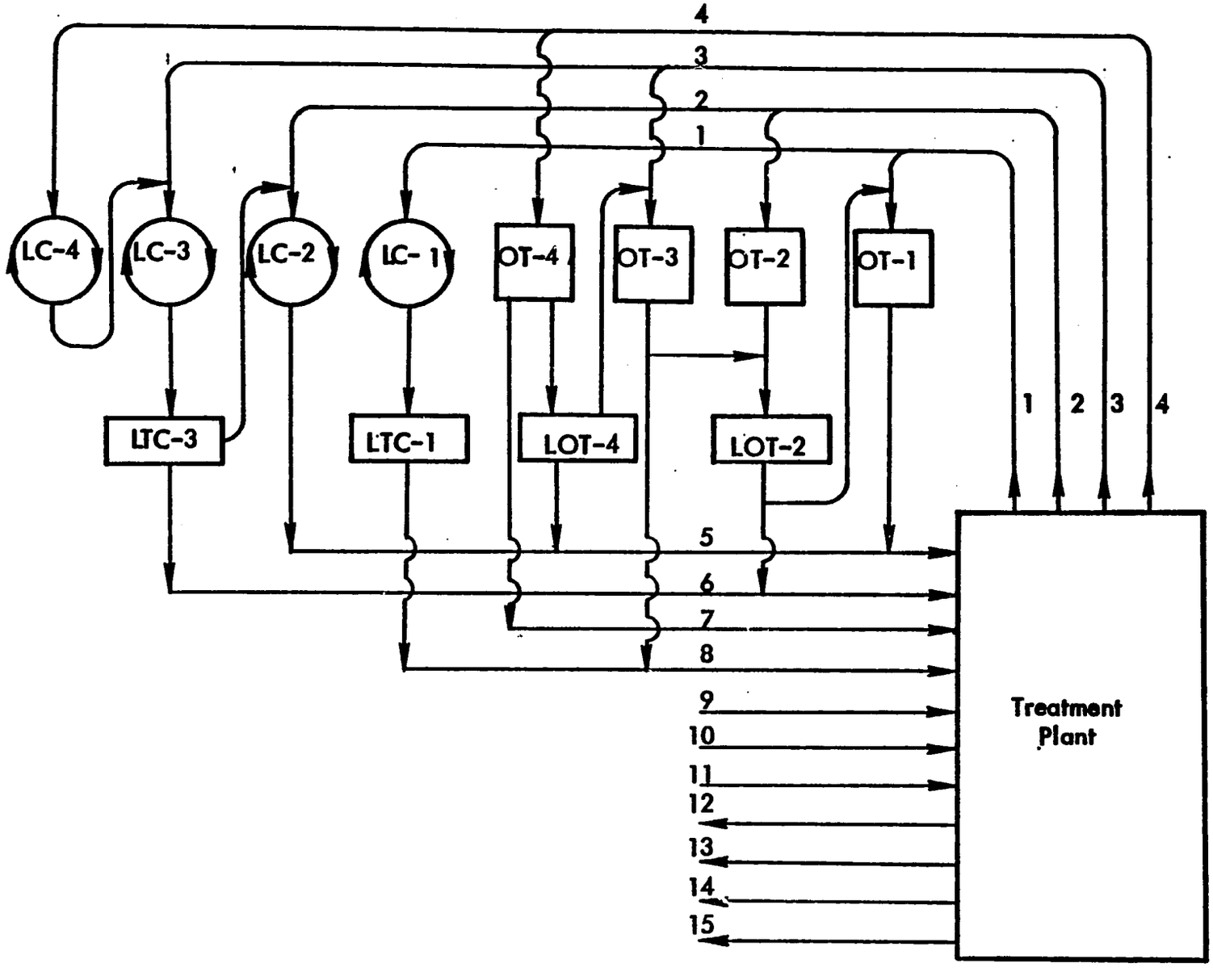


FIGURE 3-12
COMPLEX SYSTEM OF INDUSTRIAL WATER SUPPLY, TREATMENT AND REUSE

Legend

1, 2, 3, 4 - Separate water sources, respectively, from highest to lowest quality.

5, 6, 7, 8 - Separate wastewater systems with different quality for collection and treatment.

9 - Municipal wastewater.

10 - Runoff.

11 - Fresh water supply

12 - Treatment plant sludge for disposal.

13 - Concentrated wastewater for disposal.

14 - Discharged effluent.

15 - Recovered products.

LC-n - Local water circulation systems.

OT-n - "Once-through" water use.

LTC-n and LOT-n - Local treatment facilities.

FIGURE 3-12
LEGEND

An industrial treatment plant may be centralized to serve many plants, or there may be many independent treatment facilities at different locations. Not only industrial wastewater, but also municipal wastewater and runoff may be treated in the facility. If fresh water from natural sources requires treatment, this can be provided in a special fresh water works. Conventional water works for industrial users may have several types of waste discharges: sludges, brines or water with high salt concentrations, treated wastewater for discharge into rivers, and sometimes valuable components, such as fertilizers. At each step the industrial plant should control its wastewater discharge and even reach a point of no discharge.

Advanced Reuse Systems

Several experimental systems exist which discharge no effluent into natural water bodies. These projects are for refinery, integrated chemical production, metallurgical, and other plants in industrial regions.[27,89,37] One of the most advanced systems, at the Fontana Steel Plant, is described in Chapter 4 . Features of such systems usually include new regimes of cooling system operation, thorough treatment of wastewater, local treatment of wastewater, recovery of valuable products, disposal of brines and water highly concentrated with organics, and utilization of by-products from the treatment plant. Cooling systems are usually operated with a higher degree of evaporation, and therefore salt content, in the circulating water. This requires more effective inhibition of corrosion and partial desalination of makeup water. Treatment plants usually include tertiary installations for thorough organics removal; for example, adsorption by activated carbon, and desalination, usually by ion exchange. If regeneration of ion exchange filters is provided by ammoniac water and nitrogen acid, fertilizers may be recovered as a by-product and the problem of salt disposal will be less difficult. There are several ongoing attempts to recover activated sludge as an amino-vitamin concentrate for addition to feed. However, remaining disposal problems are very difficult. The treated brines are often injected into wells, and concentrated organic wastes are usually burnt.

Water Reuse for Recreation, Fish Propagation, and Domestic Use

Municipal water and conditionally pure industrial water, such as warm water from power plants may be used for the above purposes. Some admixture of industrial to municipal water usually does not hinder reuse for recreation and fish propagation. Recreational use of even thoroughly treated wastewater is limited and for swimming, additional treatment is needed. Fish propagation is common when the tertiary treatment is provided in biological ponds. But the use of warm water for intensive fish propagation is very difficult, due to secondary pollution of the water by added feed and fish excrement. There are some systems which directly reuse treated effluent for nonpotable domestic uses, and only one known system that reclaims treated wastewater by admixture for a potable water supply. Many potable water sources have received some wastewater effluent replenishing the surface or groundwater sources.

Summary of Water Quality Parameters

Table 3-10 shows some representative parameters of water quality suitable for municipal, recreational, industrial, and agricultural purposes. Although industrial requirements may vary, municipal water use usually demands a lower level of impurities present than either industrial or agricultural applications.

WATER POLLUTION TREATMENT METHODS

The appropriate treatment system for a given industrial plant will depend on the quantity of wastewater generated, the type and concentration of specific contaminants to be removed, and the desired level of control. The impact of the effluent on receiving waters can be estimated for different systems by calculating the dilution of effluent within receiving water and the self-purification of this mixture.

In many cases, the industrial plant's treatment system may only need to provide some pre-treatment. This would be the case, for example, where the industrial waste is discharged into a municipal sewer system, and the wastes discharged are almost compatible with municipal sewage (sufficiently similar to be treated effectively by the municipal sewage treatment plant). Treatment might then be limited to specific non-compatible components (e.g., heavy metals, oils, acids, detergents) as well as shock loads (excessive concentrations) of compatible contaminants. In other cases, the industrial plant may need to provide most or all of the pretreatment. Most industrial wastewaters contain a wide range of pollutants which require substantial treatment before discharge.

Classification of Wastewater Treatment Systems

Wastewater treatment methods are commonly grouped under three general classifications: primary, secondary, and tertiary treatment. These categories are not rigid; they refer to three approximate stages or levels of treatment, and some treatment processes may be used in more than one category. Industrial plant treatment systems usually include primary and secondary treatment processes, and sometimes tertiary processes also.

Figures 3-13 through 3-15 are examples of possible wastewater treatment systems. They are merely illustrative, and may not be applicable to particular industrial waste streams. Figure 3-13 shows a conventional treatment system which includes primary and secondary methods. Such a system might be modified to include mechanical-chemical primary treatment using inorganic coagulants (aluminum, iron, or lime) and/or organic flocculants. Figure 3-14 shows a tertiary type system in which biological, physical-chemical, and filtration methods are added to conventional processes. Figure 3-15 presents a typical physical-chemical treatment system which does not use biological methods.

The three treatment classifications and related treatment methods are described below.

TABLE 3-10

WATER SUPPLY QUALITY GUIDELINES FOR DIFFERENT USES[a]

Constituent	Municipal	Recreational	Industrial	Agricultural
BOD_5 (mg/liter)	1.3	-----	10	10
Cyanides (mg/liter)	0-0.02	0.02	0.2	0
Dissolved O_2 (mg/liter)	4-7	4-7	1-2	0.2
Coliform(no/100ml)	1-50	1,000-5,000	5,000	5,000
Temperature (C)	10	0-34	13-33	16
Ammonia (mg/liter ammonia-N)	0.1	1.0-2.0	-----	-----
Nitrate (mg/liter nitrate-N)	1.5	44	-----	-----
Phosphates (mg/liter)	10	10	-----	-----
Alkalinity (mg/liter calcium carbonate)	120	-----	50-150	-----
Arsenic (mg/liter)	0.01-005	1.0	0.01-0.05	1.0-5.0
Chlorides (mg/liter)	250	5.0	50-250	100
Fluoride (mg/liter)	1.4-2.4	5.0	1.5	-----
Hardness (mg/liter calcium carbonate)	80	-----	50-400	-----
pH	6.5-8.5	6.5-9.0	6.0-9.5	6.0-9.5
Lead (mg/liter)	0.05	0.1	-----	-----
TDS (mg/liter)	500	3,000	1,000	1,000
Floating solids	0	0	0	0
Oil (mg/liter)	0	0.3	0	0
Turbidity (JTU)	1-25	10-25	250	-----

[a]Before treatment for final use.

Source: 42.

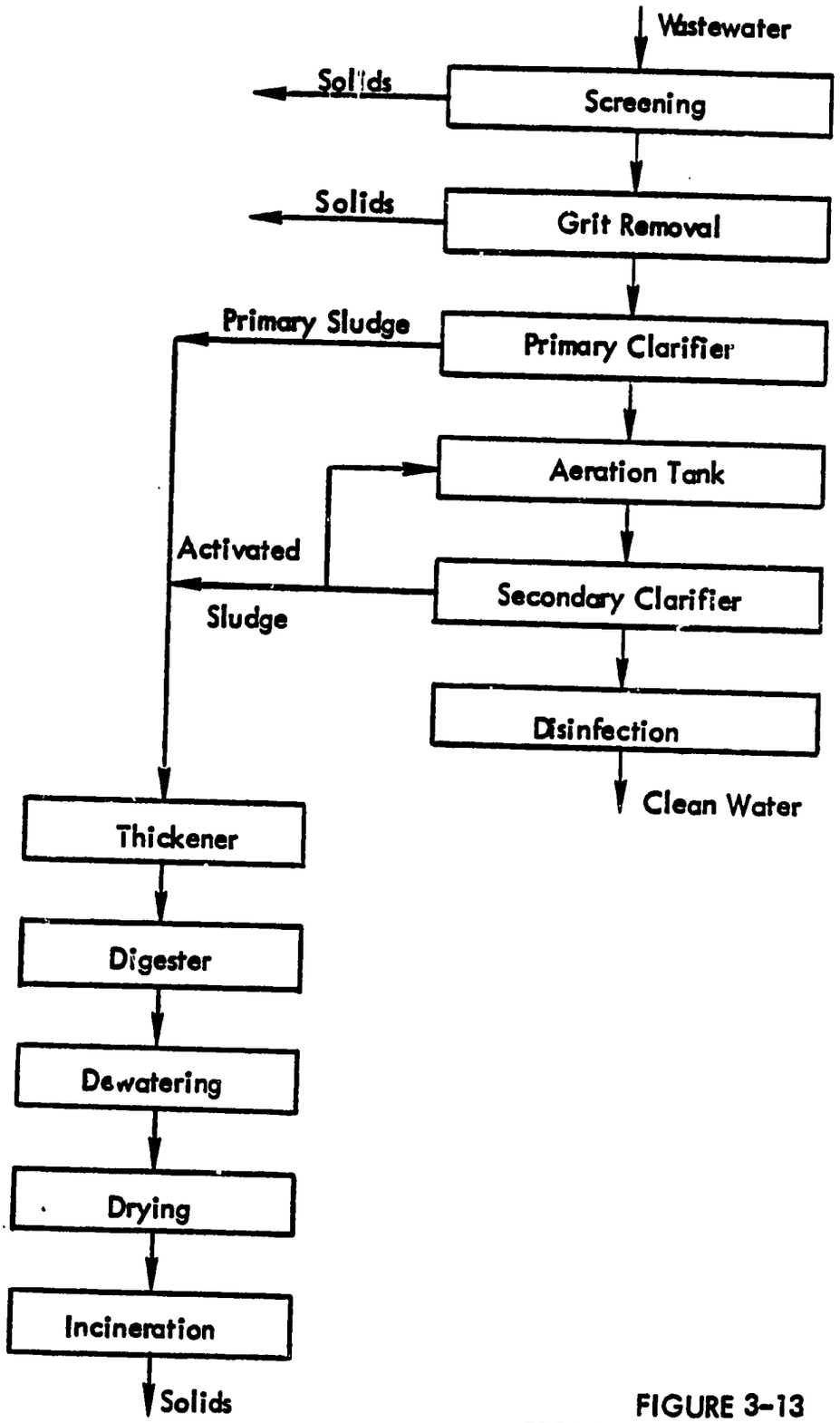
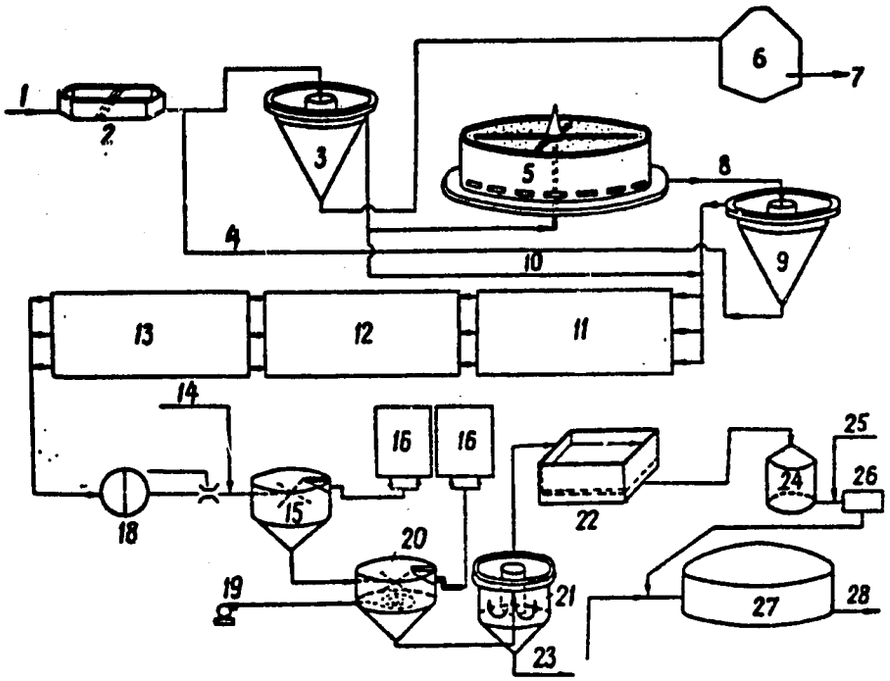


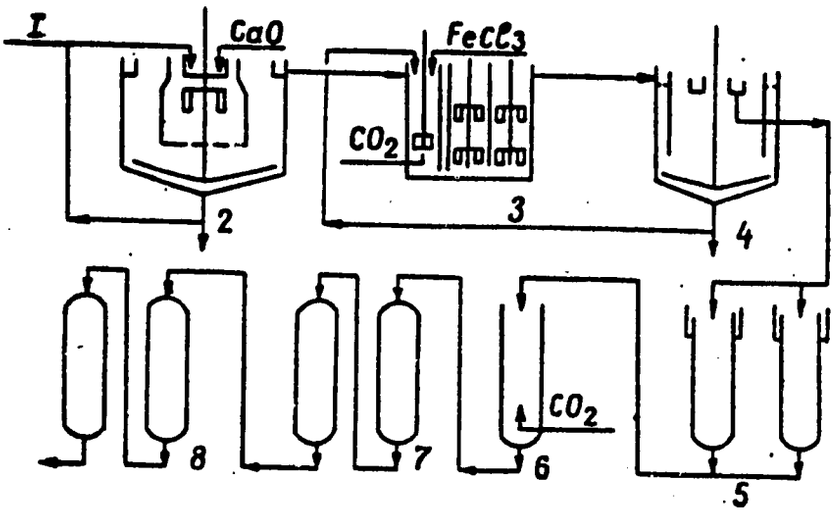
FIGURE 3-13
BIOLOGICAL WASTEWATER
TREATMENT PLANT
(SECONDARY TREATMENT)



NOTE:

1. Wastewater
2. Grit removal
3. Clarifier
4. Circulated activated sludge
5. Trickling filter
6. Digester
7. Digested sludge to field disposal
8. Biologically treated water (high concentration of nitrates)
9. Secondary clarifier
10. Primary treated water bypass
11. } Three stages of biological stabilization ponds
12. }
13. }
14. Coagulant
15. Flotation clarifier
16. Sludge drying fields
17. Venturi flow rate meter
18. pH correction
19. Blower
20. Flotator for detergent removal
21. Clarifier
22. Sand filter
23. Sludge
24. Activated carbon adsorbers
25. Chlorine
26. Contact tank
27. Sludge storage tank
28. Cleaned water for industrial reuse

FIGURE 3-14
TERTIARY TREATMENT OF WASTEWATER



Note:

1. Wastewater
2. Primary clarifier with lime milk addition
3. Reactor with coagulant and carbon oxide addition
4. Secondary clarifier
5. Sand filters
6. Recarbonater
7. Ion exchangers
8. Activated carbon adsorbers

FIGURE 3-15
PHYSICAL-CHEMICAL
WASTEWATER TREATMENT

Primary Treatment

Primary treatment begins with screens, comminutors, grit chambers, gravity settling tanks or mechanical separators, and skimmers. These devices remove flotable and coarser suspended matter from the influent. This prevents clogging or stoppage in other treatment devices and reduces pollutant loadings. Following this initial coarse treatment, the wastewater may be passed through sedimentation or flotation clarifiers. Although these clarifiers alone will remove a substantial portion of the suspended matter, coagulants, flocculants or flotation (aeration/vacuum) can be added to increase suspended solids removal efficiency and precipitate some specific compounds such as phosphorus, heavy metals, detergents, and oil emulsions. When using coagulants, pH adjustment may be required. Acids and lime or alkalies are the most frequently used pH adjustment chemicals. Photograph 3-3 illustrates a primary treatment system. Table 3-11 summarizes the advantages and disadvantages of principal methods in this category.

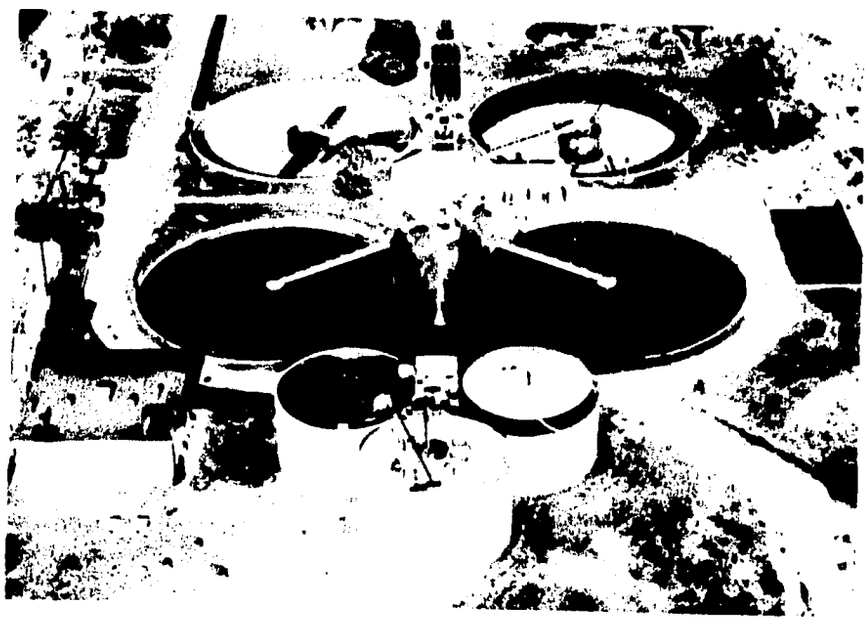
Screening is designed to remove large floating and suspended solids by straining wastewater through racks or screens. The screens themselves may take the form of bars, wires, or perforated plates. They are cleaned by mechanically operated rakes, by hand, or by backwashing. Mechanically cleaned screens are often more effective. Screenings are typically deposited on a platform or in containers to be removed at intervals by hand. For disposal, the screenings may be incinerated at temperatures between 700-900 C, disposed as solid waste, or added to sludges from subsequent treatment processes for combined disposal. Comminutors are sometimes used in place of simple screening. These devices both screen and grind large solids. The smaller-sized solids remain in the wastewater for removal later during primary treatment.

An advantage of screening is the removal of solids that may interfere with subsequent treatment steps, particularly clarification. A disadvantage is the possible ineffectiveness if screens are not cleaned regularly. Screening is particularly important for the food, meat packaging, tanning, textile, chemical, and pulp and paper industries.

Grit removal uses differential settling characteristics to remove smaller and more dense solids (such as sand, cinders, and metal filings) that may not be removed by screening alone. Grit removal may be accomplished in two ways, channel collection and washing collection. Removal of grit is either by hand or mechanically. Because of its high organic content, the grit removed is typically landfilled or incinerated. The main advantage of this process is prevention of the damage to pumps and digesters often caused by grit.

Septic tanks (Figure 3-16) are one the simplest wastewater treatment methods. They are particularly useful for small industrial systems and for wastewater containing normal suspended solids and BOD in concentrations typical of domestic wastewater. Retention times are about several days for wastewater, and up to several months for the settled or flotable sludge; sludge must be removed periodically. After removal, the partially digested sludge is normally landfilled or further treated in a plant. The quality of the effluent leaving the septic tank is not very high, and it is usually disposed in sub-surface leach fields or pits.

Clarification is a group of processes used to further separate solids from wastewater following preliminary screening. The main process in clarification is the use of settling (sedimentation) tanks; the clarification process is often aided by coagulation and flocculation,

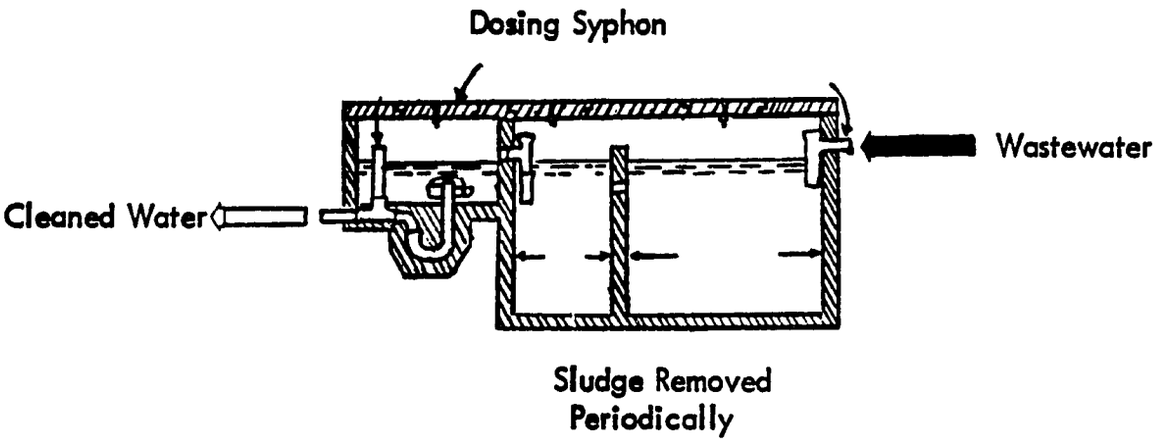


Photograph 3-3

Primary wastewater treatment system. Sludge settles out in the four large circular clarifiers (top of picture) and is pumped to the three anaerobic digesters (bottom of picture). The system removes about 40 to 60 percent of the total organic water pollutants.

TABLE 3-11
ADVANTAGES AND DISADVANTAGES OF SELECTED PRETREATMENT AND PRIMARY TREATMENT PROCESSES

Process	Advantages	Disadvantages
Screening	Removes solids which might interfere with subsequent treatment steps	Screens need frequent cleaning
Grit removal	Removes grit which might damage sedimentation tanks, pumps, and digesters	
Sedimentation	Efficiently removes settleable solids	High maintenance cost for sludge removal
Coagulation and flocculation	Improved solids removal	Produces large amount of sludge
Dissolved air flotation	Efficiently removes oil, grease, and settleable solids	High operating and power costs



No Scale

Source: 30.

FIGURE 3-16
SEPTIC TANK

depending on wastewater characteristics. Flotation process tanks are sometimes used instead of settling tanks. Coagulation and sedimentation (discussed below) may be included with clarification.

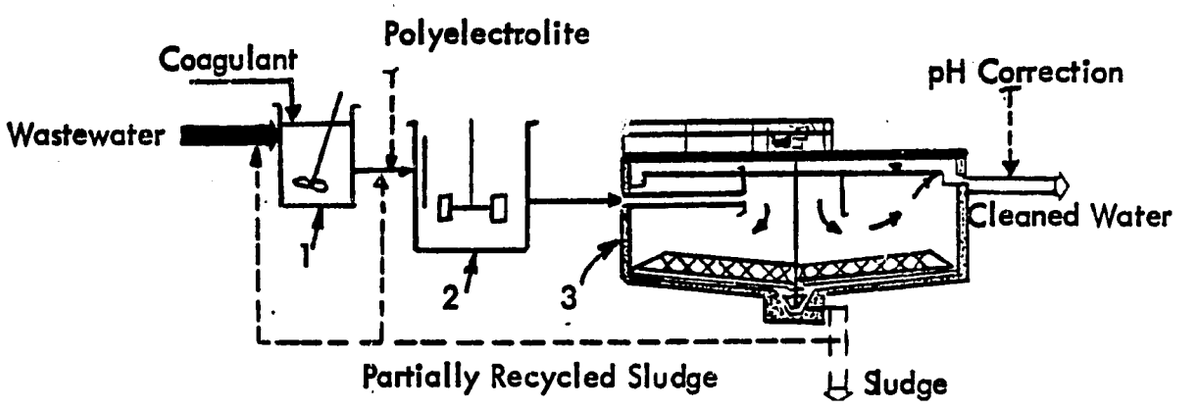
Settling tanks (clarifiers), shown on Figure 3-17, reduce wastewater flow velocity to the point where most suspended solids settle to the bottom of the tank, forming sludge. The primary maintenance requirements of settling tanks are sludge and scum removal, cleaning, painting, etc. Typically, sludge collectors and skimmers remove the solids to a hopper where they are stored until removed, either periodically or continuously, by gravity or pumping.

Air flotation is often used to remove oil, grease, or fibrous materials. Air bubbles released under pressure at the bottom of the wastewater holding tank attach to the oil and suspended particles which then rise to the liquid surface and form a floating scum. The scum removed is typically either incinerated or digested. A disadvantage of dissolved air flotation is the additional energy requirement for pumping, resulting in relatively high operating costs. Flotation combined with conventional clarification is shown in Figure 3-18; pneumatic-mechanical flotation is illustrated in Figure 3-19.

The lime process is a mechanical-chemical modification of primary treatment. Before sedimentation, lime is mixed in with the wastewater as a coagulant. Lime addition might be as low as 50 mg/liter, or higher than 200 mg/liter. Adding flocculants improves sedimentation and precipitates some heavy metals, phosphorus, and some organic matter. Ammonia stripping may also be done. Since effluent from the process will have a pH of approximately 11-12, carbonation (CO_2) may be used for pH adjustment. Sometimes second step clarification provides additional sedimentation. Sludge from the first step is partially recirculated; the remaining residue containing some $CaCO_3$ is dewatered by vacuum filtration and then land-disposed or incinerated for lime recovery. Carbon dioxide from the incineration process may be used in the recarbonation unit.

Coagulation and sedimentation (Figure 3-17) is another common mechanical-chemical industrial primary treatment process. Adding aluminum or iron coagulant, possibly in combinations with organic flocculants, improves the sedimentation process. Sometimes influent pH correction is done to form better flocs. More effective removal of suspended solids and emulsions may also reduce phosphourus, detergents, and organic content.

Microstraining (Figure 3-20) is an alternative to sedimentation. The microstrainer (or microfilter) includes a horizontal revolving drum covered with a fine cloth (metal or fabric) netting, and a chamber. The mesh of the netting is quite small, usually from 20 to 100 microns. The drum is partially submersed in the chamber. Above the drum, there is a perforated tube for backwashing; inside the drum, there is a tray for collecting backwash water. Wastewater is pumped inside the drum, filtered through the microfilter, passed into the chamber, and then discharged from the unit as effluent. Dissolved solids collected on the filter are removed by backwashing. Microstraining has been used as a primary treatment, but is usually used as a tertiary treatment following the activated sludge process.



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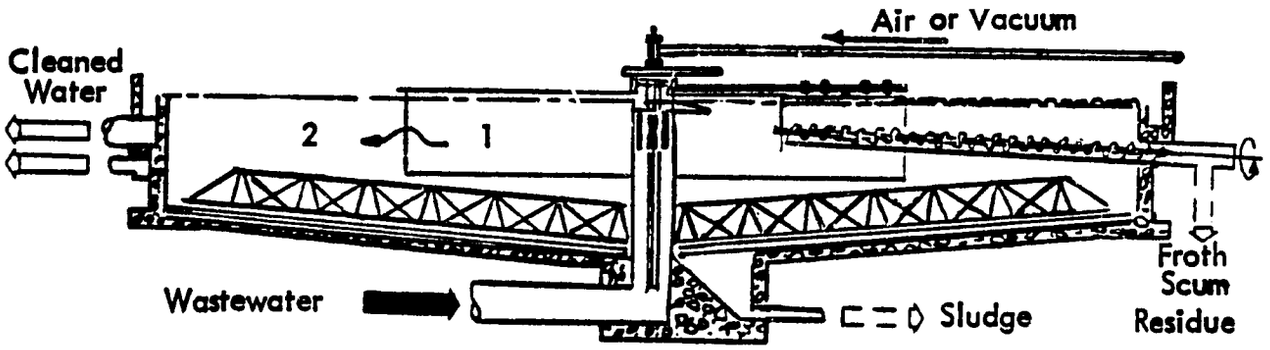
NOTES: 1 - Mixer
2 - Flocculator
3 - Clarifier

Source: 42.

FIGURE 3-17
CLARIFIER (PRIMARY
WITH COAGULANT ADDITION)



NOTES: 1 - Flotation zone
2 - Sedimentation zone

No Scale

FIGURE 3-18
FLOTATION CLARIFIER

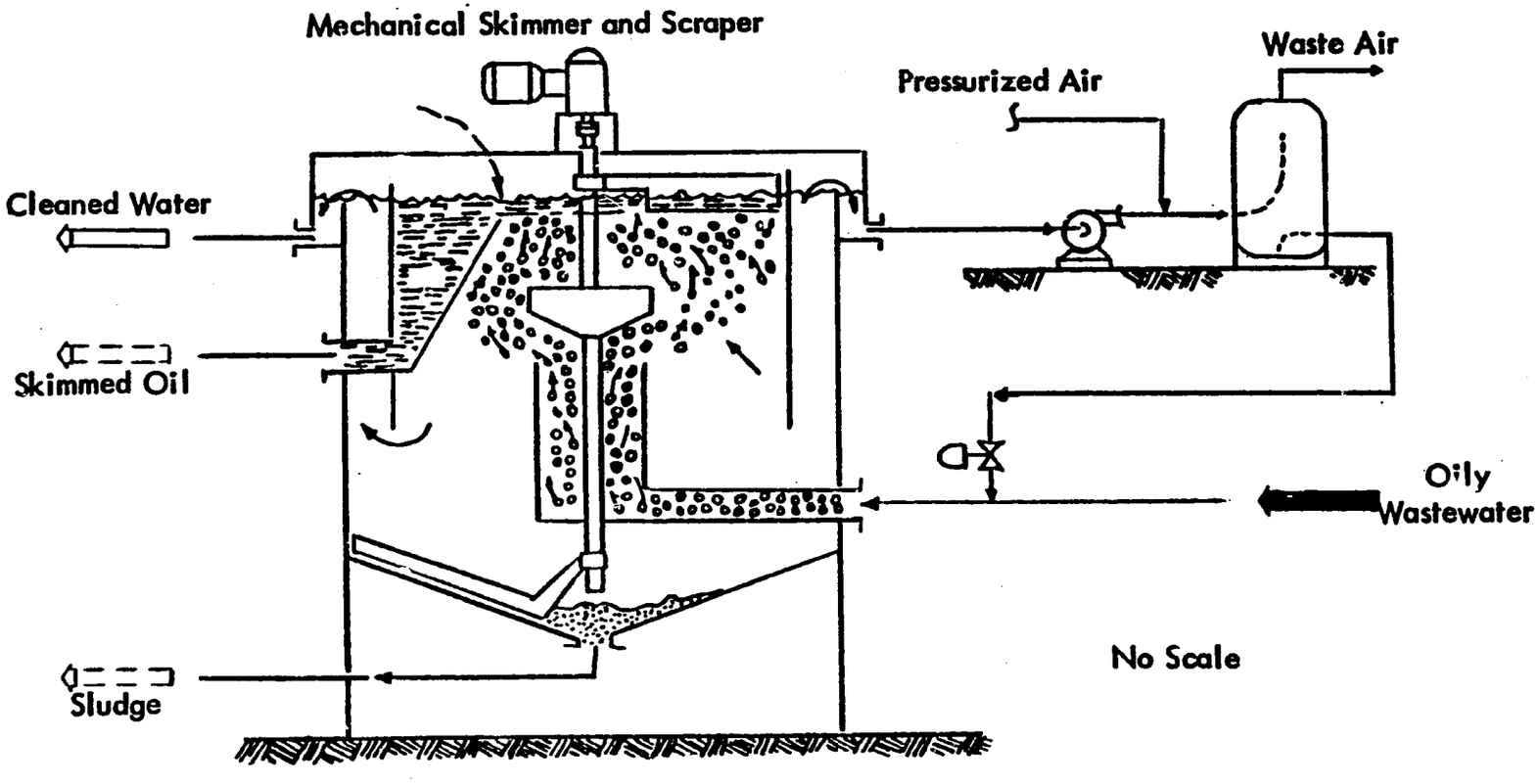


FIGURE 3-19
PRESSURE FLOTATION

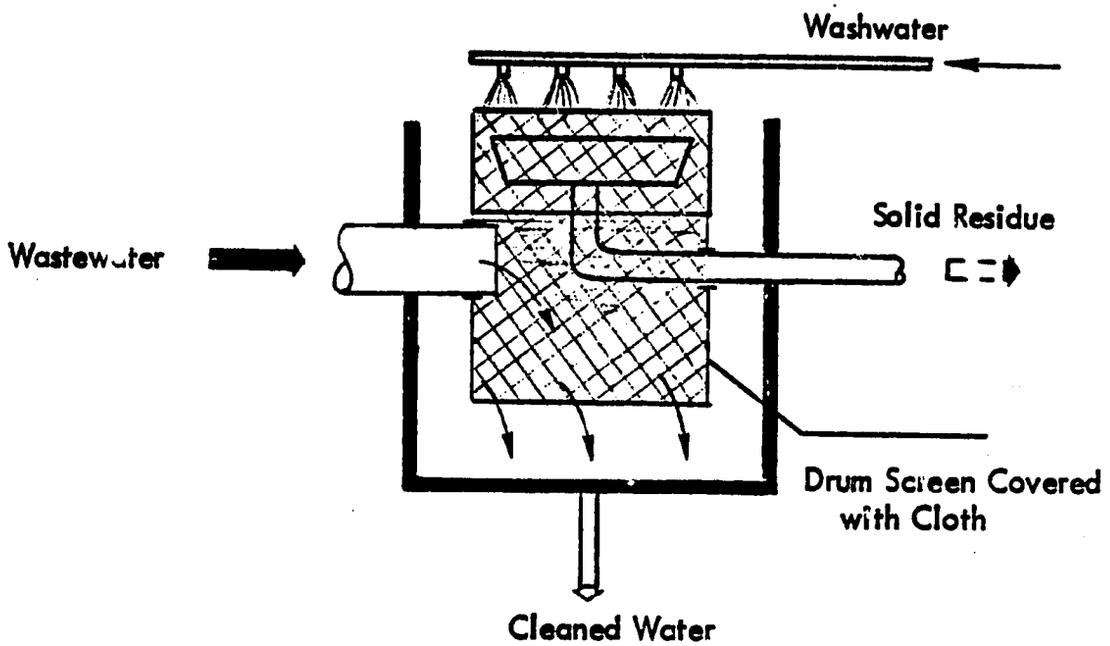


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FIGURE 3-20
ROTARY MICROSTRAINER

There are other methods for suspended solids removal: hydrocyclones (Figure 3-21), centrifuges, and vibro sieves, for example.

Secondary Treatment

Following primary treatment, wastewater still contains fine suspended solids and high concentrations of dissolved solids and organics. Secondary treatment is the removal of dissolved pollutants largely by biochemical processes. Neutralization may also be provided and the effluent is commonly disinfected. Photographs 3-4 and 3-5 illustrate two secondary biological wastewater treatment processes. Biological treatment is designed to remove the bulk of the biologically oxidizable organic matter; it uses biological organisms to decompose the organics in wastewater to simpler compounds. The degree of treatment is measured by the BOD_5 reduction.

There are several biological treatment options depending on local conditions and the specific application. The three most common methods of biological secondary treatment are the use of activated sludge, trickling filters, and oxidation ponds. Advantages and disadvantages of these processes are summarized in Table 3-12; the processes are discussed below.

Activated sludge (Figure 3-22) employs high concentrations of microorganisms to assimilate organic matter contained in wastewater. Air is supplied to the process either by compressors or mechanically (using paddles or an impeller). Aeration functions to mix primary effluent with sludge, to keep sludge in suspension, and to supply oxygen to allow biological stabilization. In a conventional activated sludge process, wastewater in a primary tank is allowed to settle, after which it is decanted and aerated for approximately 6 to 8 hours. A final sedimentation tank is then employed in which the activated sludge settles out; a portion of this sludge is returned to the primary tank.

Modifications of this general scheme include contact stabilization, and extended aeration over longer periods to reduce sluge volumes. Extended aeration (Figure 3-23) can remove more than 95 percent of the BOD_5, compared with approximately 90 percent removal for conventional activated sludge. The process also produces relatively small amounts of sludge, and the effluent tends to be milkier than conventional activated sludge effluent.

Contact stabilization, a type of activated sludge treatment, is a two-step process in which the applied BOD is first adsorbed from the wastewater for a period of from one-quarter to one-half hour, after which the micro-organisms are separated from the bulk of the liquid which leaves the plant as effluent. Before being returned to the first contact portion of the process, the separated micro-organisms are aerated for a period of 2 to 4 hours during which removal of the BOD is accomplished.

The advantages of activated sludge over other biological treatments include short retention time, flexibility in the process, minimal odor and fly problems, and relatively small space requirements. Disadvantages include high operating and maintenance costs and susceptibility to operating problems when treating certain types of industrial waste.

Oxidation ponds, also called stabilization basins, biologically stabilize either raw or primary wastewater through retention in the ponds for a period of several days to several weeks, depending on types of waste, climate, and the type of pond used. Oxygen is supplied to the process by absorption from the air and photosynthetic activities of algae

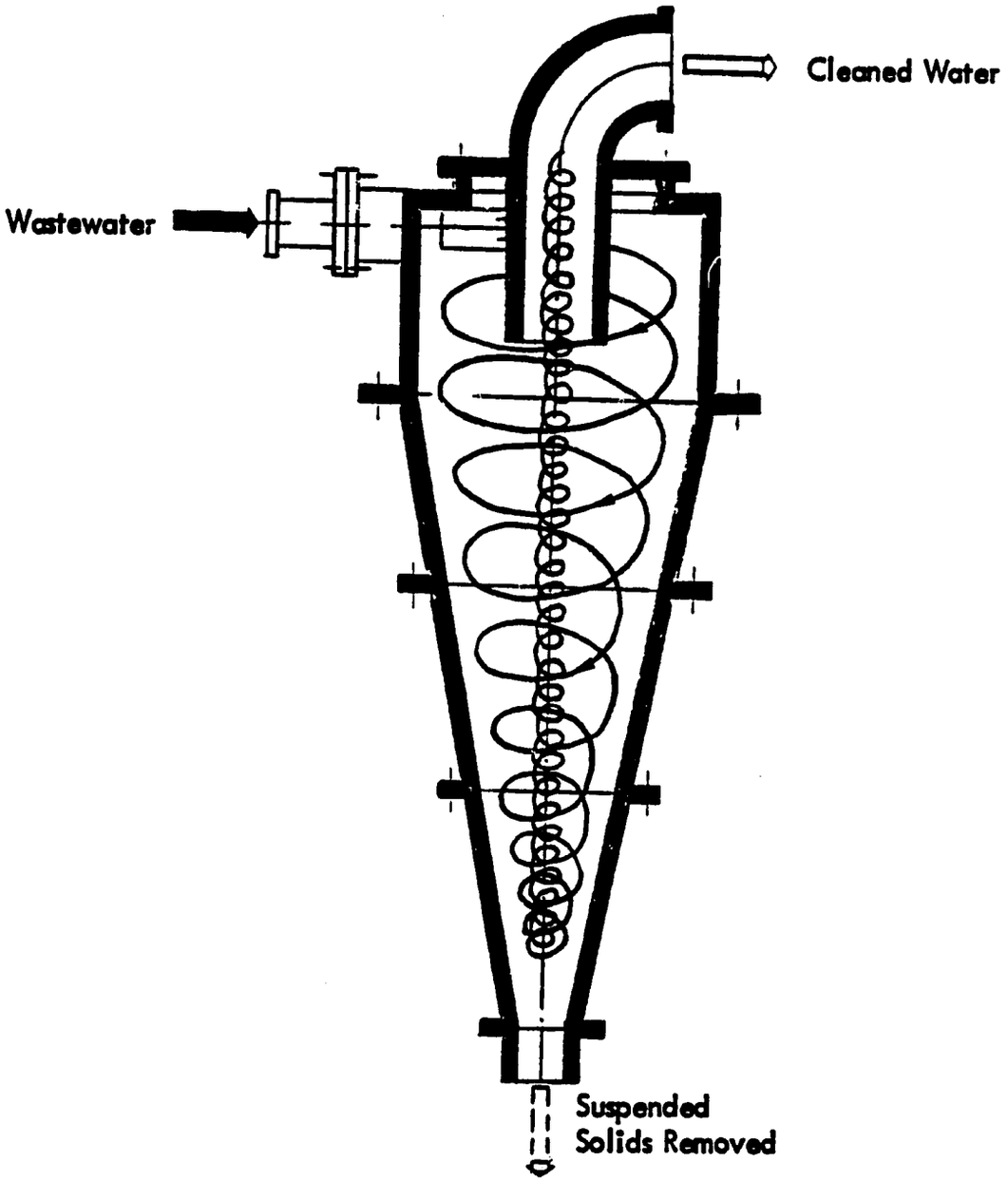

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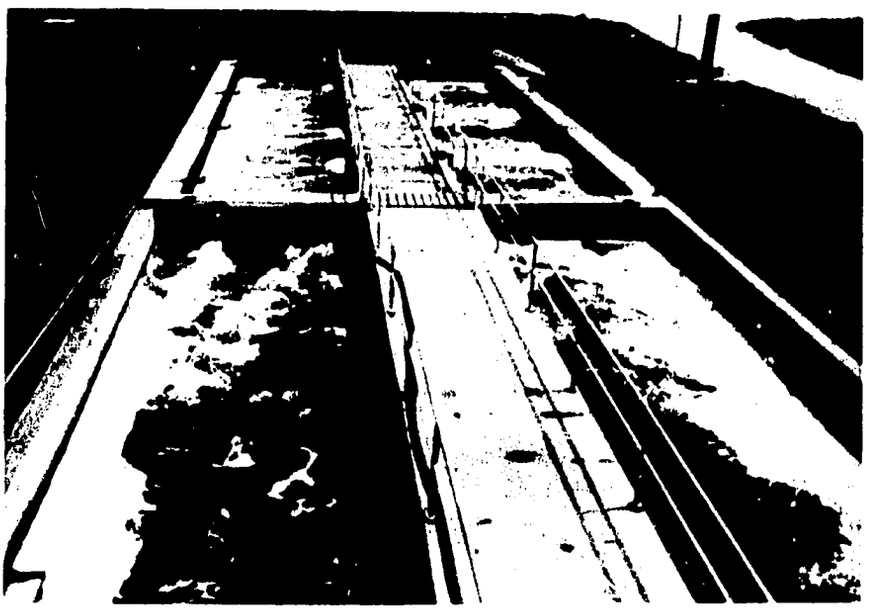
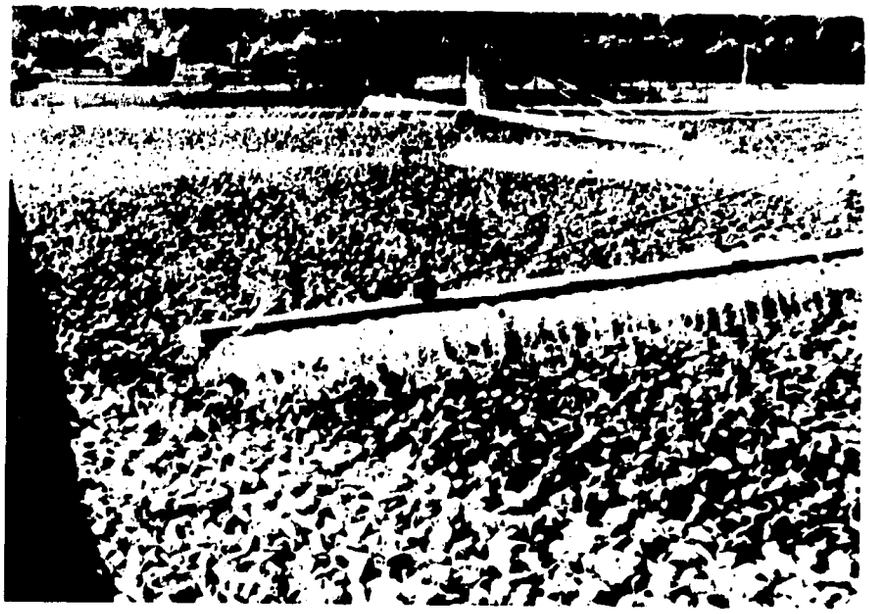
FIGURE 3-21
HIGH HEAD HYDROCYCLONE



Photograph 3-4

Activated sludge aeration tanks used in secondary biological wastewater treatment.

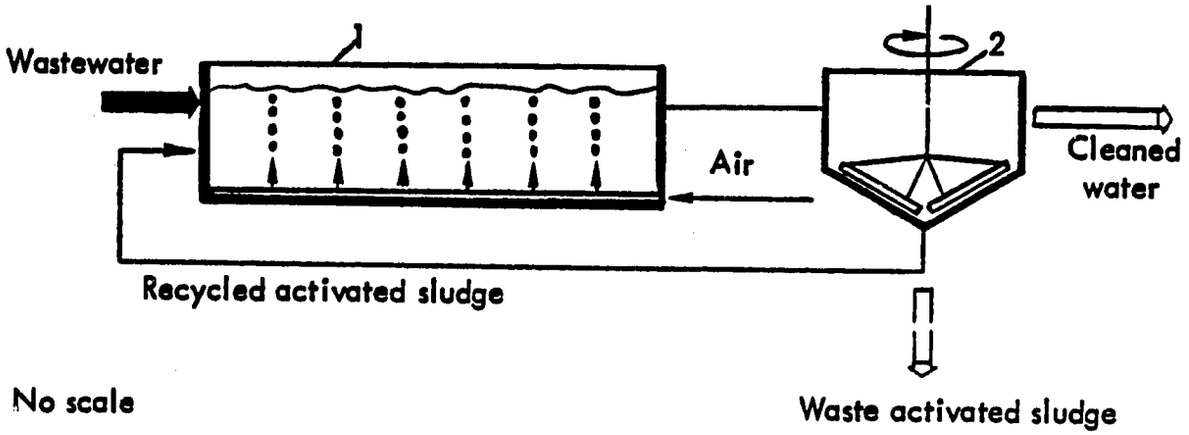


Photograph 3-5

Rotating distributors in trickling filters which are part of a secondary wastewater treatment system.

TABLE 3-12
ADVANTAGES AND DISADVANTAGES OF
SELECTED SECONDARY TREATMENT PROCESSES

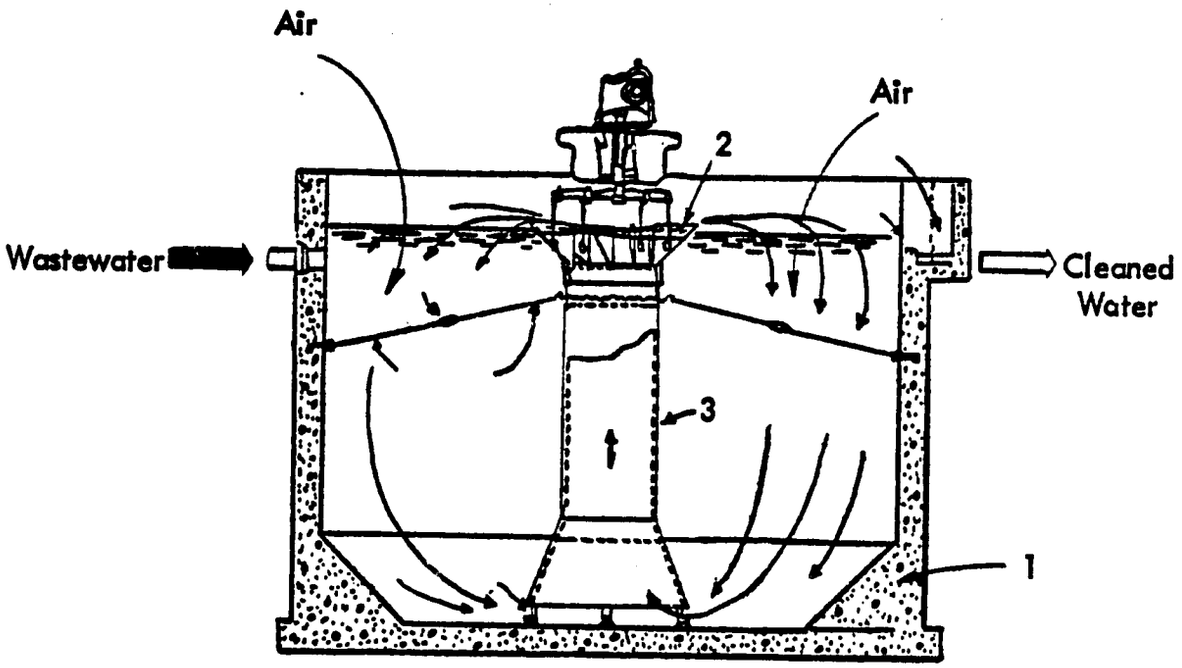
Process	Advantages	Disadvantages
Activated sludge	Flexibility Minimal odor and vector problems Compact Short retention time	High operating and maintenance costs Susceptible to operating problems
Oxidation ponds	Low construction cost Low operating costs Can be used for primary or advanced treatment	Large land requirements Produces algal BOD Effectiveness sensitive to climate
Trickling filters	Flexibility Moderate operating costs Short retention time Accommodate high intermittent waste loads	Large land requirements Insect and odor problems Only partial BOD removal
Land treatment	Flexible Low construction and operating costs High efficiency Accommodates intermittent toxic waste loads Possibility of agricultural reuse	Large land requirements May have odor or surface drainage problems



Note: 1 - Aeration basin

2 - Secondary clarifier

FIGURE 3-22
ACTIVATED SLUDGE SYSTEM



NOTE:

1. Aeration tank
2. Aerator
3. Recycling tube

Source: 67.

FIGURE 3-23
MECHANICAL AERATOR INSTALLED
IN ACTIVATED SLUDGE TANK

in the wastewater. These ponds may be used for both primary and secondary treatment, secondary treatment alone, or as a supplemental treatment following secondary treatment.

Advantages of oxidation ponds are low construction cost (if land is available and values are relatively low) and low operating and maintenance costs. Disadvantages include large land requirements (the ponds may be kept shallow to promote algal growth and provide a large aerobic surface area) and changes in treatment effectiveness with reduced sunlight or nightfall.

Biological processes in oxidation ponds may be accelerated by aeration (mechanical or pneumatic). Aeration can reduce the required retention time to 2 to 7 days, depending on specific circumstances. Aerated ponds should be operated in series, with two to four connected so that effluent from one is the influent to the next. The final pond may be used to settle out any remaining suspended solids. In this case, the final pond is usually smaller and non-aerated. A pond can also be used for chlorine contact or other disinfection. Aerated ponds are less dependent on algae growth. When sludge recirculation is employed, the ponds are similar to the extended aeration type of activated sludge process.

The trickling filter process (Figure 3-24) is another alternative biological treatment, in which wastewater is filtered through a prepared bed of rock, slag, or (less commonly) plastic media. A biologically active film of bacteria on the filtering medium stabilizes the wastewater, and a drainage system is supplied at the filter floor to collect treated wastewater. The wastewater is applied to the trickling filter uniformly, via either rotary distributor or a network of pipes. Both methods may employ natural ventilation or mechanical blowing. Trickling filters typically achieve 50-70 percent BOD_5 removal. Movable disc filters have been developed as a modification of the trickling filter process.

Advantages of trickling filters include moderate operating costs (less than activated sludge), short retention time, flexibility in the ability to treat different influent loads, and ability to absorb some toxic wastes; disadvantages include possible odor and insect problems, lower BOD removal effectiveness, and sometimes clogging of bed surfaces.

Neutralization is a process often employed where effluents are too acidic or alkaline. Acid wastes may be treated economically by addition of lime and limestones; alkaline wastes may be economically treated by addition of flue gas, sulfur, sulfuric acid, and industrial waste acids. Many other chemicals or waste products are available for neutralization of specific types of wastewaters. There are several types of neutralization facilities, such as limestone rock filters or tanks using baffles and chemical dosing (Figure 3-25). Variations of pH and the flow rate are the most important factors in determining the type of neutralization system.

Disinfection of wastewater is usually accomplished by chlorination; ozonation is an alternative disinfection method. Wastewater is usually disinfected before discharge to natural watercourses. Both these oxidants function to destroy pathogenic viruses and

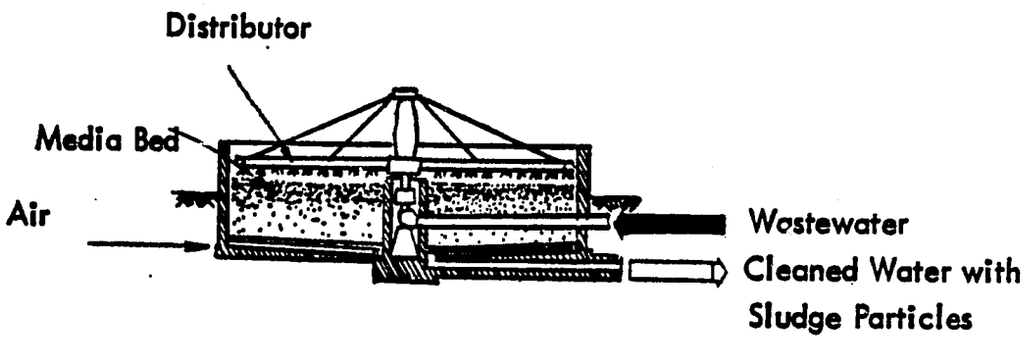


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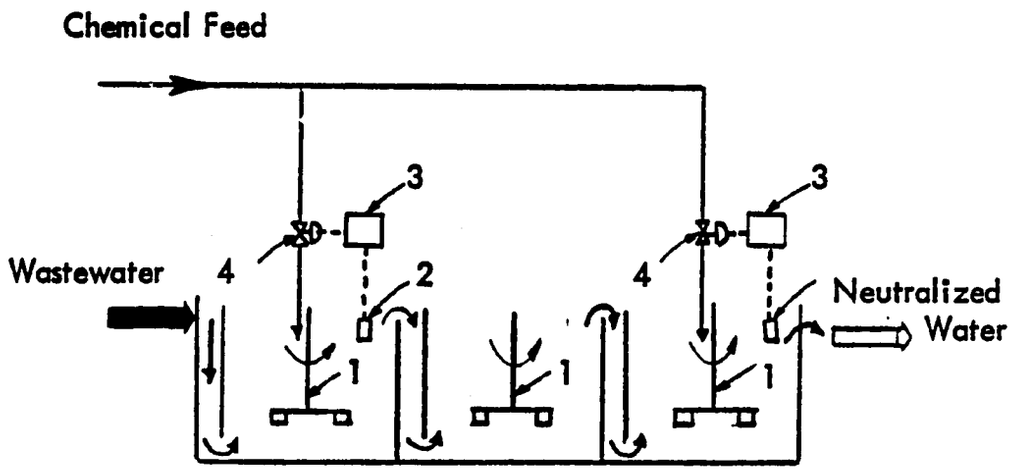
FIGURE 3-24
TRICKLING FILTER



Note:

1. Agitators
2. pH Indicators
3. pH Controller
4. Chemical Feed Valves

No Scale

Source: 43.

FIGURE 3-25
pH NEUTRALIZATION

bacteria, although virus inactivation is seldom 100 percent following disinfection. Chlorine and ozone can also be added to wastewater in higher concentrations and serve as chemical oxidizing agents.

Figure 3-26 is an example of a common vacuum chlorinator for saturating water with chlorine gas. The saturated chlorine solution must be mixed with the main stream of wastewater and then be retained in a contact basin for approximately a quarter to half an hour before discharge.

Tertiary and Advanced Treatment

Following conventional primary and secondary treatment, a wide assortment of tertiary wastewater purification processes may be used. The process choice depends on both the nature of the influent water and the uses to which the finished effluent will be put. Tertiary treatment provides for additional removal of suspended solids, organic pollutants, and dissolved inorganic compounds. Some typical tertiary treatment methods include storage reservoirs, flotation, sand or other filtration installations, flocculation, and physical-chemical treatment devices such as carbon adsorbers and ion exchangers. Polishing wastewater often permits effluent reuse for plant operations or other purposes requiring high quality water. Photograph 3-6 shows a granular carbon adsorption system.

Several possible and more costly wastewater treatment methods have been adapted from potable water purification systems. These include distillation and reverse osmosis which remove soluble minerals from the reclaimed water and create a highly concentrated brine that may cause a disposal problem. These methods may be suitable for tertiary wastewaters high in industrial wastes, if the concentrated brine can be properly disposed or recovered as a by-product. For example, reverse osmosis treatment of dairy wastes can be used to recover amino acids which can be used as animal feed. Sometimes the evaporation of highly concentrated waste solutions will allow the economical by-product recovery of fertilizers or other products. In these cases, the brines are usually recirculated and 100 percent treatment may be possible.

Several common advanced wastewater treatment processes are reviewed below.

Filtration is often used in conjunction with other treatment methods for additional solids and dissolved organics removal. Filtration may be used in physical-chemical treatment systems or as a tertiary treatment in a biological system. Sand and mixed media (with anthracite, activated carbon, etc.) are two common types of filter beds. Mixed media filters, often composed of an upper layer of select anthracite coal and a lower layer of sand, make use of the entire filter bed. They are more effective than sand filters with respect to their removal efficiency and operating time before regeneration is needed. Coagulants are often added to improve the filtration removal. Figure 3-27 illustrates a typical gravity filter.

Carbon adsorption is used primarily for removing organics. It can also be used to remove suspended solids, but then frequent backwashing is necessary. Column adsorbers with granulated carbon beds are the type most commonly used (see Figure 3-28).

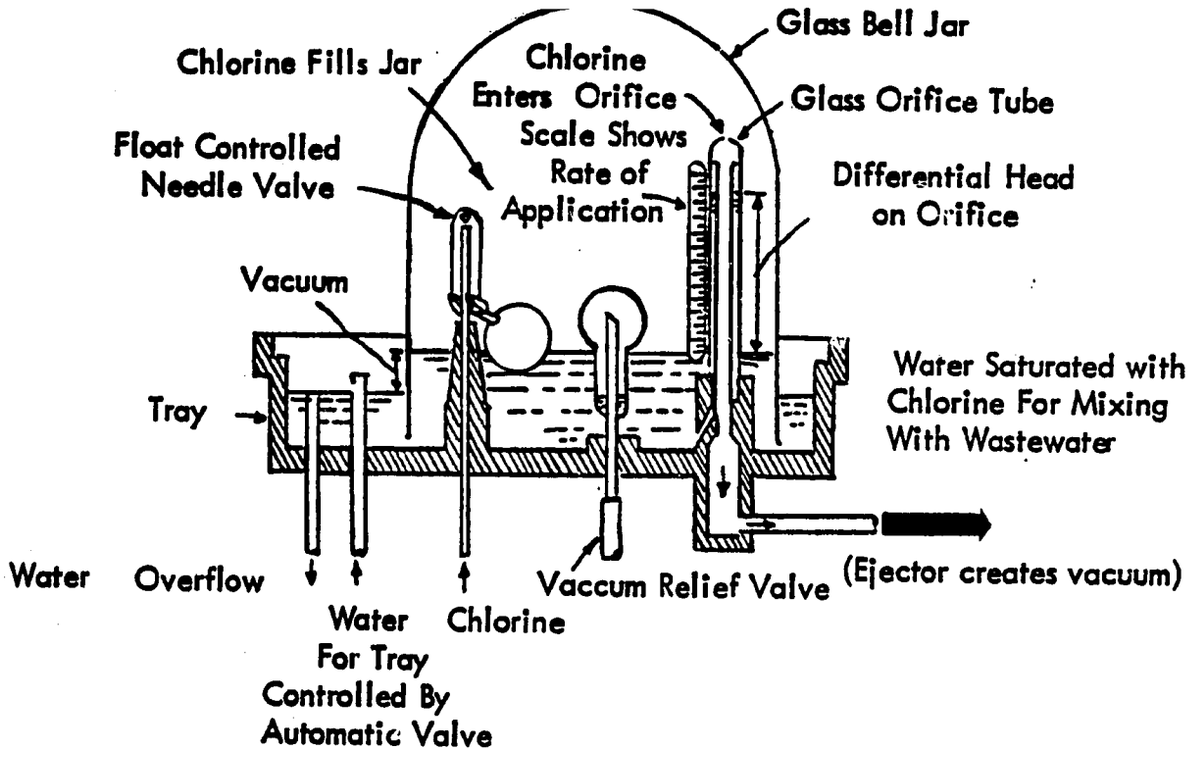


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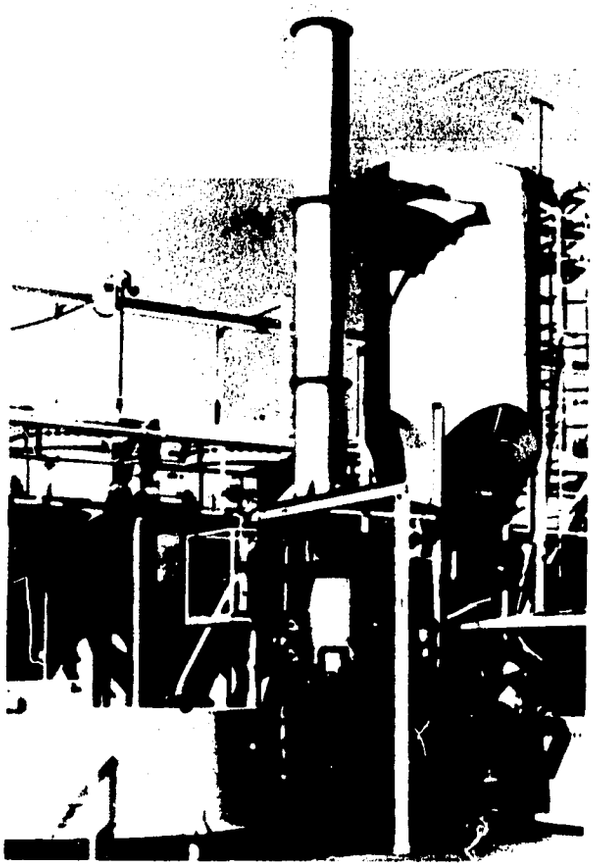
FIGURE 3-26
VACUUM CHLORINATOR



Photograph 3-6

Modern physical-chemical carbon adsorption system (test unit) for removing organic pollutants.

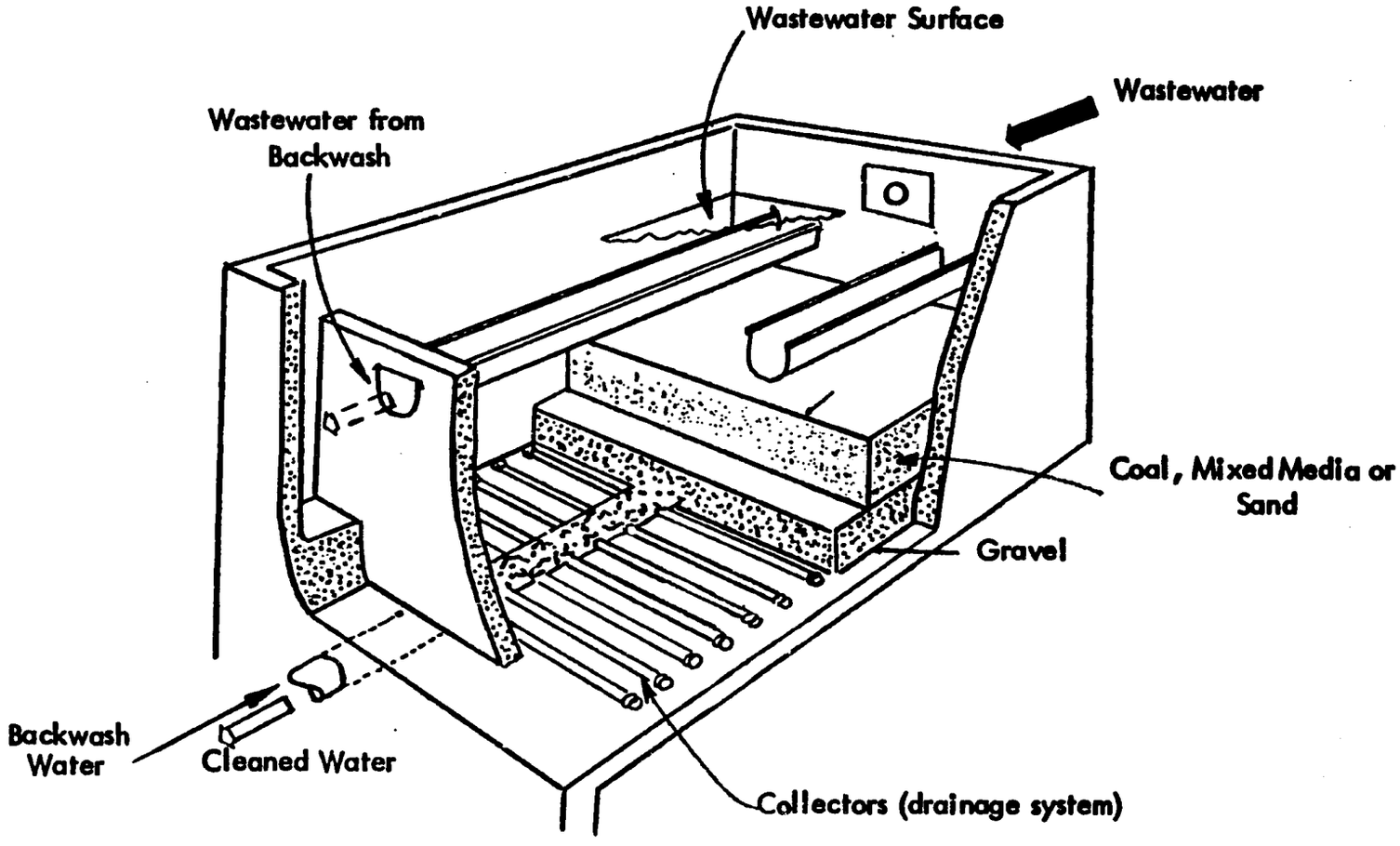


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FIGURE 3-27
GRAVITY FILTER

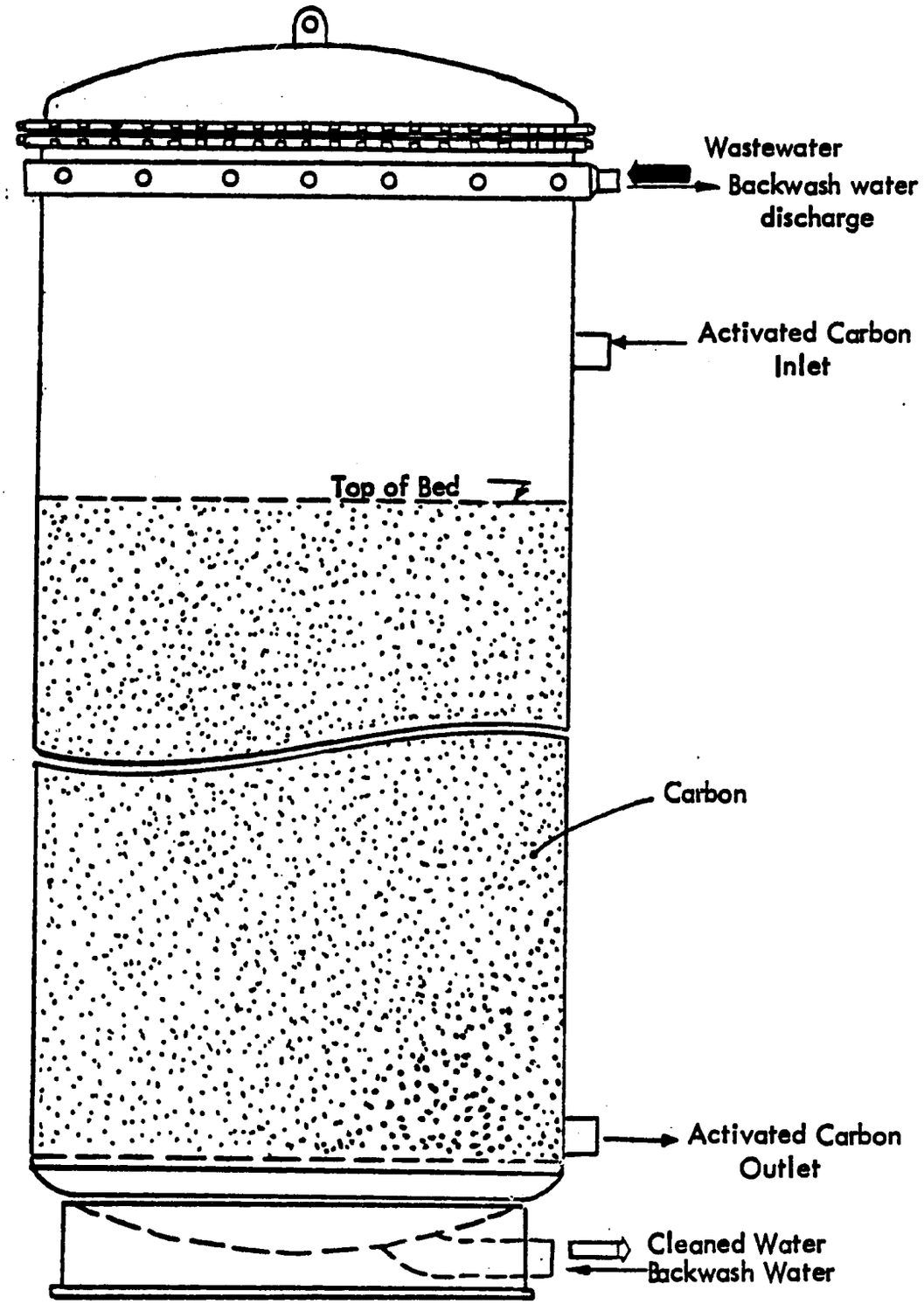

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FIGURE 3-28
DOWNFLOW GRANULAR ACTIVATED CARBON PRESSURE FILTER

Powdered carbon is also used but involves mixing and settling. The carbon is regenerated thermally, usually in multi-hearth furnaces.

Ion exchange (Figure 3-29) is used to remove dissociated inorganic and, occasionally, organic ions from wastewater. Its operation is based on the property of some resins to exchange one type of ion for the ion to be removed from the waste stream. This makes it possible for different types of exchange resins to adsorb hardness, heavy metals, nitrates, nitrites, and other compounds. Ion exchange resins can be regenerated with saturated solutions of acids and alkalines or salt and ammonia. A large installation regenerating with ammonia and nitric acid may produce fertilizer as a by-product. Partial or complete water softening or even deionization can be achieved with ion exchange.

Electrodialysis may also be used for removing inorganic and organic ions; a typical demineralization unit is shown schematically in Figure 3-30. Electrodialysis units utilize electromotive forces to transport ionized materials across semipermeable membranes separating solution chambers. An operating electrodialysis unit consists of several chambers (formed by alternating anion- and cation-permeable membranes) situated between two electrodes. The contaminated influent passes through the chambers and, under the influence of electromotive forces, the cations move toward the cathode and the anions toward the anode. Since each membrane allows only one type of ion to pass, and the membranes are alternated, no ion will be able to pass through more than one membrane. Consequently, the chambers are alternated, with half containing concentrated waste and the other half, purified water. The advantage of this method is that higher efficiency may be possible. However, demineralization is a costly method and its application has significant operating difficulties.

Reverse osmosis has been to desalinate some wastewater treatment effluents. The process is particularly useful for recovering valuable components from wastewater. Reverse osmosis installations usually follow one of two configurations: tabular membranes or planar membranes (Figure 3-31). The cellulose acetate membranes of the devices are permeable to water, but not to the common dissolved impurities in water. As the wastewater is pumped through the membranes under high pressure (up to 50 kg/sq cm), these impurities are filtered out.

Advantages of reverse osmosis treatment include (1) ion removal, (2) the universality of the impurities removed, (3) the potential for recovering valuable components from the wastewater, and (4) small space requirements. Disadvantages include (1) the quantity of concentrated brines produced, (2) the high pressure required to force the water through the membrane, (3) partial ion removal, (4) the shortened membrane lifetime if certain organic contaminants are present, and (5) relatively high cost.

Distrillation (see Figure 3-32) is a thermal evaporation method of separating salts from solution and thus can be used to purify wastewater. It involves the separation of water from the non-volatile components of a solution by conversion of the water to a vapor followed by condensation of the vapor apart from the influent. As water evaporates

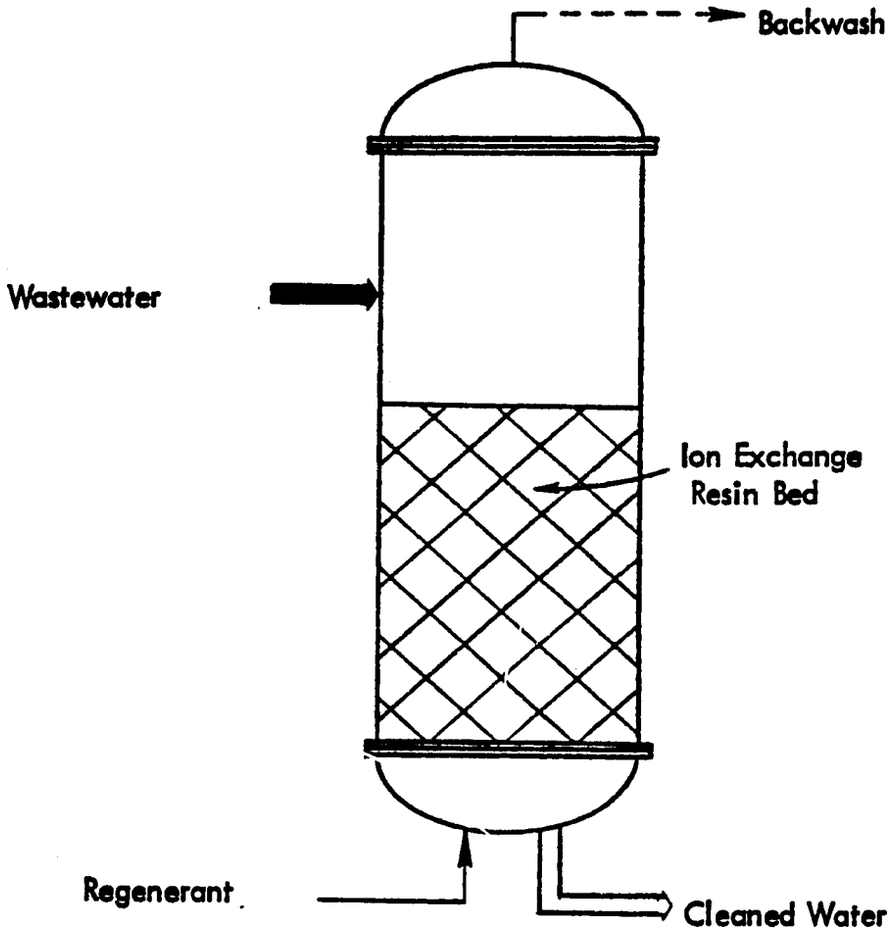

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FIGURE 3-29
ION EXCHANGER COLUMN

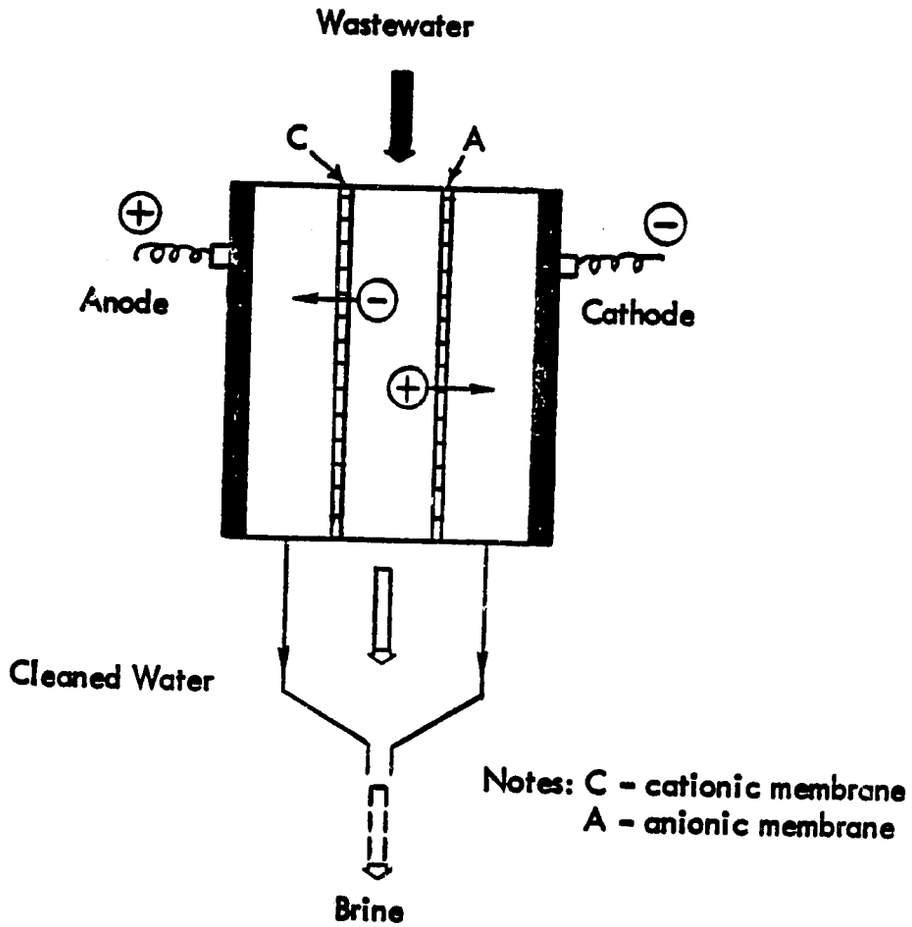

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FIGURE 3-30
ELECTRODIALYSIS
SCHEMATIC

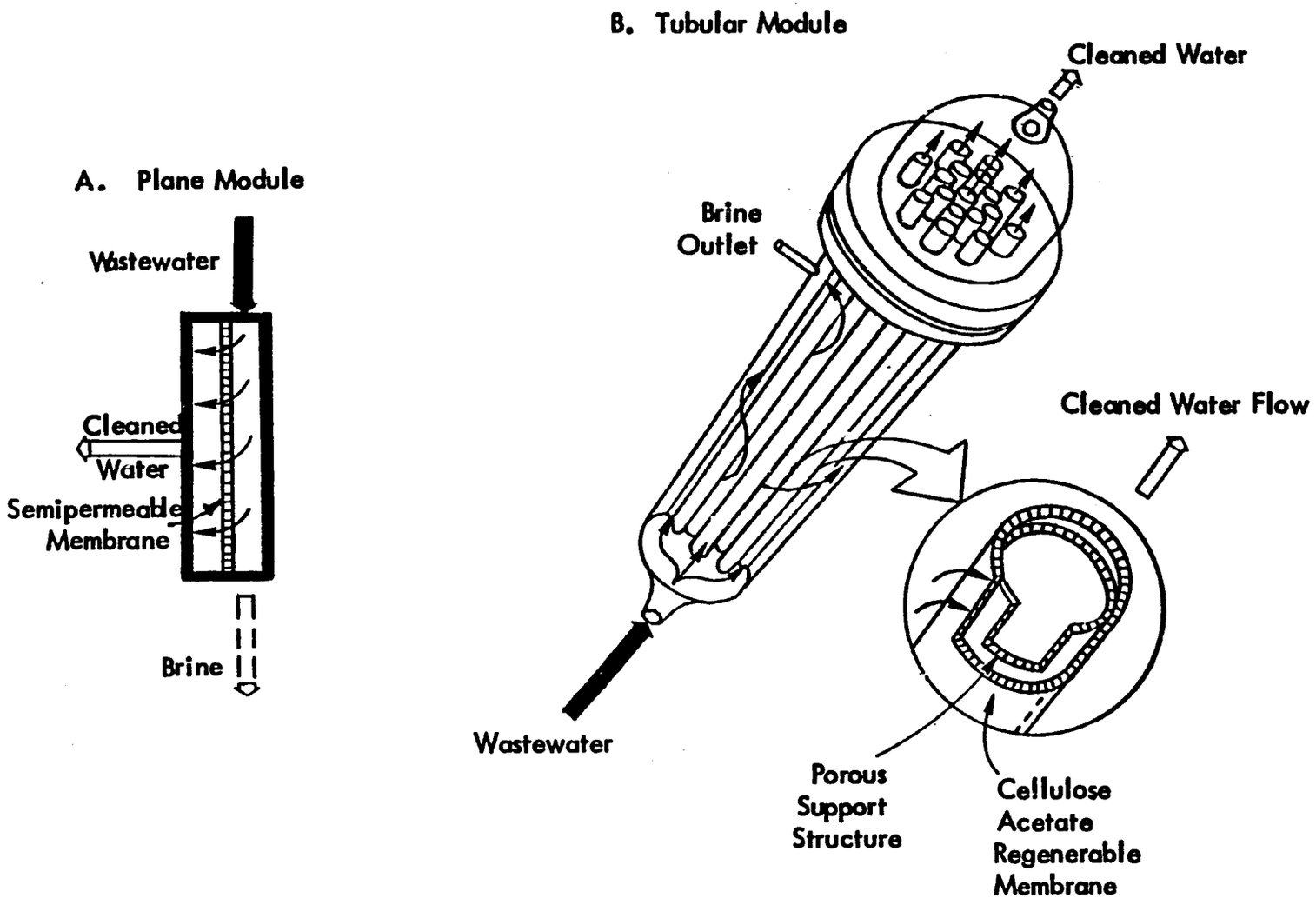

FIGURE 3-31
REVERSE OSMOSIS

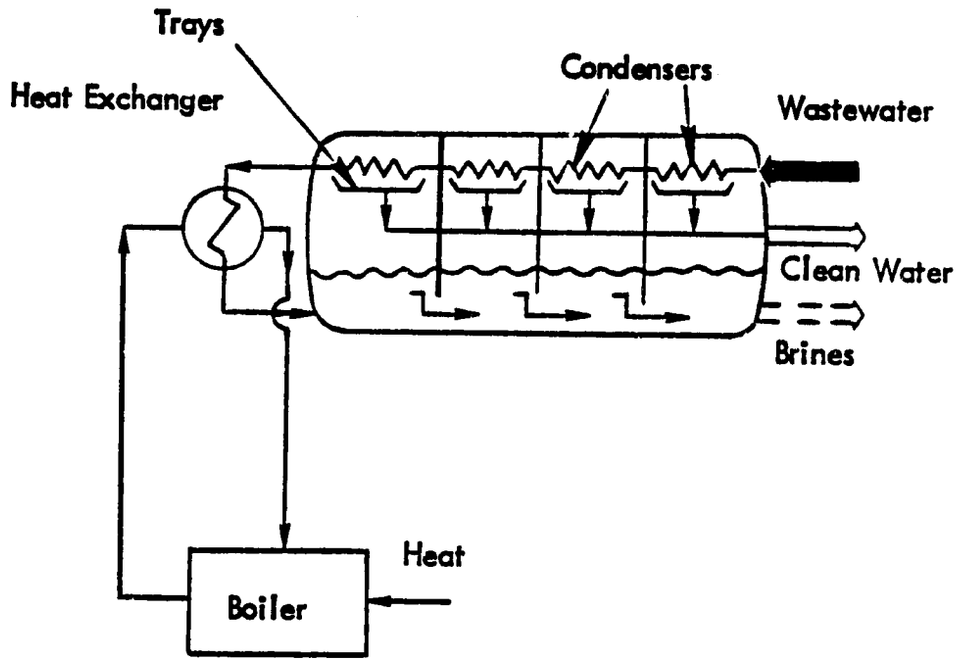

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FIGURE 3-32
FLASH DISTILLATION

in the distillation process, dissolved salts become increasingly concentrated in the remaining brine. Eventually, the concentration exceeds the solubility of the dissolved salts and scaling may result. These scales can plug piping and reduce heating efficiency and must be removed; pH and other chemical control can reduce the problem somewhat. Concentrated solutions of inorganic salts can also be very corrosive; consequently, only more expensive corrosion-resistant metals can be used in critical sections of distillation units. Ideally, distillation should provide a product water 100 percent free of non-volatile contaminants. Realistically, product waters can range from 500 to less than 1 mg/liter of dissolved solids, depending on the type of distillation system. Advantages of this process include its ability to remove all types of non-volatile organic and inorganic contaminants, potential for by-product recovery from the brine, and a potentially high treatment efficiency. The major problems associated with distillation relate to energy requirements, corrosion, scaling, and, primarily because of the first three, cost. Cost is the main constraint on more widespread application. Even though large scale facility economies do exist, the process is economically infeasible except when: (1) inexpensive waste heat is available, (2) a very high degree of waste treatment is required, (3) contaminants cannot be removed by any other method, or (4) by-product recovery is feasible and practical.

Land treatment is achieved by spreading or spraying effluent on land. The soil acts as a "living filter," purifying the wastewater as it moves downward through the biologically active mantle. The main application of land treatment is for industries with organic wastes (such as food canning, petrochemical, and meat packing, due to the system's highly efficient removal of soluble organic wastes. Grasses (such as reed canary grass) are usually planted in the treatment field to protect soils from erosion; the grass may also be used for animal grazing, hay, or sold as a crop. If crops grown on land used for industrial wastewater disposal are harvested for human consumption, toxic materials (such as heavy metals) should be controlled at their source to prevent their entering the waste stream. Otherwise, these toxic materials may concentrate in the crops. Techniques for land application include irrigation methods, overland flow, and infiltration-percolation.

Cooling of heat-containing effluent before discharge is a significant requirement for certain industrial wastewaters (e.g., power generation). Several types of installations can be used for this purpose: cooling ponds, spray basins, and cooling towers. Water evaporation is the operating principle underlying all cooling methods. Effluent can be cooled even if the air temperature is above the effluent temperature, provided the relative humidity is not too high.

Cooling ponds have relatively large land requirements, but lower capital and operating costs. Sometimes they can be used for fish farming, but this may introduce concern about fish contamination. Spray basins, because of greater air/water contact, can cool an equivalent amount of water with a smaller land requirement than a cooling pond, but their capital and operating costs will be higher. Cooling towers are compact and demand little land but have higher capital and operating costs. To obtain the appropriate draft for a given application, two types of cooling tower are available: natural

ventilation (see Figure 3-33) and forced air ventilation. Cooling towers are usually used for recirculated cooling water, with only a portion of the water discharged with each cycle. To prevent corrosion, scaling, and algal problems in recirculating cooling systems, various chemicals are usually added to the water. Because of these additives and the chemical buildup (caused by evaporation) of various mineral impurities, discharges from recirculating systems may require further treatment prior to discharge.

Sludge Treatment

Sludge buildups must be removed at regular intervals for wastewater treatments to operate efficiently. These sludges must then be further treated and disposed. Photographs 3-7 and 3-8, respectively, illustrate an anaerobic digester for sludge treatment and a centrifuge for dewatering digested sludge. These and other common methods for treating sludge are discussed below.

Sludge thickeners reduce the water content and the related volume of sludge, and therefore increase the concentration of solid material in the sludge. Flocculants are sometimes used to improve this process. Figure 3-34 shows an example of a sludge thickener.

Sludge digestion allows the sludge to decompose and stabilize prior to disposal and also reduces solids volume. In anaerobic digestion, the sludge is fermented in digestion tanks (see Figure 3-35), which encourages decomposition. Heat is often added to speed the process. Liquid drawn off from a digester is generally returned for primary treatment, while combustible gases produced (primarily methane) may be burned or used for fuel. Potential disadvantages of anaerobic digestion include odors, corrosion, upsets from toxic metals, long detention times, and cost. Aerobic stabilization may be used as a quick substitute for slow anaerobic digestion. It is performed in conjunction with contact stabilization or extended aeration, both modifications of the activated sludge process. Construction of aerobic stabilization tanks is the same as for aeration tanks for the activated sludge process. The disadvantages of aerobic digestion include extra energy requirements.

Vacuum filtration is one method of dewatering sludge after anaerobic digestion. A schematic of a typical vacuum filter is shown in Figure 3-36. It includes a vat and a drum covered with cloth. Under force of a vacuum, suspended solids accumulate on the filter cloth surface. This layer of solids, called cake, is dried and removed from the drum. Alternatives to dewatering by vacuum filtration are incineration, air drying, press filtration, and centrifuging. To improve water reduction, coagulants and flocculants are sometimes used in the dewatering process.

Lagooning of sludge is often used to increase solids content, the lagoons consisting of natural earth basins. If low-cost land is available, lagooning can be a very inexpensive method of further treating sludge. Characteristics of the site which must be taken into account before lagooning is implemented include topography, climate, soils, and geologic conditions. Potential disadvantages of lagooning are long detention times and odor generation. Figure 3-37 shows a cross section schematic of a facultative lagoon.

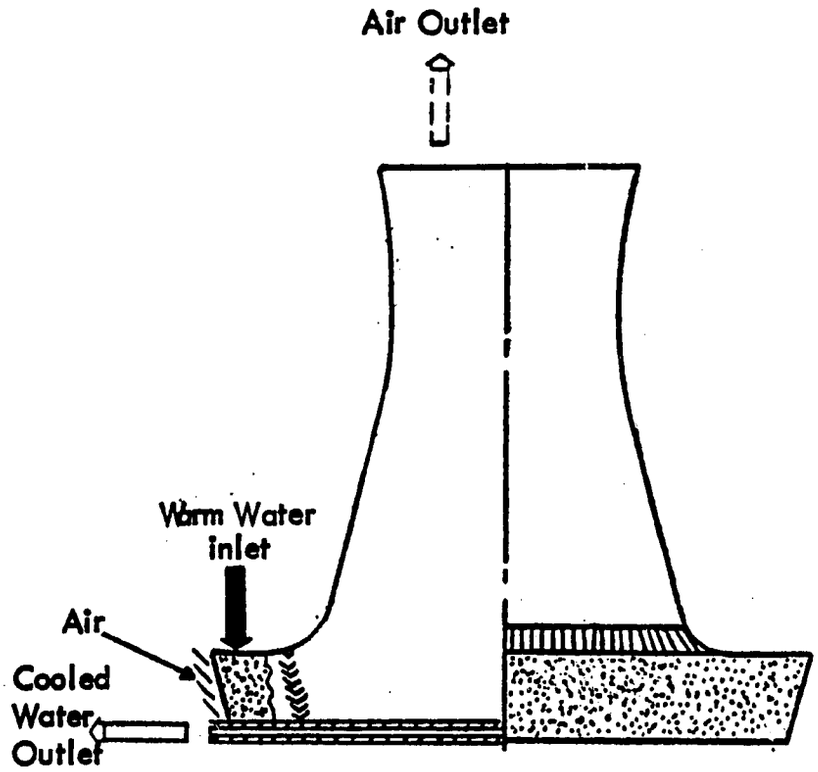

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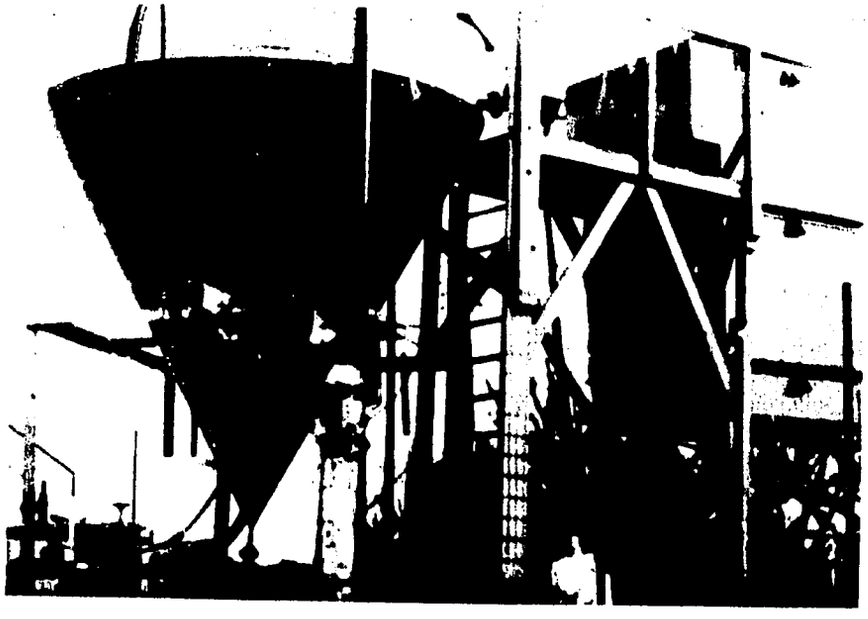
FIGURE 3-33
COOLING TOWER



Photograph 3-7

Anaerobic digester for treating sludge removed from wastewater.

Photograph 3-8

Centrifuges used to dewater digested sludge solids.

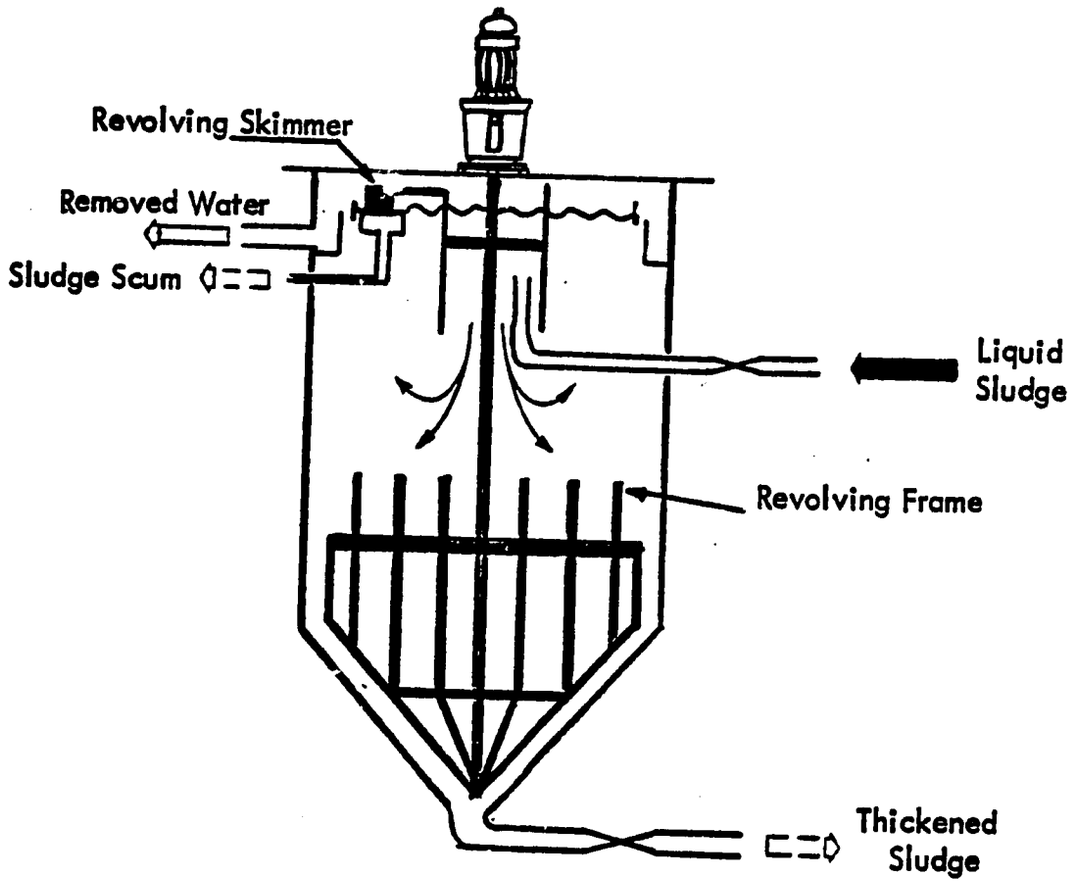


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FIGURE 3-34
GRAVITY SLUDGE THICKENER

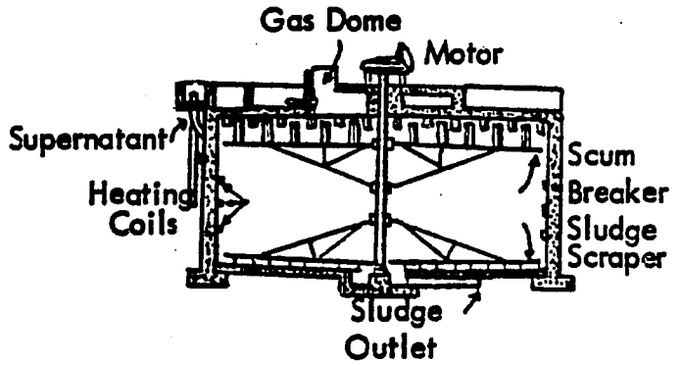

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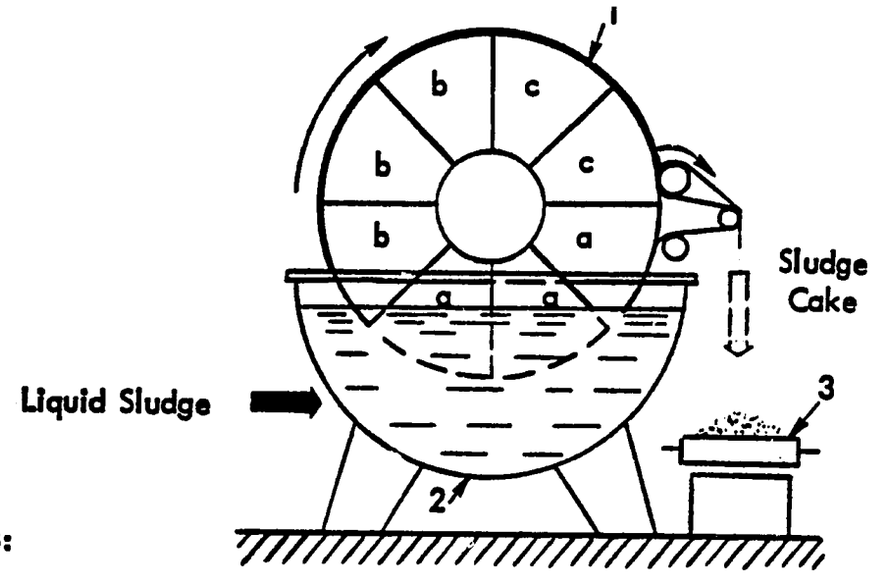
FIGURE 3-35
ANAEROBIC SLUDGE DIGESTER



Notes:

1 - Drum covered with cloth
2 - Vat
3 - Conveyor
a - Cake formation zone
b - Dewatering zone
c - Pressurized air separation zone

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FIGURE 3-36
VACUUM FILTER
SCHEMATIC

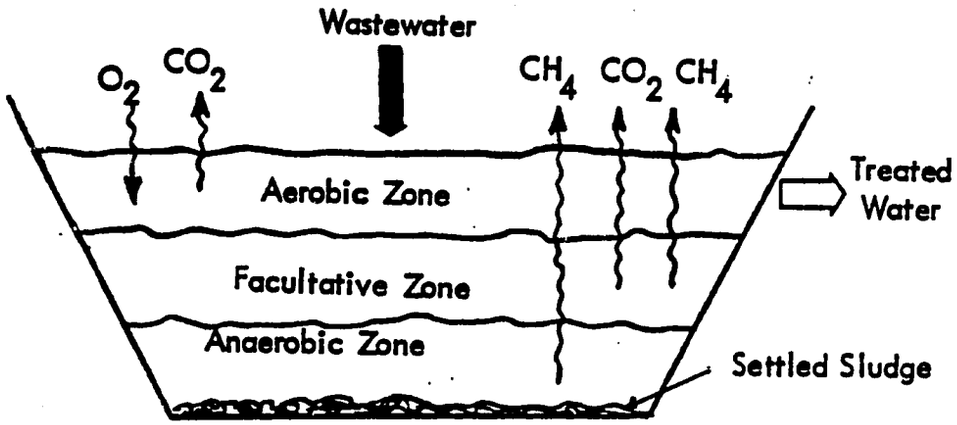

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FIGURE 3-37
FACULTATIVE LAGOON
CROSS SECTION

Sludge Disposal

Common methods of sludge disposal include incineration, land spreading, landfilling, sale as a fertilizer or soil conditioner, or ocean disposal. Incineration may be performed by a multiple-hearth furnace (see Figure 3-38). Dewatered and dried sludge is fed into the upper part of the furnace for additional drying and then burned in the middle portion. The lower part of the furnace is for cooling the ash and preheating the combustion air to be introduced in the combustion area. Incineration has higher capital and operating costs than the other disposal methods, but may be the preferred method where sale or ocean disposal are infeasible for environmental or other reasons and low-cost land is not available for land spreading or landfilling. Large volumes of sludge may also be used to reclaim barren land such as former strip-mined areas. Although the sludge is capable of reclaiming land for more productive uses, runoff, odors, and pathogens represent potential problems.

All four sludge disposal alternatives involve some potential environmental risks. Incineration generates air pollutants to be controlled and the ash will require careful land disposal. Land spreading or landfilling the sludge or the ash poses problems of leachate control and possible ground or surface water contamination. Ocean disposal creates water pollution problems. And agricultural reuse may cause water pollution problems and problems of plant uptake of pollutants. The choice among methods will depend on cost, environmental impact considerations, and characteristics of the specific sludge to be disposed of.

Alternative Wastewater Treatment Options

General considerations concerning suitable treatment methods based on the type and concentration of impurities present in the wastewater are presented in Table 3-13. The information in the table should be considered illustrative only. The appropriate treatment system for a given industrial plant will depend on many specific factors. Table 3-14 is a sample worksheet of data which may be useful in the design of a water supply, reuse, and treatment system. Similar data should be collected for air pollution control and solid waste management (Tables 3-5 and 3-17) to develop an integrated pollution control program for the individual industrial plant.

SOLID WASTE POLLUTION

SOURCES AND TYPES

Origin of Industrial Solid Wastes

Industrial solid wastes are generated by production activities and as residues of waste treatment methods. There is an interrelation between solid wastes and liquid residues. Wastes that are processed and disposed of as solid residues may have originated as liquids or gases depending upon their moisture and temperature. For example, air and water pollution treatment methods produce organic and mineral sludges which require

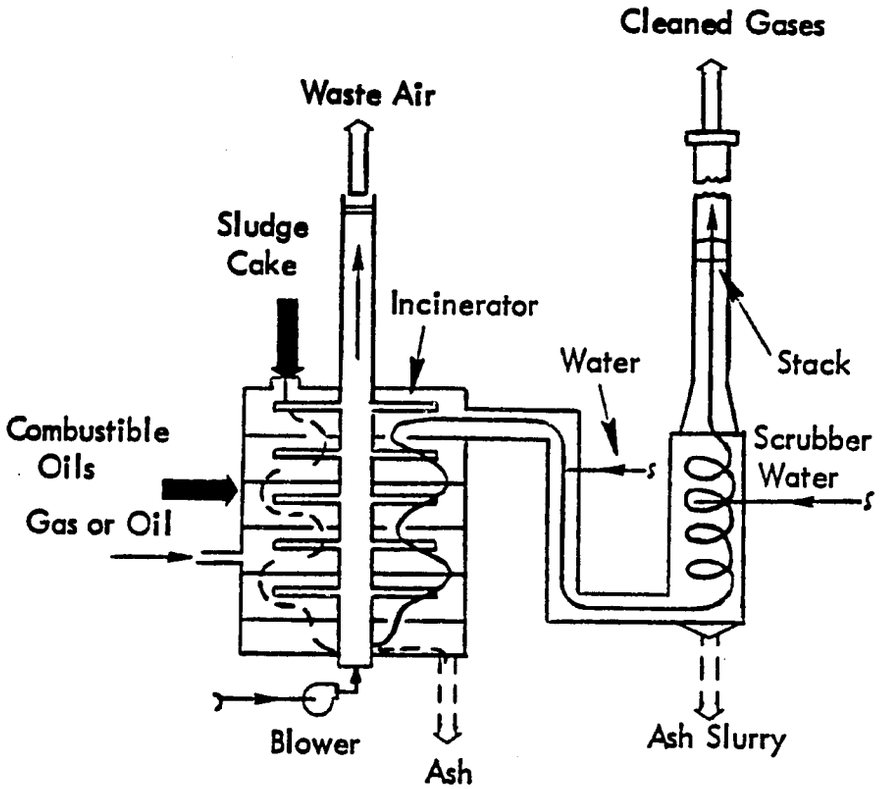

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FIGURE 3-38
SLUDGE INCINERATOR
(MULTIPLE HEARTH)
CROSS SECTION

TABLE 3-13

WASTEWATER TREATMENT OPTIONS

Concentrations (mg/l)	Organic Compounds			Inorganic Compounds
	Boiling Point (110 - 120 C)	Boiling Point (180 to 250 C)	Boiling Point (about 250 C)	
1 - 500	Biochemical, chemical treatment; sorption		Chemical treatment; sorption	Sorption; ion exchange; chemical precipitation
500 - 5,000	Chemical treatment (ozonation, chlorination); sorption; liquid phase oxidation with biological treatment; incineration	Chemical precipitation, coagulation, oxidation; extraction; liquid phase oxidation with biological treatment; incineration	Sorption; extraction; chemical precipitation, coagulation, and oxidation; liquid phase oxidation with biological treatment; incineration	Sorption; ion exchange; evaporation; chemical precipitation
5,000 - 30,000	Chemical methods; extraction; liquid phase oxidation with biological treatment; incineration			Evaporation; distillation; ocean disposal; land disposal; deep well injection; drying in fluidized bed
Above 30,000	Extraction; incineration	Extraction; incineration	Extraction; incineration	Same as above

TABLE 3-14

WATER POLLUTION WORKSHEET

I. Plant Site

A. Description of Manufacturing Process

B. Products Manufactured

C. Plant Capacity

D. Plant Operation: _____ hr/day _____ days/wk

E. Raw Materials Requirements

F. Number of Employees

Mat'l	Qty	Storage		Pollution Potential			
	Kg/day	Type	Capacity	Suspended Solids	Dissolved Solids	Aesthetic	Hazards

F. Pollutants by Water Use

Biological and Recreational Use

Source	Operation		Effluent Rate	Frequency of Release	Duration of Release	Pollutants						Length of Effluent Pipe In Water + Effective Independent Flow Distance of Effluent	Product Recovery	Type Treatment
						Nutrients		Toxins		Suspended Solids				
	Flow Rate	Temp.	Kg/day			Type	Kg/day	Type	Kg/day	Type	Kg/day			

TABLE 3-14 (Cont.)

Industrial and Municipal Uses

Source	Operation		Effluent Flow	Frequency of Release	Duration of Release	Pollutants														Length of Effluent Pipe In Water + Effective Independent Flow Distance of Effluent	Product Recovery
	Flow Rate	Temp.	l/day			BOD		Floatables		Settleable Solids		Suspended Solids		Total Dissolved Solids		Oils and Grease		Other			
						Amt	Type	Mg/l	Type	Mg/l	Type	Mg/l	Type	Mg/l	Type	Mg/l	Type	Mg/l			

G. Treatment
   1. Segregation or Elimination of Pollutants by Process Change
   2. Substitution of Raw Materials
   3. Value of Recovered Product
   4. Possible Improvements to Existing Effluent System

H. Existing or Planned Pollution Control Equipment
   1. Type
   2. Description
   3. Supplier
   4. Design Capacity (quantity of flow, percentage removal)
   5. Standby Facilities

I. Available Plant Facilities
   1. Area and Location for Control System
   2. Utilities
      Electricity: _____ Kw/hr
      Process Water: _____ l/m @ _____ Kg/Cm^2, _____ °C
      Cooling Water: _____ l/m @ _____ Kg/Cm^2, _____ °C
      Gas & Oil: _____ l/hr of _____.
   3. Waste Treatment
      Plant Facilities
      Municipal Facilities
      Other Facilities

TABLE 3-14 (Cont.)

Sampling

Sample Point	Sampling Methods	Required Tests	Frequency	Stability of Pollutants	Shipping Requirements

II. Site Restrictions

A. Drainage
   1. Map
   2. Seasonal Flow Rates and Flow Contours at Discharge Points
   3. Existing Pollution (chemical, thermal, suspended solids)

B. Hydrology and Hydrogeology
   1. Streams, Rivers, and Lakes
   2. River Flow Rates and Variations
   3. Water Levels and Variations
   4. Consumers of Water from These Reservoirs
   5. Nearest Consumer Downstream
   6. Nearest Hydrological Data Collection Office
   7. Underground Water Sources, Their Quantity and Quality
   8. Quality of Natural Water Sources

C. Aquatic Life
   1. Species Population and Distribution
   2. Pollutant Tolerances
   3. Commercial Species
   4. Unique Species

D. Recreation
   1. Existing
   2. Projected Future

E. Municipal and Industrial Demands on Water Resource
   1. Amount by Use
   2. Tolerance Limits for Pollutants by Use
   3. Future Demands by Use

F. Government Regulations

disposal. The organic sludges are usually digested and dewatered; this leaves a solid residue of low moisture content which may be incinerated, landfilled, or used as a soil conditioner. The mineral sludges are usually dewatered, dried, and disposed of by landfilling in a "secure" (non-polluting) location. Sawdust, shavings, or metallurgical slags are generated as solids. Spent vat or still solutions from chemical or petrochemical plants are highly concentrated wastes that may contain little liquid. Particulates separated from gaseous waste streams are a source of solid residues.

Solid Waste Classification

Residue classification is a necessary preliminary to the design of solid waste management facilities. Solid wastes that are processed by incineration may be classified by moisture content. Table 3-15 presents a simple general solid waste classification method that summarizes moisture, energy, and incombustible solids characteristics. Industrial solid waste composition may be categorized by these parameters.

The waste classification will indicate the appropriate recovery or disposal possibilities. For example, Table 3-15 shows that trash and rubbish may be burned without additional fuel and may even allow some heat recovery. Refuse and garbage may be biologically composted or burned with additional fuel.

Due to recent successes in the recovery and reuse of industrial solid wastes, however, a more useful classification is based on the relative ease with which solid wastes can be recovered. Both convertible and directly recoverable solid wastes can be reused instead of disposed. Convertible wastes, however, must be changed into a suitable chemical form before reuse, whereas recoverable wastes can be reused in their existing form.

Non-recoverable wastes may be further categorized according to their degree of biodegradability, combustibility, and hazard. These factors are important for the choice of processing and disposal technology. Hazardous wastes (e.g., pesticide wastes, munitions wastes) pose particular problems for ultimate disposal. The primary hazards associated with solid wastes are fire, public health effects, toxicity to other fauna and flora, and reactivity with other chemicals.

INDUSTRIAL SOLID WASTE MANAGEMENT

Solid waste systems employ some or all of the following steps:

- On-site gathering and storage
- Collection and transport
- Processing (sorting, shredding, compacting, and baling)
- Resource recovery
- Disposal

TABLE 3-15
SELECTED INDUSTRIAL SOLID WASTE CATEGORIES

Description	Moisture Content (%)	Incom-bustible Solids (%)	Energy Content (kcal/kg)
TRASH: a mixture of highly combustible waste; paper, cardboard cartons, wood boxes, and combustible floor sweepings, from commercial and industrial activities. Contains up to 10% by weight of plastic bags, coated paper, laminated paper, treated corrugated cardboard, oily rags and plastic or rubber scraps.	10	5	4,700
RUBBISH: a mixture of combustible waste; paper, cardboard cartons, wood scrap, foliage and combustible floor sweeping, from commercial and industrial activities. Contains up to 20% by weight of restaurant or cafeteria waste, but little or no treated papers, plastic or rubber wastes.	25	10	3,600
REFUSE: a mixture of rubbish, garden trimmings, and garbage.	50	7	2,391
GARBAGE: animal and vegetable wastes from restaurants, cafeterias, clinics, markets, and like installations.	70	5	1,400
ANIMAL RESIDUES: carcasses, organs, and solid organic wastes from food processing, abbatoirs, laboratories, wastewater treatment plants, etc.	85	5	600
BY-PRODUCT, LIQUID OR SEMI-LIQUID RESIDUES: tars, paints, sludges, oils, etc., from industrial operations.	Varies	Survey Required	
SOLID BY-PRODUCT RESIDUES: rubber, plastics, wood waste, etc., from industrial operations.	Varies	Varies	Varies
TOXIC AND HAZARDOUS WASTES: radioactive, chemical, explosive, pathogenic, or other materials requiring special handling and disposal.	Varies	Survey Required	

The first two steps usually have minimal long-term environmental impact. Processing is important primarily as it impacts on disposal alternatives. Resource recovery can reduce the quantity of wastes requiring processing and disposal. Some options for processing, resource recovery, and disposal are shown in Table 3-16 along with their approximate cost range.

Processing. Large pieces of solid waste can be converted into small convenient sizes by equipment such as shredders, crushers, grinders, chippers, rasps, hammermills, rasp and disc mills, and drum pulverizers. Shredders, for example, usually consist of a high-speed rotor (rotating wheel) with attached steel hammers or other cutting devices enclosed in a housing. The rotating mechanism "shreds" the waste into smaller particles.

Shredded material is more uniform in composition, easier to handle automatically for resource recovery, incineration, or land disposal. Shredding for landfill disposal increases the waste compaction, and reduces odor, windblown debris, and scavenger problems. It also can reduce the bulk refuse volume by about 50 percent and makes transport easier and less costly. The disadvantages of shredding are its increased costs, equipment maintenance requirements, elevated noise levels, and explosions within the plant.

Balers and compactors are also used to reduce the residue volume and increase the density of solid waste. Balers compress loose materials into compact bundles which are usually tied with fiber or metal binding. Compactors reduce bulk in a fill area by rolling and tamping. Compaction allows more waste to be disposed of in a given area.

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TABLE 3-16

PROCESSING, RECOVERY, AND DISPOSAL OPTIONS: COST

Method	Cost Range ($/kkg)
Processing	
Shredding	5-6
Baling	4-7
Resource recovery	
Pyrolysis	
Composting	5-10
Disposal	
Incineration	10-30
Ocean dumping	0.1- 2.0
Land disposal	1- 7

Source: 108.

Resource Recovery.

Most industrial wastes are derived from unwanted raw materials or final produce residues. Some industrial solid wastes are of relatively uniform composition, and may be directly reused for making new products. For example, metallurgical slags can be reclaimed in brick production; power plant fly ashes can be used as an addition to cement or bituminous materials; and sawdust can be used to make fiberborad products or as a source of organic chemicals. (See Photograph 3-9).

Composting is a controlled biological process by which organic cellulose wastes are partially decomposed by organisms, with the production of carbon dioxide, water, some heat, and a more stable solid organic residue. Figure 3-39 shows a composting plant. The process requires some old compost starter, new wastes, air, moisture, periodic mixing and time. The addition of commercial fertilizers can improve the nutrient value of the final product. Inert materials such as metal are usually reclaimed, and the organic matter (compost) is used as a conditioner-type soil amendment. This process may be particularly applicable for tropical climates, where ample vegetable wastes combined with moisture and heat will hasten the decomposition processes. Compost may improve soil structure, moisture, aeration and fertility for difficult sandy or lateritic soils sometimes found in tropical, arid or other regions.

Pyrolysis is a new method of treating organic solid wastes through dehydration by heating in the absence of oxygen. Useful products such as oil, coke, tar, and activated carbon are produced. Pyrolysis is not an economically proved system and may generate other gaseous or liquid waste products that require special handling for disposal.

Final Disposal.

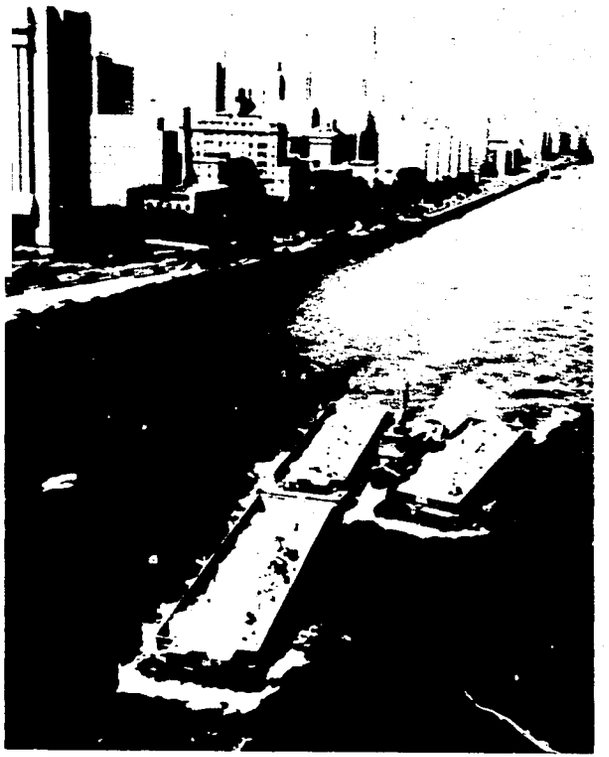
Solid wastes are ultimately disposed to air, land, or water, or reduced through burning. Ocean or lake dumping is a simple, inexpensive method of disposal. However, it can harm aquatic life and create other environmental problems. As a result, this method is generally unacceptable. (See Photograph 3-10.)

Land disposal has historically been the principal method of disposal; it is generally less costly than incineration and it is applicable to most land areas. Until recently, land disposal of solid wastes was largely through unregulated open dumping. Without proper site selection, engineering design, monitoring, and maintenance, land disposal may create a public health hazard from rats, flies, surface and groundwater contamination, and fires. Open dumping may also cause litter and odors, and limit the normal use and value of land. For these reasons, sanitary landfilling methods are preferable to open-dumping. (See Photographs 3-11 and 3-12.)

Figure 3-40 shows a section view of a sanitary landfill. Solid waste is spread in 120 cm thick layers which are continuously covered with soil (about 15 cm thick) at the end of each day. Each cell of waste and of soil is compacted as it is put in place. A top soil finish layer about 0.6 m in depth is added when the site is completely full.

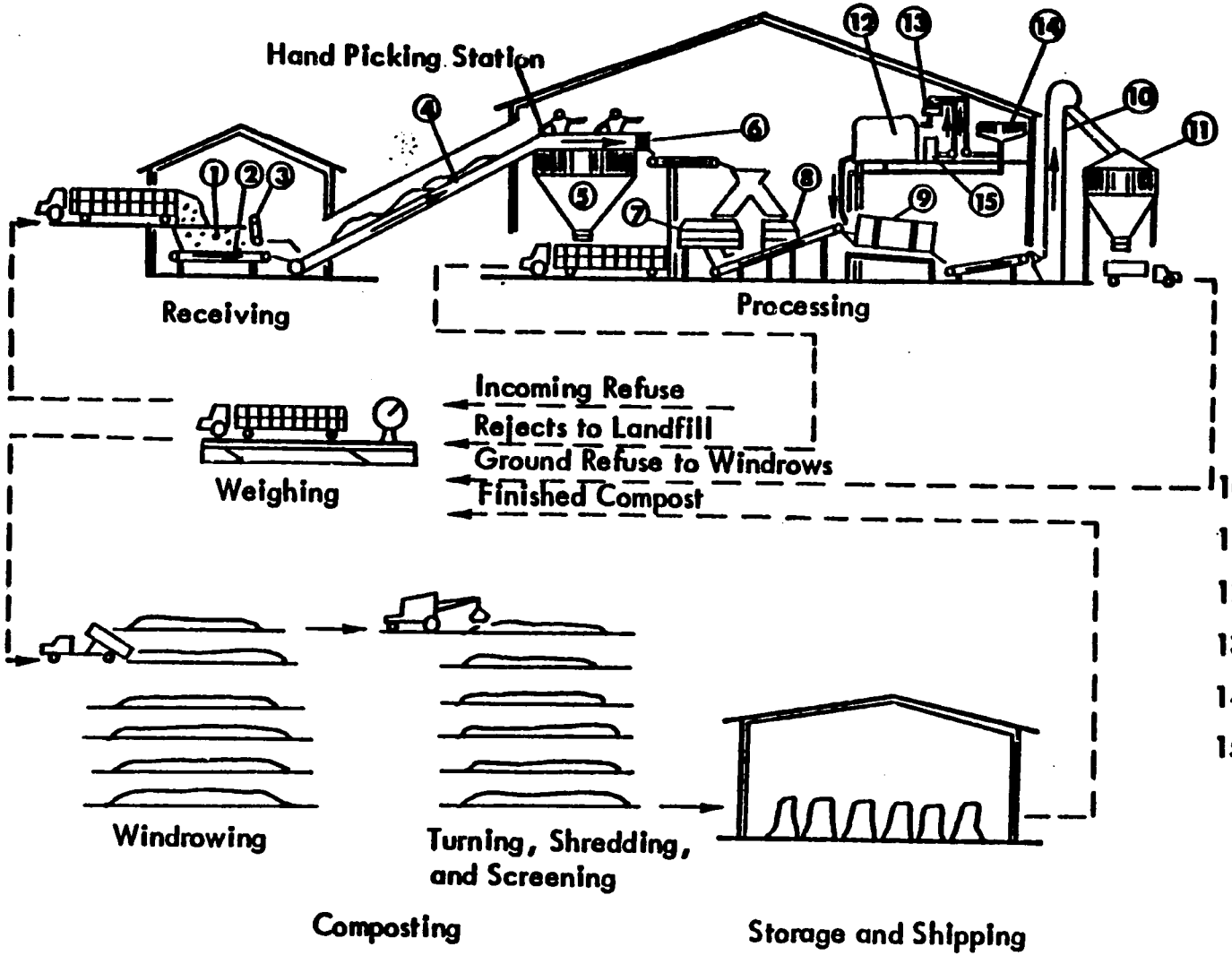
Photograph 3-9

Sorting metal and paper products to partially reclaim solid waste.



Photograph 3-10

Solid waste in barges being towed to the sea for ocean dumping. Because the waste floats back to shore, the practice has been discontinued.



LEGEND

1. Receiving Hopper
2. Receiving Hopper Conveyor
3. Leveling and Metering Gate
4. Elevating Belt Conveyor
5. Rejects Hopper
6. Magnetic Separator
7. Rasper
8. Grinder
9. Mixer
10. Bucket Elevator
11. Ground Refuse Storage Bin
12. Sludge Thickener
13. Sludge Coagulating Tank
14. Sludge Holding Tank
15. Chemicals Mixing Tank

Source: 44.

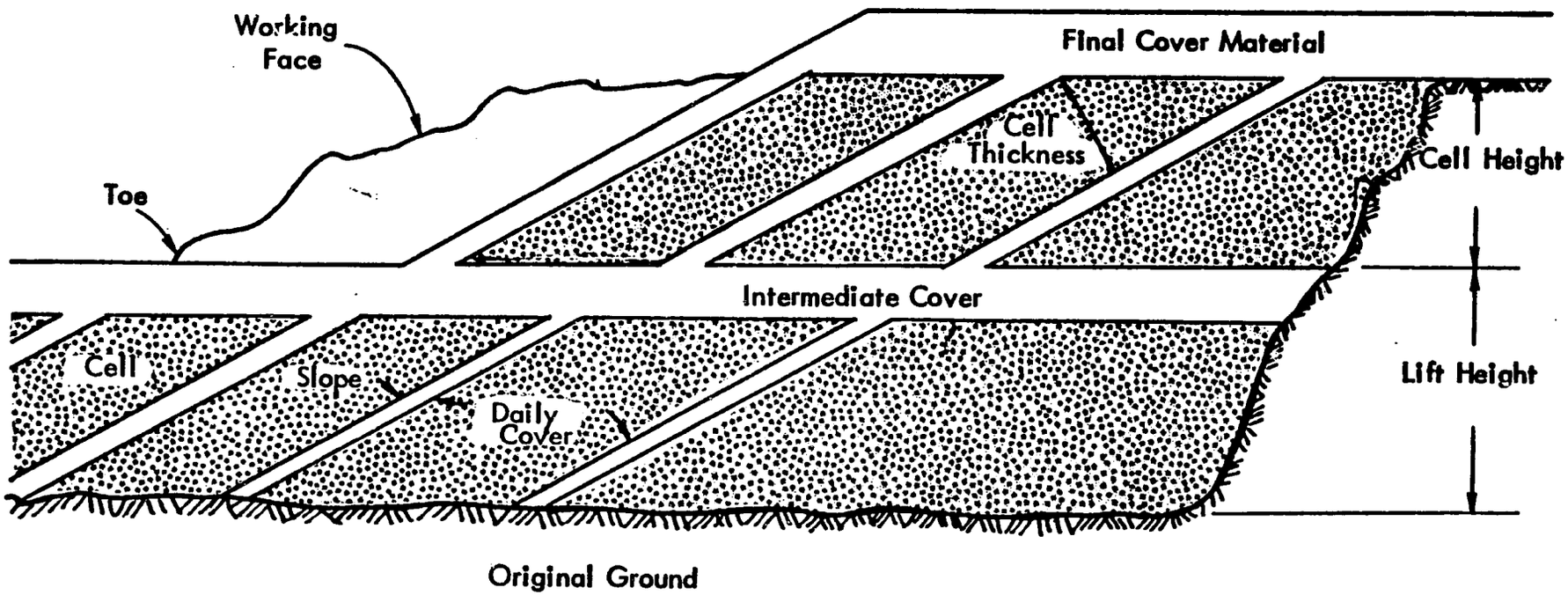
FIGURE 3-39
COMPOSTING PLANT

Photograph 3-11

Completed landfill reclaiming steep canyon area to provide level park land and arboretum. All types of industrial wastes were disposed since there is no usable groundwater.

Photograph 3-12

Solid waste at an open dump.



Source: 44.

FIGURE 3-40
SECTION VIEW: SANITARY LANDFILL

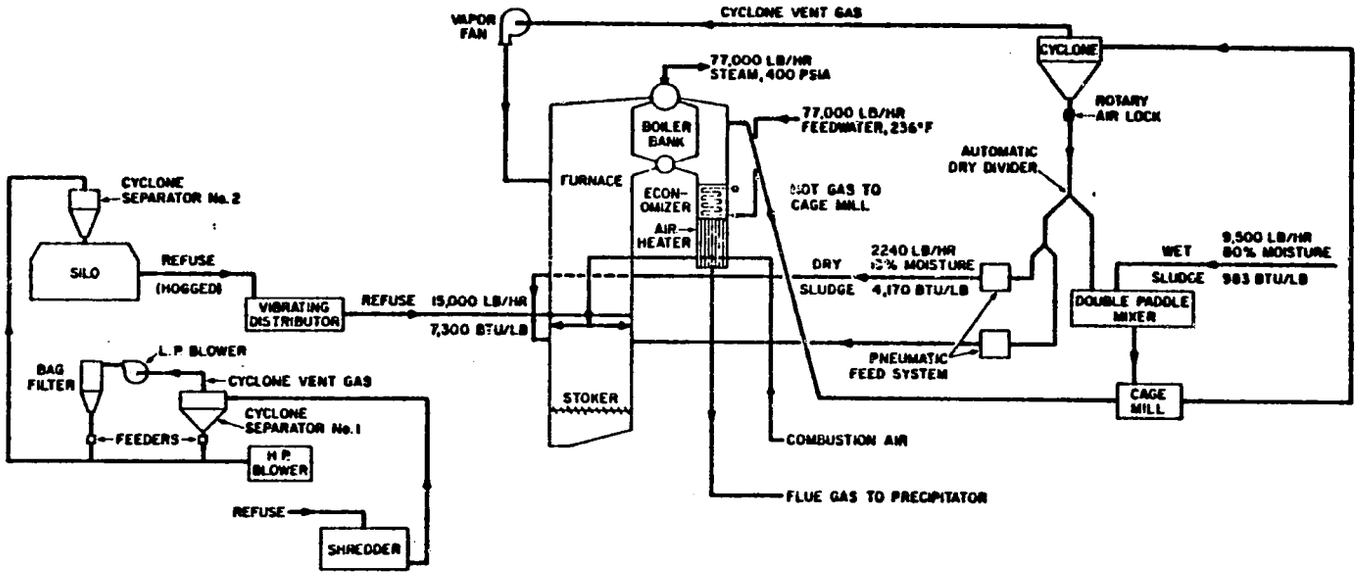
To avoid contamination of surface and groundwater by materials leached from the wastes, the landfill should normally be located away from natural drainage courses, wetlands, and aquifer recharge areas. It may be necessary to install artificial collection and drainage systems to divert water from the landfill.

Hazardous materials such as toxic chemicals, explosives, drugs, etc., may be disposed of in a secure landfill. Water should be excluded to avoid leaching of the materials to surface and groundwaters, and air may be excluded to avoid fires or air pollution. Water and gas monitoring well systems can be used to direct adverse environmental effects. Information should also be collected on the origin, weight, and placement of these hazardous substances, and inspection procedures used, to insure the security of the operation.

Incineration can create air pollution. Available air pollution control devices are costly but can reduce emissions to acceptable levels. Incineration may be the preferred method where land is scarce, water supplies are vulnerable, and emissions will not adversely affect the air quality.

Incineration produces some solid waste residues, but it is generally considered a disposal method because it reduces total waste volume. An incineration system (such as in Figure 3-41) includes facilities for receiving and storing wastes prior to incineration and a system for feeding the waste into the incinerator and ignoring it. Most incinerators need some start up supplementary fuel in addition to the waste burned. Energy recovery from the incineration process is possible for certain wastes, such as from paper and wood products industries. However, it may cost more than conventional fuel sources.

Table 3-17 is a sample worksheet of data which may be useful in the design of a solid waste treatment system for a specific plant and site. Similar data should be collected for air and water pollution control (Tables 3-5 and 3-14) to develop an integrated pollution control program.



Source: 44.

FIGURE 3-41
INCINERATION SYSTEM

TABLE 3-17
SOLID WASTE WORKSHEET

I. Plant Site

A. Description of Manufacturing Process:

B. Products Manufactured:

C. Plant Capacity (Population served/ tons per hr, etc.)

D. Plant Operation: _____ hr/day _____ days/wk

E. Raw Materials Requirements:

Mat'l	Quantity	Storage		Pollution Potential		
	Kg/day	Type	Capacity	Recyclable	Non-Recyclable	Hazards

F. Waste Products by Source (next page)

G. Disposal and Treatment

1. Recyclables

In-plant or salable
Value?
Special preparation or handling?

2. Non-Recyclables

Landfill, incineration, or special handling?
Elimination through process change?
Potential for recycling?

H. Handling Equipment

1. Collection
Type
Supplier
Manpower

2. Disposal
Type
Supplier
Manpower

TABLE 3-17 (Cont.)

F. Waste Products by Source

(Separate Table for Each Source)

Source	Solid Waste Management Options	% Waste by Weight and Volume Components of Waste																																	
		Corrugated		Other Paper		Ferrous Metal		Aluminum		Other Metal		Textiles		Plastics		Glass		Lumber		Trimmings		Rubber		Food		Sweepings		Chemicals & Radioactive	
		Wt	Vol	Wt	Vol	Wt	Vol	Wt	Vol	Wt	Vol	Wt	Vol	Wt	Vol	Wt	Vol	Wt	Vol	Wt	Vol	Wt	Vol	Wt	Vol	Wt	Vol	Wt	Vol
	Reusable In-Plant																												
	Reusable/Salable Out of Plant																												
	Residues Requiring Final Disposal																												

I. Available Plant Facilities

1. Waste storage areas
2. Landfill areas (private or municipal?)
3. Utilities for special handling

Electricity:	Kw/hr		
Process water:	l/min @	Kg/cm^2,	°C
Gas and oil:	l/hr of _____		
Manpower:	Man-hours		

Treatment Chemicals: Amount and cost

J. Sampling (Toxic Substances or Reusable Content)

Sample Area	Type of Waste	Sampling Methods and Shipping Requirements	Required Tests	Frequency	Toxicity	Reusable

II. Site Restrictions

A. Drainage (Landfill)

1. Surface runoff description
2. Aquifers
3. Physical strength characteristics of soil - compressional and tensile strength

B. Land Requirements (Landfill)

1. Amount, including preclusion of future uses
2. Type vegetation - farm or wild
3. Distance from residential area

C. Meteorology (Landfill and Incineration)

1. Wind speed and variation (wind rose)
2. Obstruction or diversions
3. Seasonal temperature
4. Seasonal precipitation
5. Frequency of inversions, fog, etc.

D. Regulations

COST-ESTIMATING CURVES

The cost curves in Figures 3-42 through 3-80 can be used to estimate the capital investment and operating and maintenance costs for selected pollutant treatment processes, methodologies, and equipment types. Their purpose is to show the approximate comparative costs of alternative air and water pollution control options. Each industrial pollution control system must be engineered and costed separately. Although these curves can be used for preliminary evaluation of alternative control technologies, actual current costs will be needed for final construction decisions. (See Table 3-16 for approximate solid waste processing/disposal costs.)

The curves were constructed from U.S. cost data developed by public and private agencies. All capital costs are given in constant U.S. dollars for mid-1974, and are based on an Engineering News Record (ENR) Index of 196; operating and maintenance costs are shown as a percentage of capital costs and are based on an ENR Index of 188. Capital cost can be annualized based on local interest rates and the useful life of the equipment or process. A commonly used formula is:

$$y = x + \frac{x}{(1+r)} + \frac{x}{(1+r)^2} + \ldots + \frac{x}{(1+r)^n}$$

where y = total capital cost

x = annual capital cost

r = interest rate

n = expected life in years minus one

If the curves are used to project costs over the useful life of the equipment or to anticipate future investment or other cost requirements, four considerations may limit the accuracy of the results: 1) Future technological developments may improve efficiencies and/or reduce costs. 2) Inflation may increase capital-replacement, labor, energy, or other costs. 3) United States cost data are not directly applicable in other countries; local variations in the prices of factors such as energy, labor, or transport may cause significant departures from the costs given here. And 4) Land costs, import taxes, and shipping costs for imported equipment and material are not included in the cost curve data. Variations in any of the factors listed in (3) and (4) may influence the overall cost rankings of alternatives. In general, however, the cost curves can be used to make comparative estimates of the various costs of alternative pollution treatment processes and different levels of pollutant removal. The curves are not intended to serve as a final cost-calculating method.

How to Use the Cost Curves

On the proper set of curves, the size of the considered unit is shown on the abscissa, the total capital cost is shown on the left-hand ordinate, and the annual operating and maintenance (O and M) cost is shown on the right-hand ordinate as a percentage of the total capital cost. The small arrow adjacent to a curve indicates the ordinate axis to which it relates.

Where more than one source was available for costing a particular process, two curves are shown on the appropriate axis to indicate the upper and lower limits of known U.S. costs. The vertical distance between the two curves includes the high to low range of those costs. On Figures 3-43 and 3-45, multipliers are given for adjusting capital cost for alternative devices which may be used in the air fan and particulate removal systems.

Power costs, when given, are represented by a dashed line. These are in addition to other O and M costs. For biological treatment systems, there may be a set of curves corresponding to different BOD_5 loadings.

The curves should be used as follows (a hypothetical example is included):

1. Determine the type and size (capacity in liters/sec) of the process or equipment under consideration. (An electrostatic precipitator with a capacity of 1,000 liters/sec will be considered.)

2. Find the appropriate figure. (Figure 3-44 shows cost curves for electrostatic precipitators.)

3. To find the total 1974 base period capital cost, locate the chosen capacity on the abscissa and move vertically until the capital cost curve is intercepted. Then move horizontally to the left-hand ordinate and find the total capital costs. (On Figure 3-44 the total capital cost in the United States for an electrostatic precipitator with a capacity of 1,000 liters per second ranges from $25,000 to $38,000.)

4. To find the 1974 base period annual operating and maintenance (O and M) cost, enter the curves at the chosen capacity on the abscissa and move vertically to a point of intersection with the O and M cost curve. Then move horizontally to the right-hand ordinate and read the percentage. Multiply this percentage by the total capital cost at the same capacity to determine the annual O and M cost. (For the above electrostatic precipitator, annual O and M costs in the United States range from 2 to 6 percent of capital costs, or from $500 to $2,280 per year; annual power costs in the United States range from 0.003 to 0.015 percent of total capital costs, or from $75 to $570 per year.)

FOR FURTHER READING

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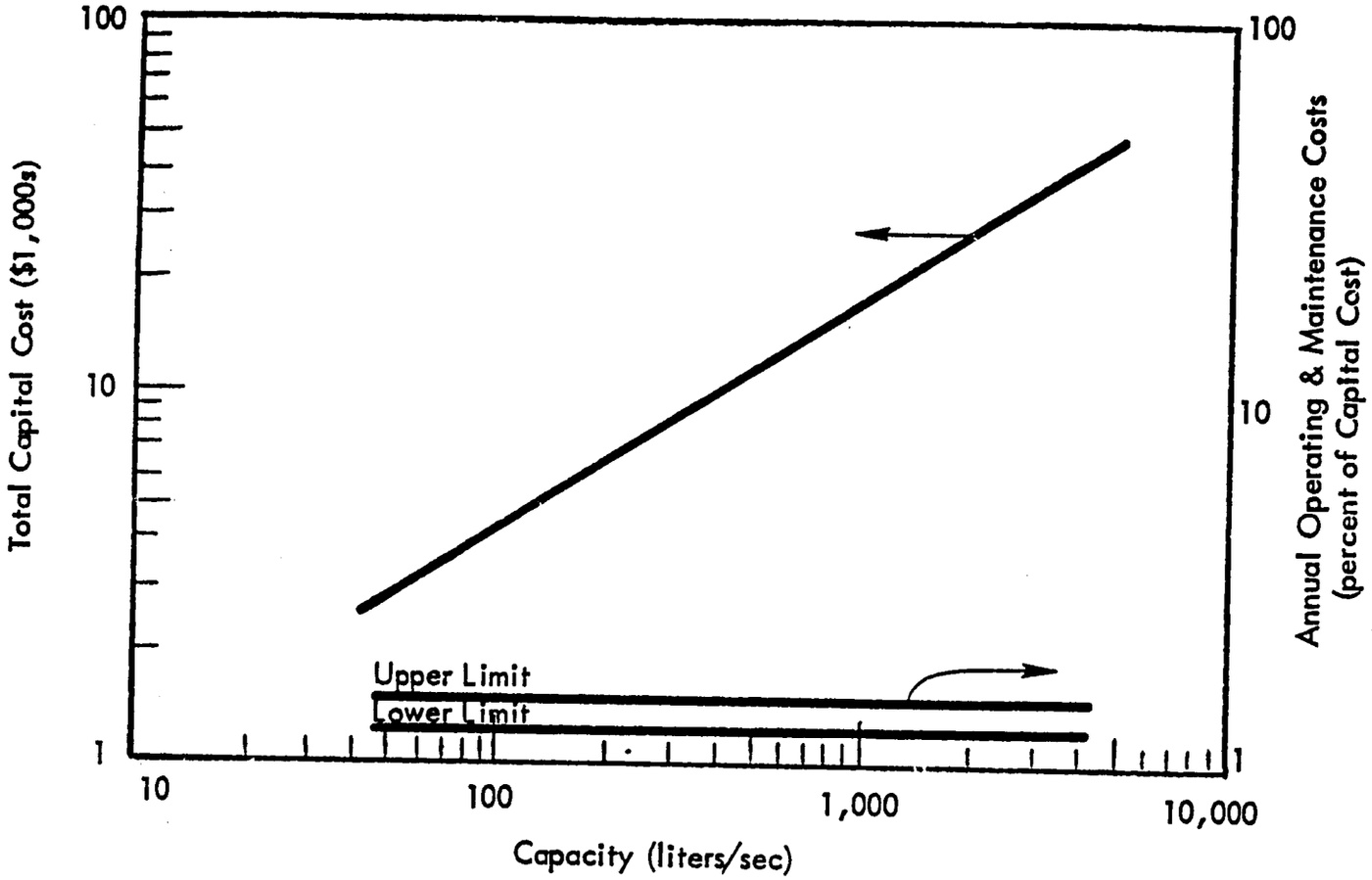
AIR POLLUTION

EQUIPMENT COSTS



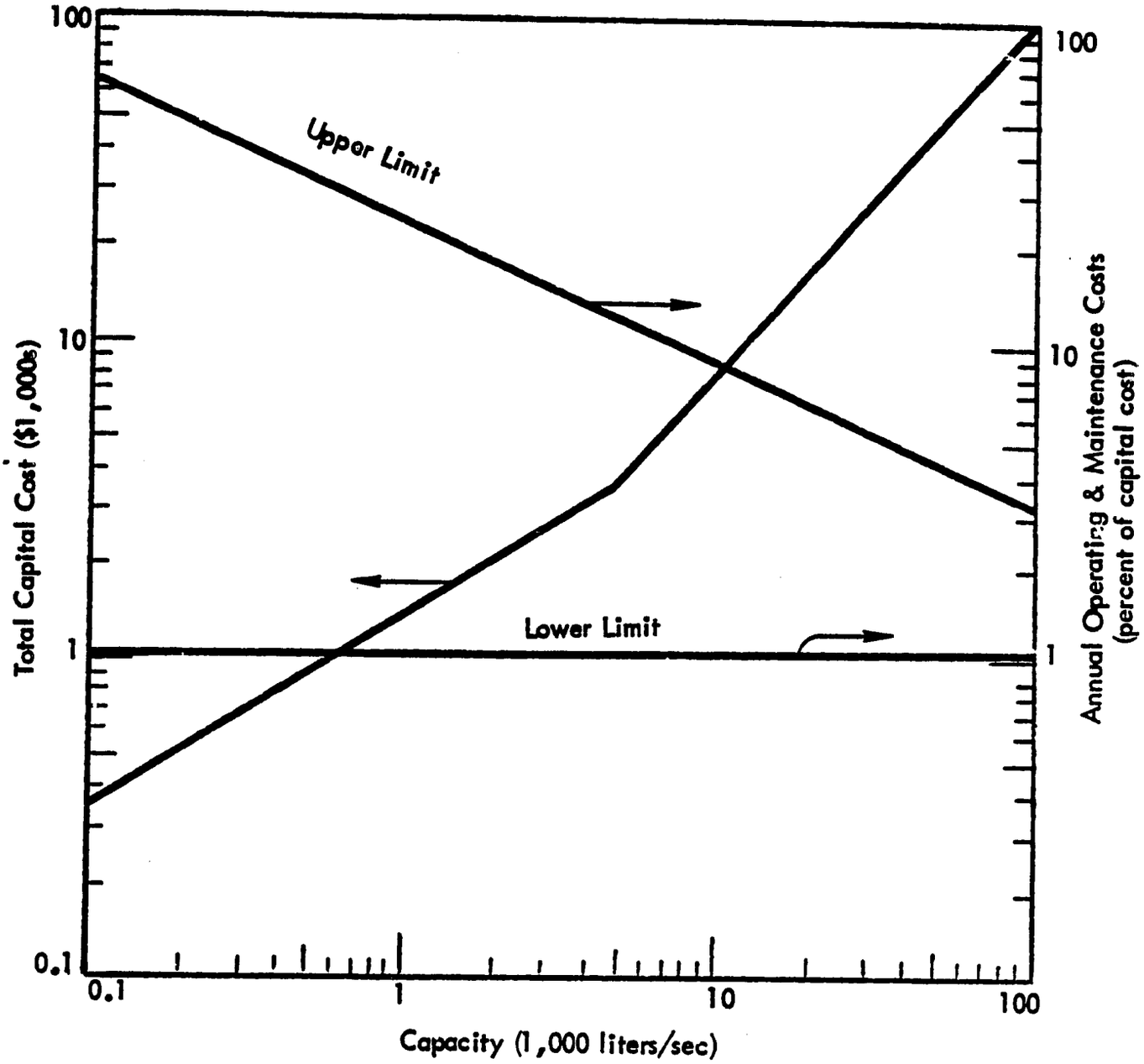
Design Adjustment

Type	Capital Cost Multiplier	Pressure Range
Centrifigal Turbo	1.0-20.0[a]	0.07-2.1 kg/sq cm
Centrifugal Compressor	32.110	70 kg/sq cm
Centrifugal	0.106	--
Propeller	0.063	--
Rotary Blower	1.692	0.7 kg/sq cm
Vane Axial	0.134	--

[a] Dependent on kg/sq cm

Source: 16, 47.

FIGURE 3-42
AIR FANS:
ESTIMATED 1974 COSTS



NOTE: The wide range in operation and maintenance costs reflects the wide range in power requirements. Greater power requirements are associated with higher removal efficiencies.

Source: 72 .

FIGURE 3-43
CYCLONES:
ESTIMATED 1974 COSTS

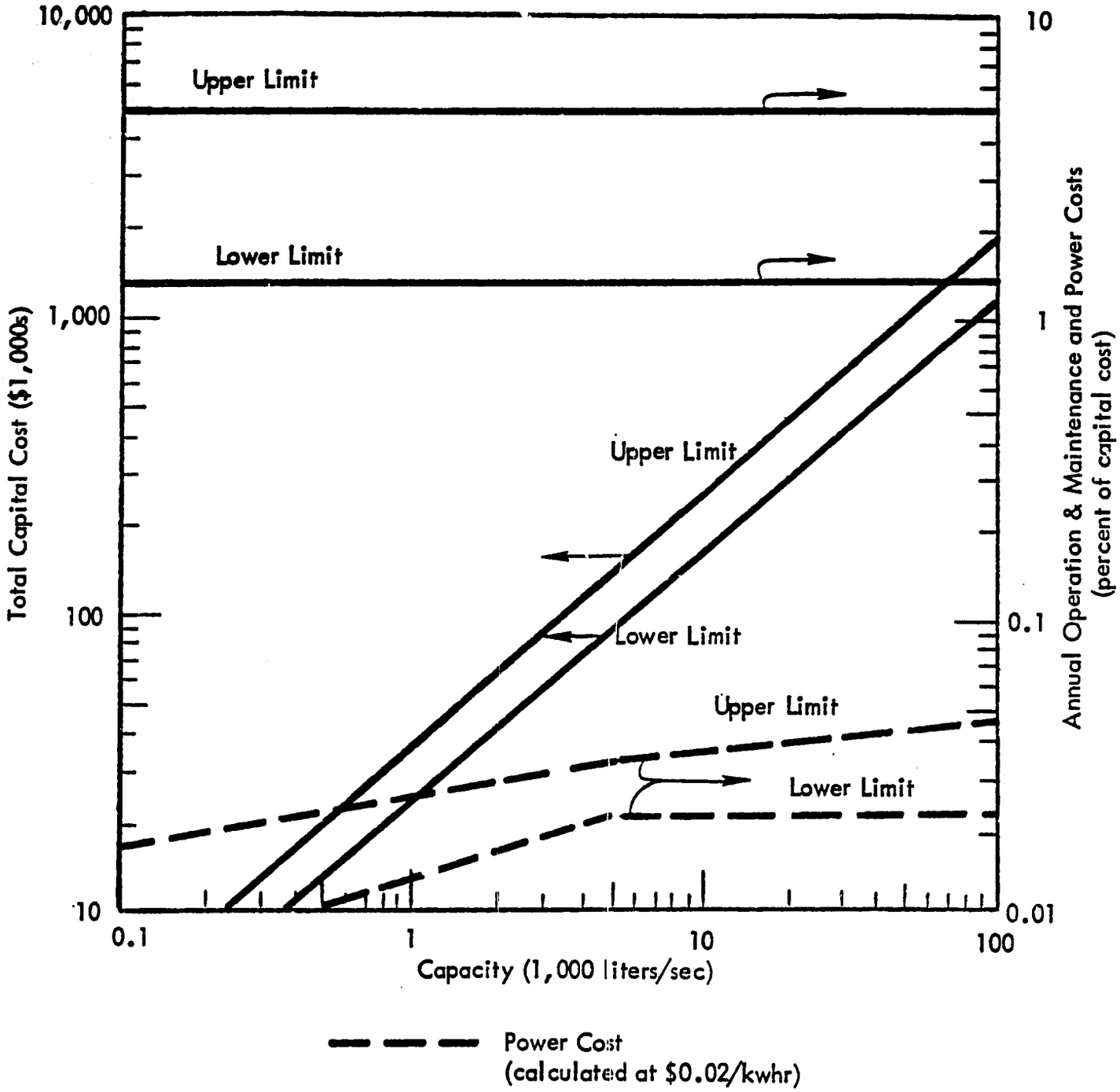
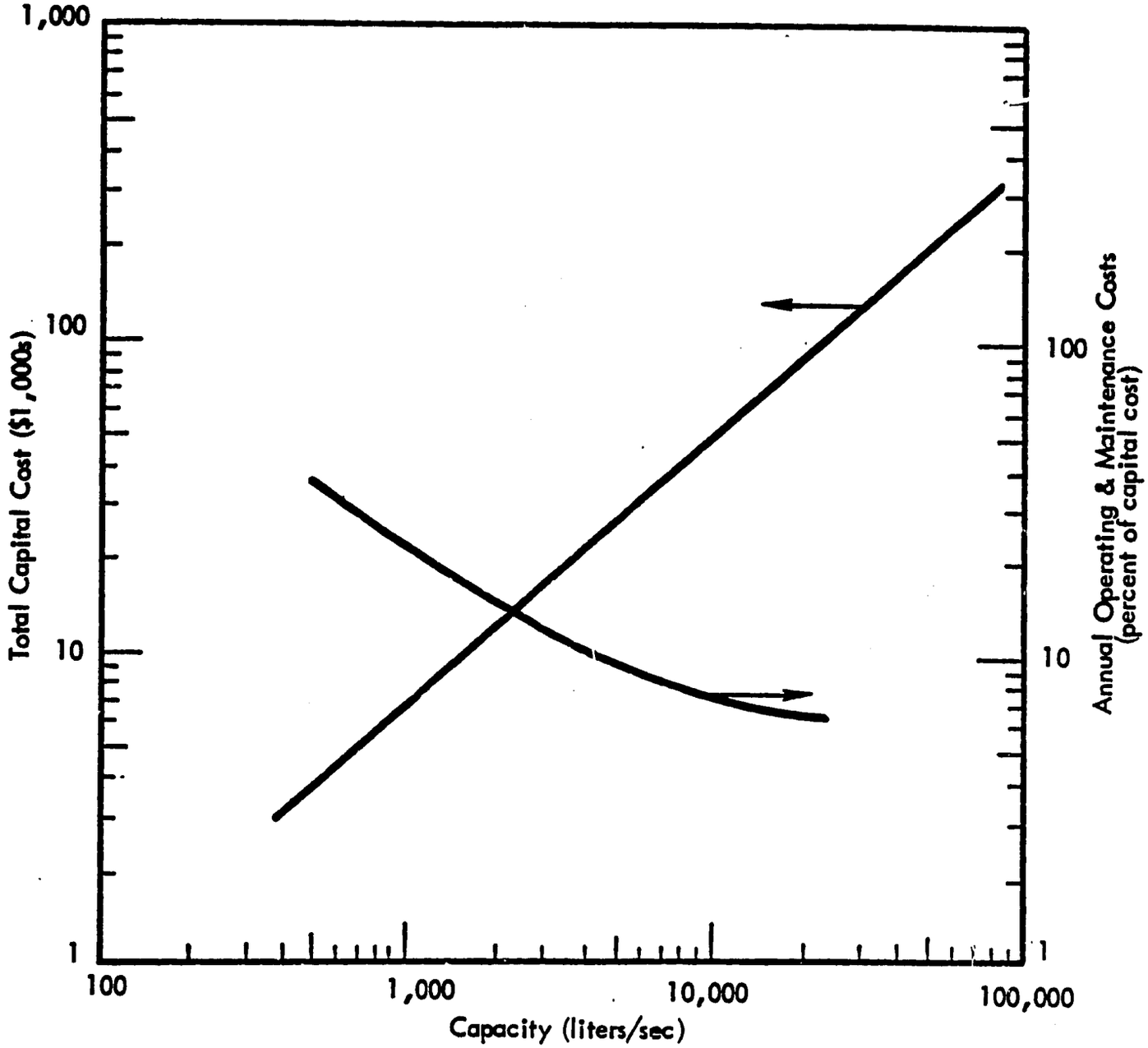


FIGURE 3-44

ELECTROSTATIC PRECIPITATOR:
ESTIMATED 1974 COSTS

Source: 10, 16, 47.



Cost Adjustment Factors

Type of Collector	Capital Cost Multiplier
Cloth bag	1.000
Centrifugal precipitator	0.840
Cyclone	1.213
Electrostatic precipitator	
Hi-voltage	5.060
Low-voltage	3.403
Multiple cyclone	0.327
Scrubbers	0.967
Automatic cloth filter	0.658

Source: 5, 72.

FIGURE 3-45
PARTICULATE COLLECTION
ESTIMATED 1974 COSTS

WATER POLLUTION

EQUIPMENT COSTS

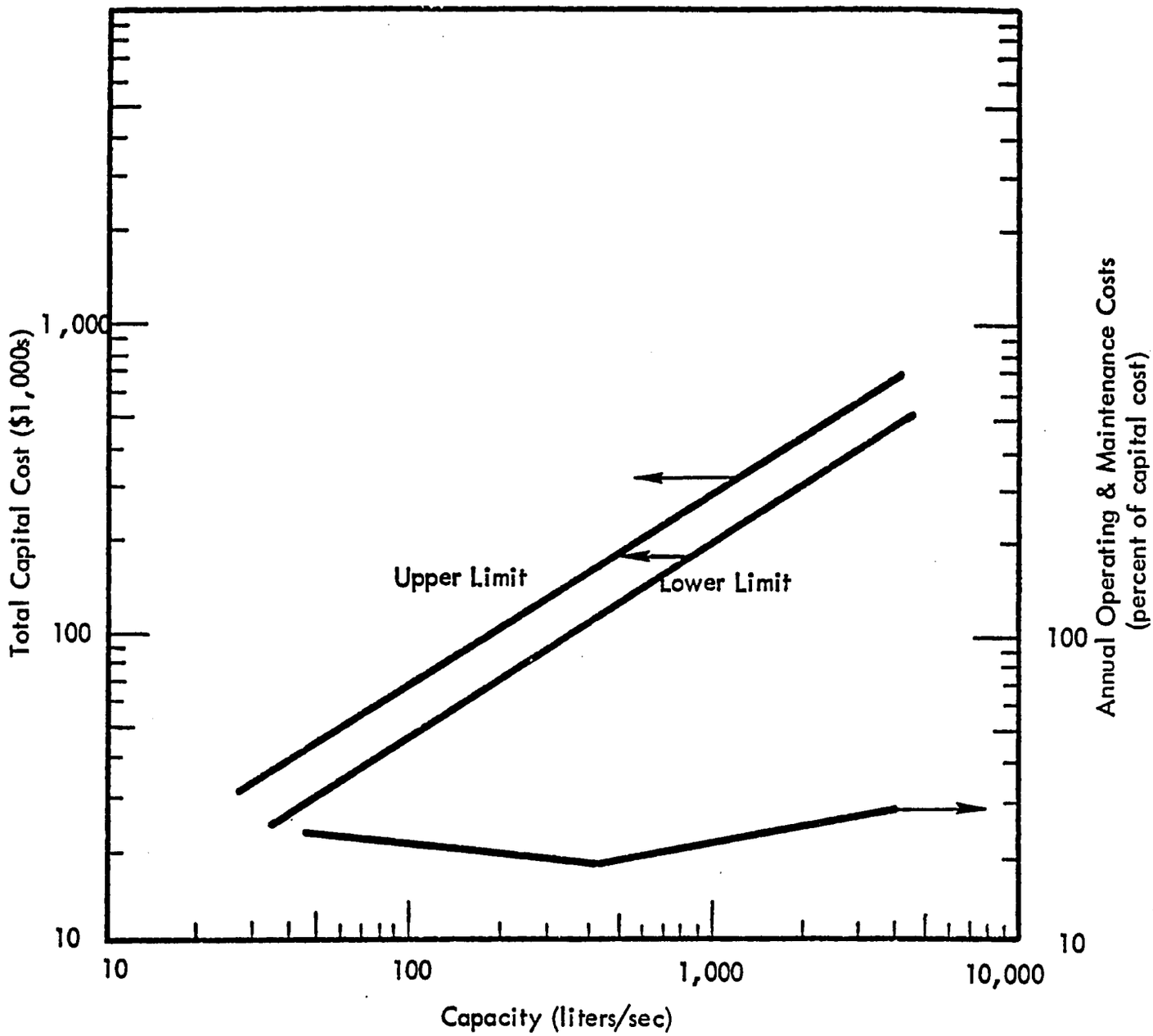
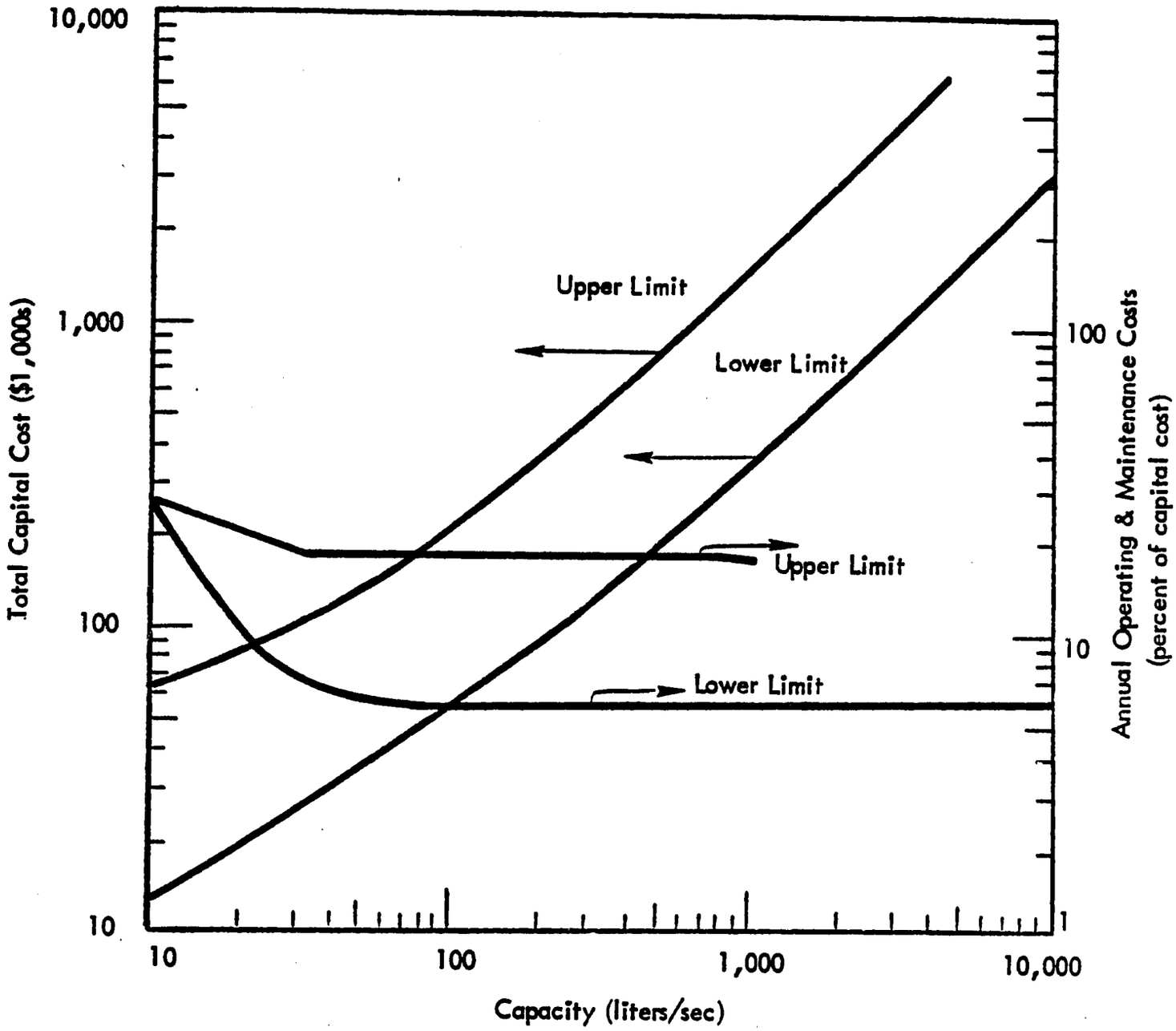


FIGURE 3-46

PRELIMINARY TREATMENT, SCREENING, GRIT REMOVAL, AND METERING: ESTIMATED 1974 COSTS

Source: 10, 63.



Source: 10, 63, 87.

FIGURE 3-47
PRIMARY CLARIFIER:
ESTIMATED 1974 COSTS

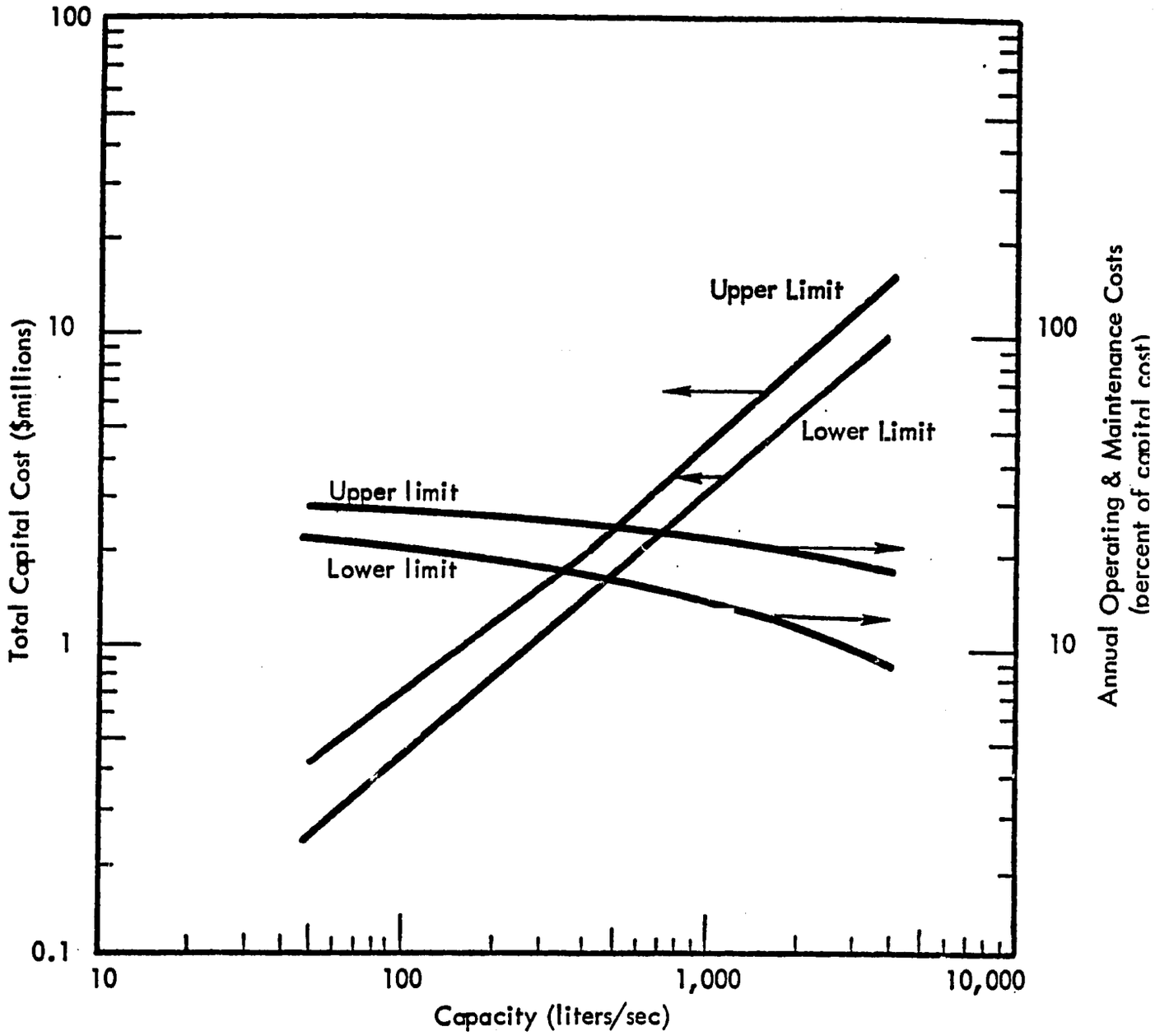


FIGURE 3-48

PHOSPHATE REMOVAL
BY TWO-STAGE LIME CLARIFICATION:
ESTIMATED 1974 COSTS

Source: 46,63.

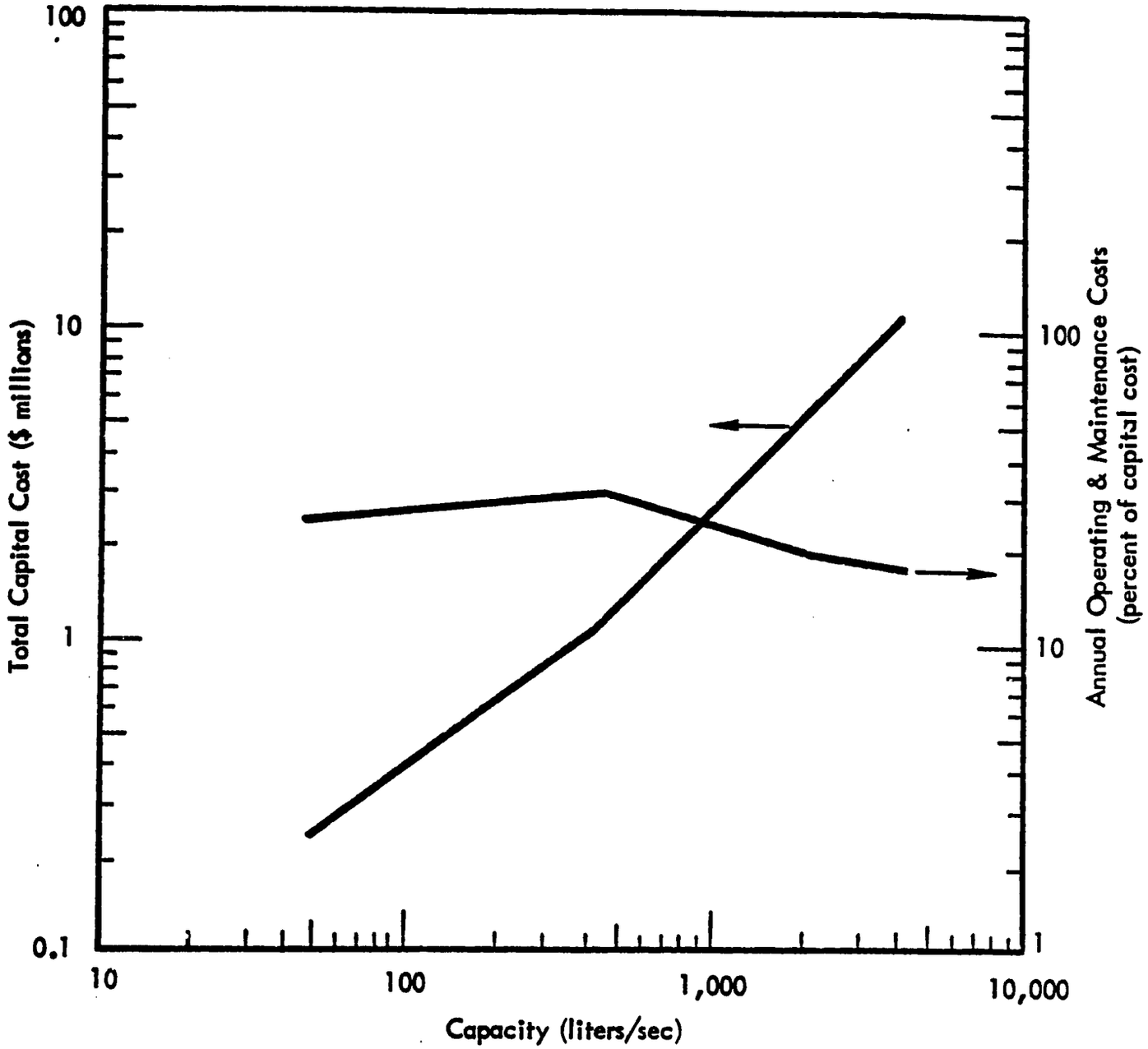
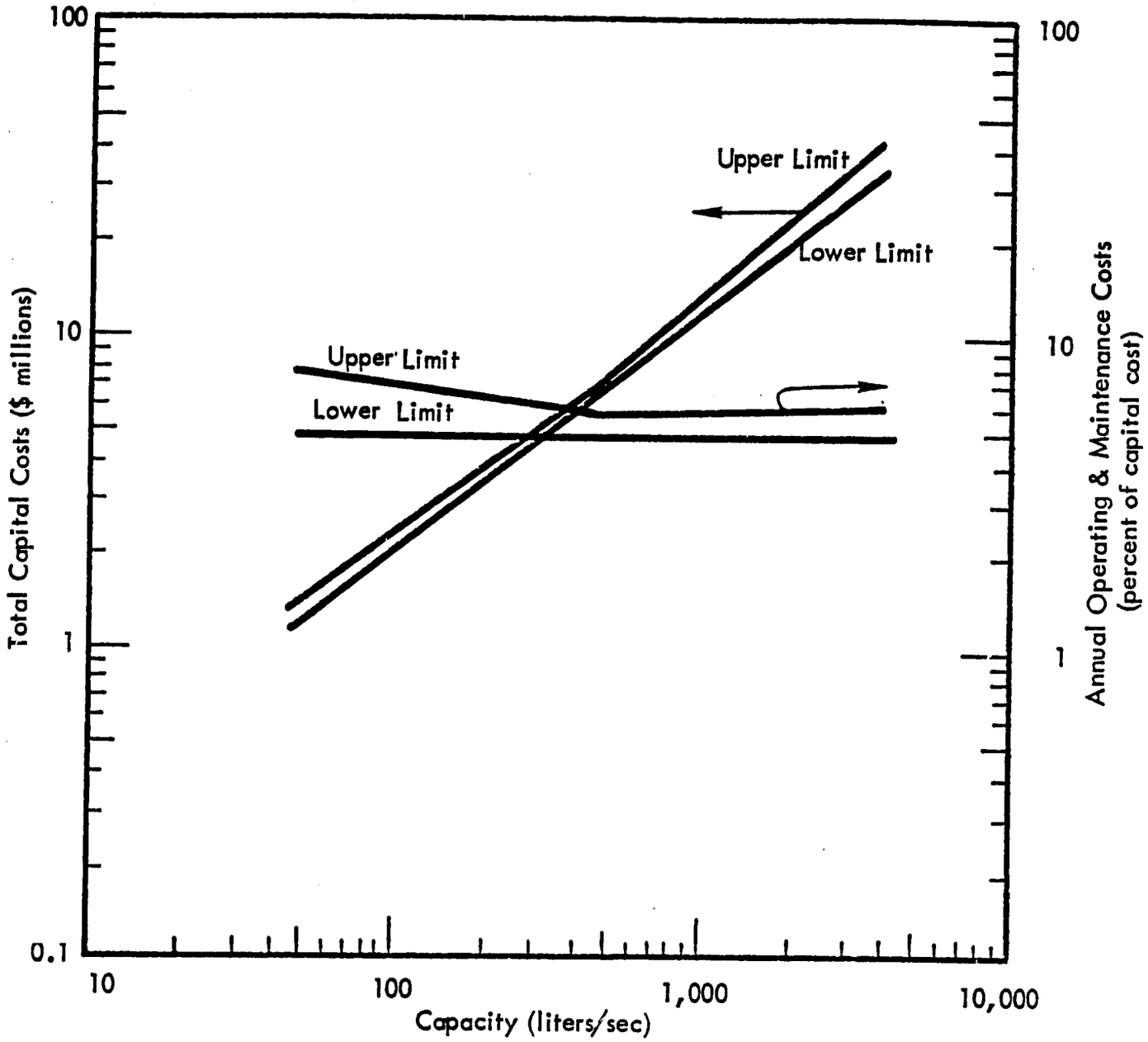


FIGURE 3-49
PRIMARY CLARIFIER
WITH $FeCl_3$ ADDITION:
ESTIMATED 1974 COSTS

Source: 63.

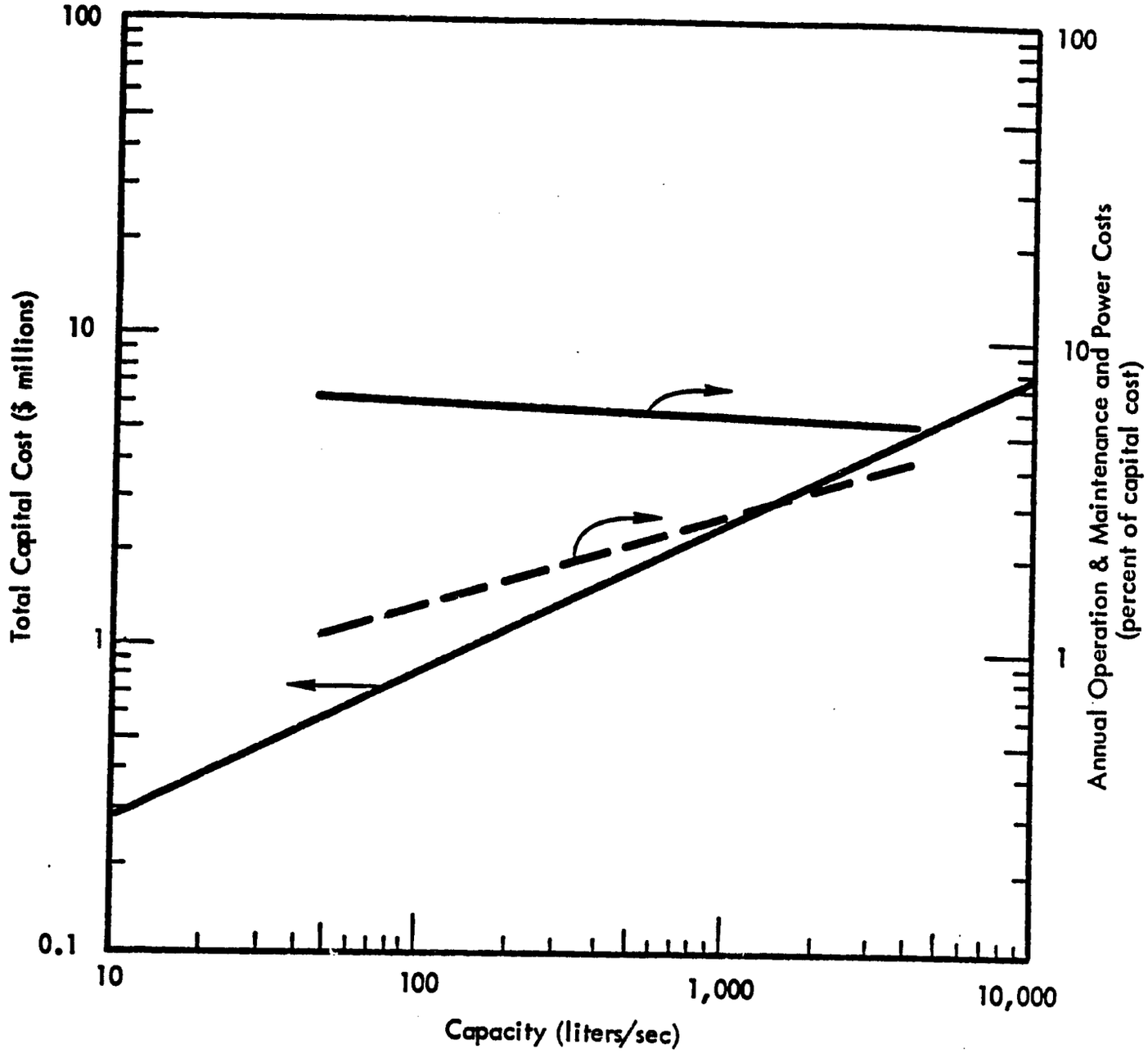


NOTE: Costs include raw sewage pumps, preliminary treatment, primary sedimentation, primary sludge pumps, aerators, diffuse air system, final settlers (multiple), recirculation pumps, sludge thickeners, anaerobic digesters, sludge holding tanks, vacuum filtration, multiple hearth incineration, chlorination, laboratory.

FIGURE 3-50

CONVENTIONAL ACTIVATED SLUDGE PLANT: ESTIMATED 1974 COSTS

Source: 46, 63.



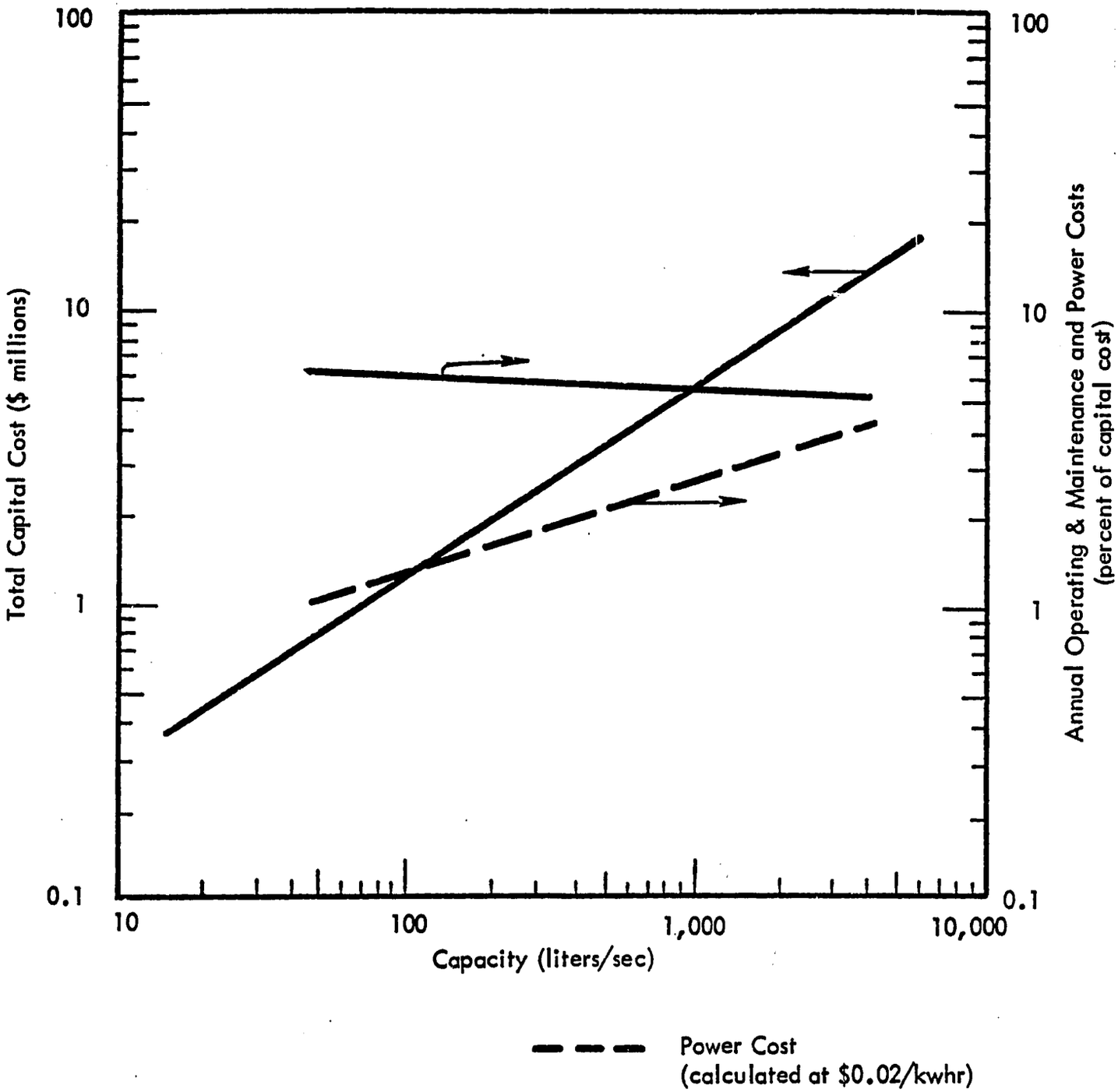
Power Cost
(calculated at $0.02/kwhr)

NOTE: Capital cost does not include cost of hookups or pipes.

Source: 5, 72.

FIGURE 3-51

CONTACT STABILIZATION:
ESTIMATED 1974 COSTS

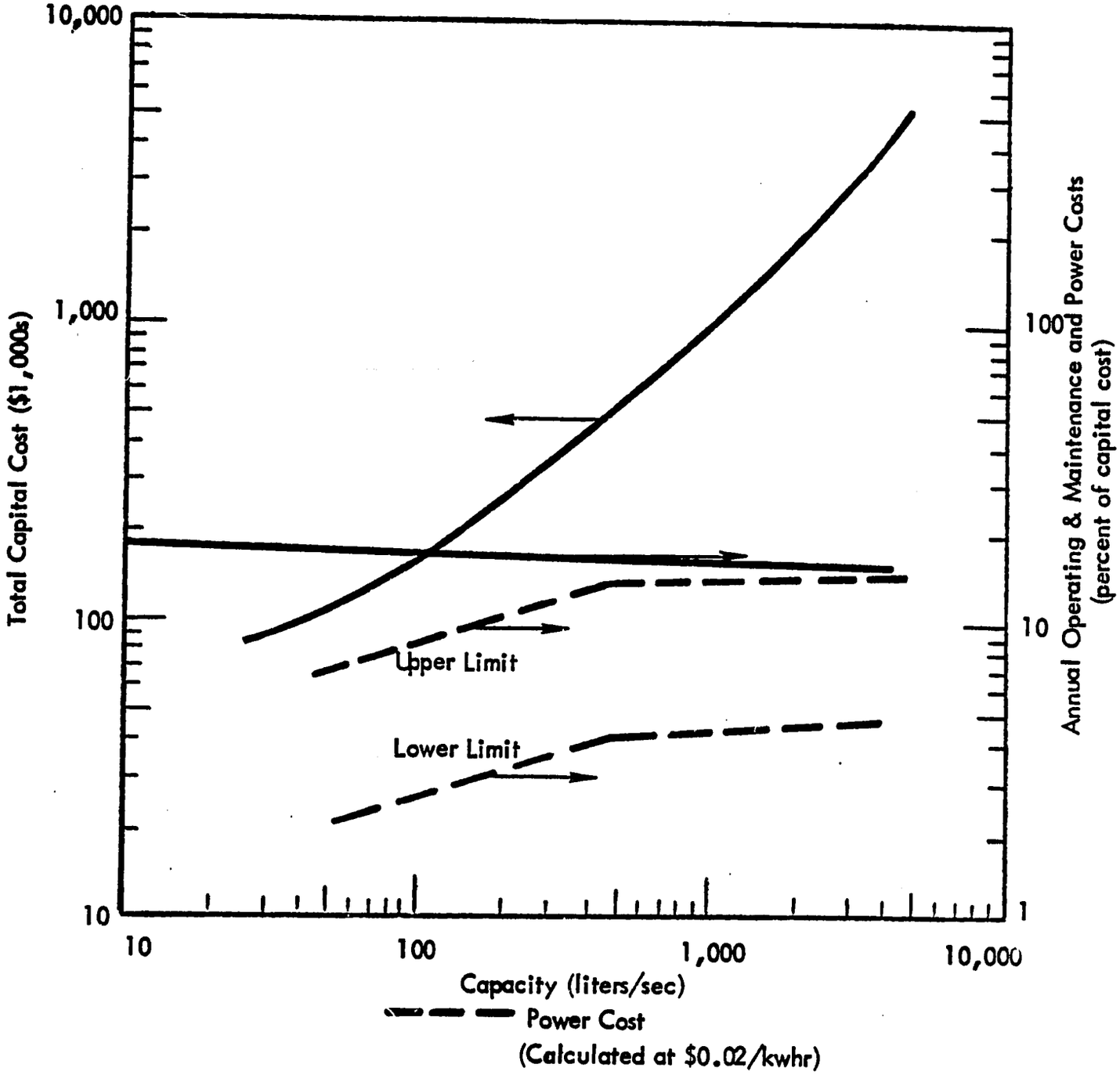


NOTE: Based on an estimated cost of excavation and embankment construction of $3.90/cu m.

Source: 5, 72.

FIGURE 3-52

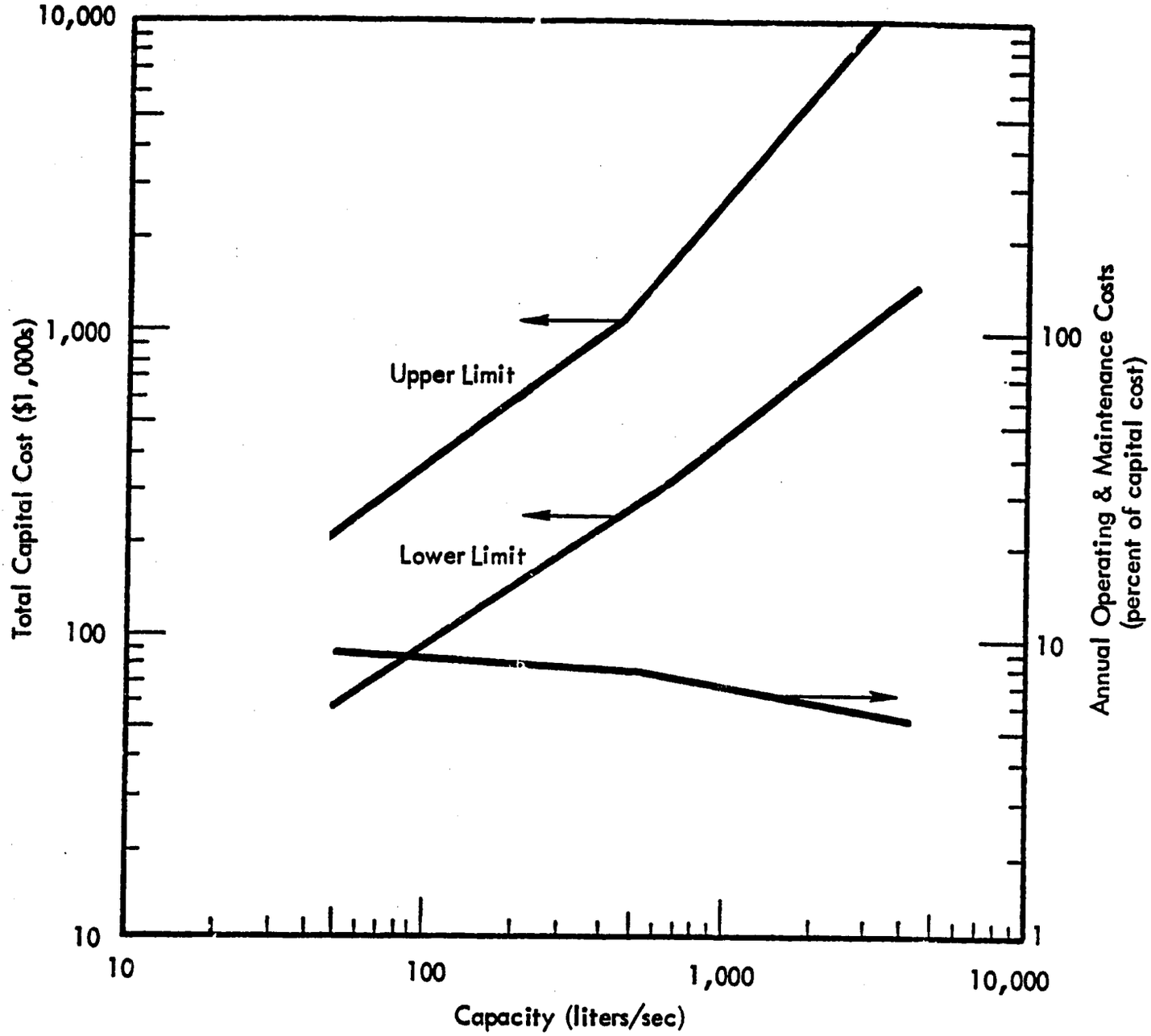
EXTENDED AERATION: ESTIMATED 1974 COSTS



NOTE: Costs include building housing the blowers and associated electrical work, air piping, air diffusers, aeration basins.

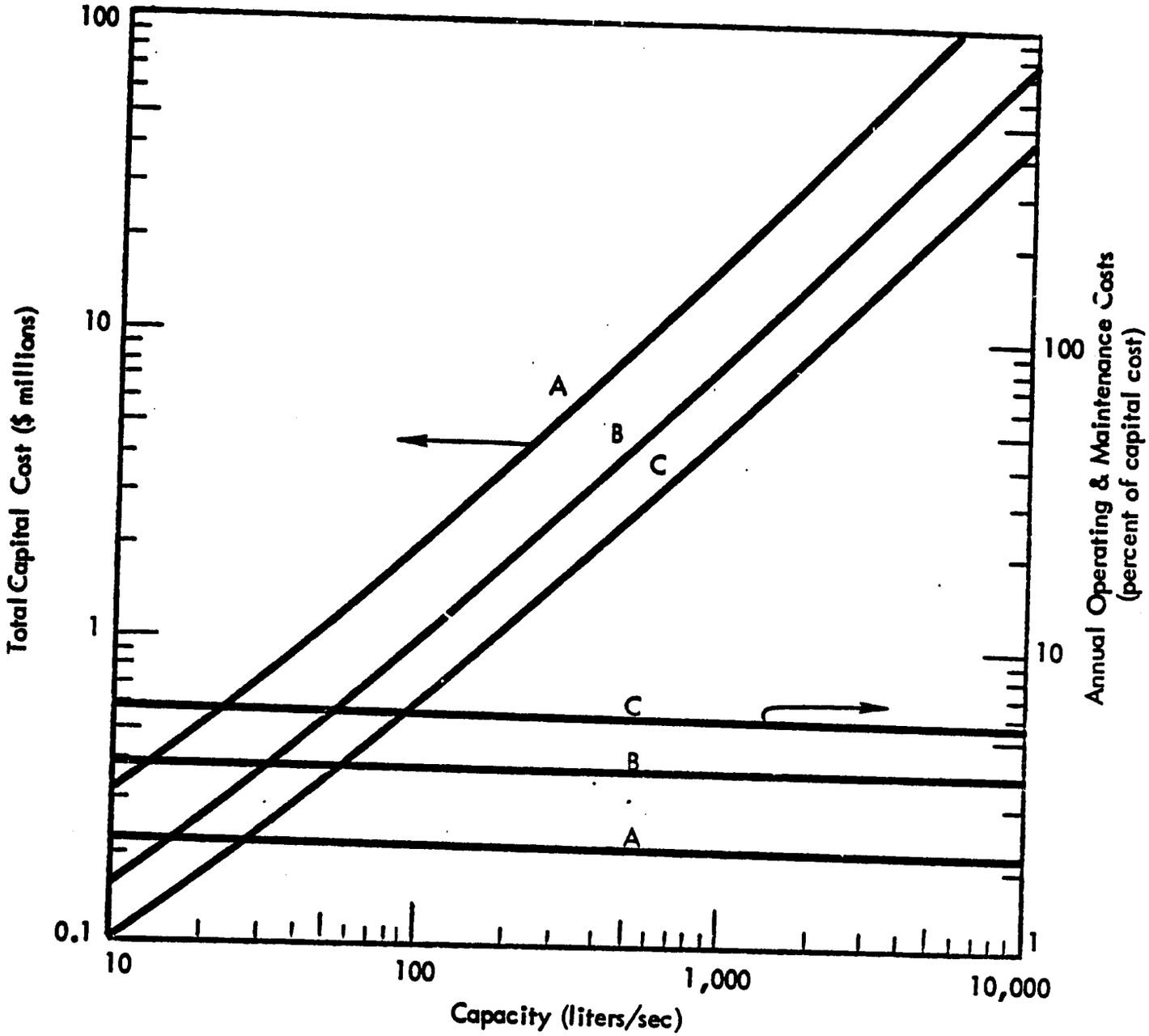
Source: 10.

FIGURE 3-53
AERATION SYSTEM:
ESTIMATED 1974 COSTS



Source: 10, 6, 87.

FIGURE 3-54
SECONDARY CLARIFIERS:
ESTIMATED 1974 COSTS

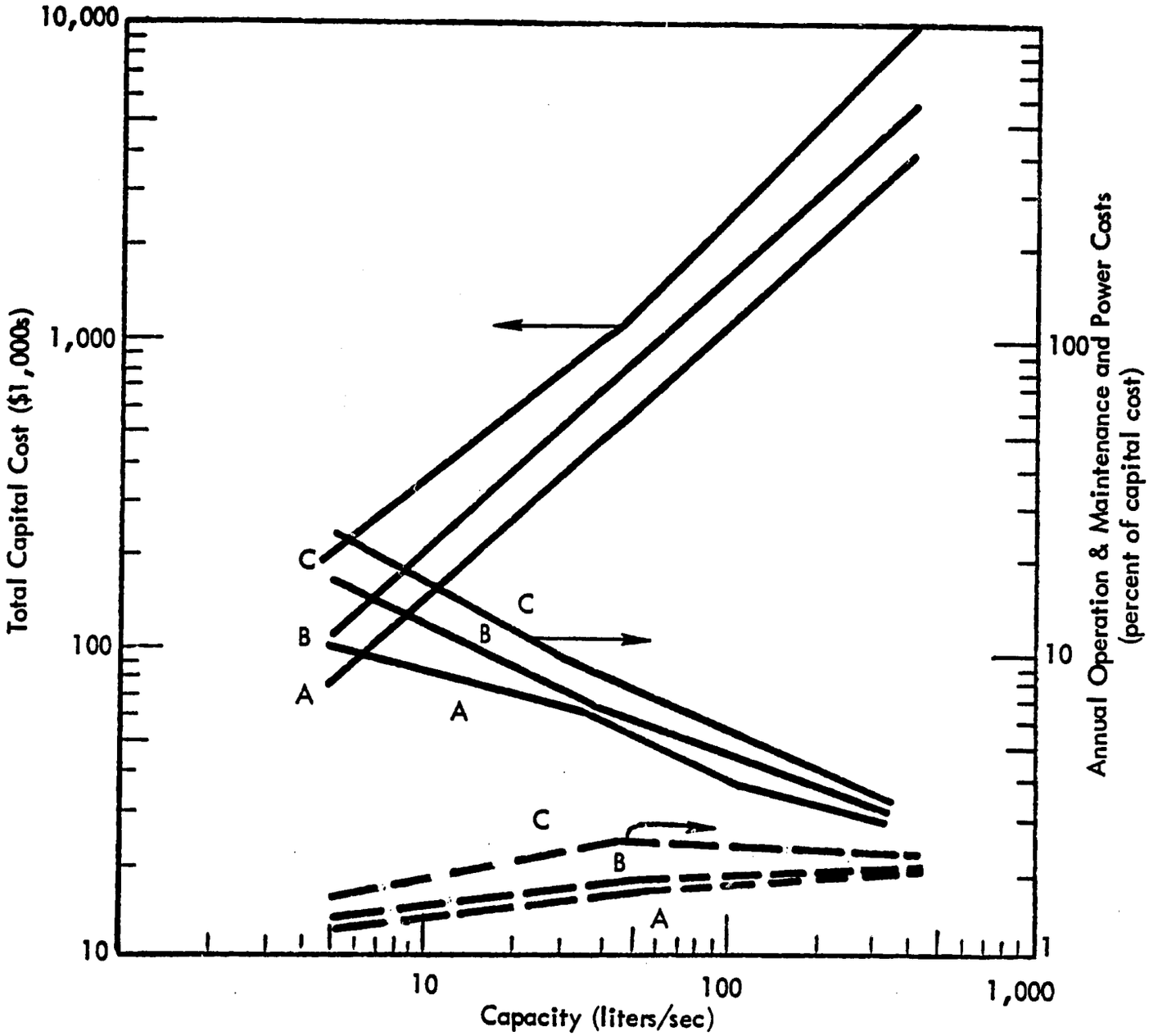


Cost Curve	BOD_5 Loading (kg/ha/day)
A	30
B	75
C	125

Note: Based on an estimated cost of excavation and embankment construction of $3.90/cu m and a lagoon depth of 1.75 m.

Source: 72.

FIGURE 3-55
FACULTATIVE LAGOON: ESTIMATED 1974 COSTS FOR VARIOUS BOD_5 LOADINGS



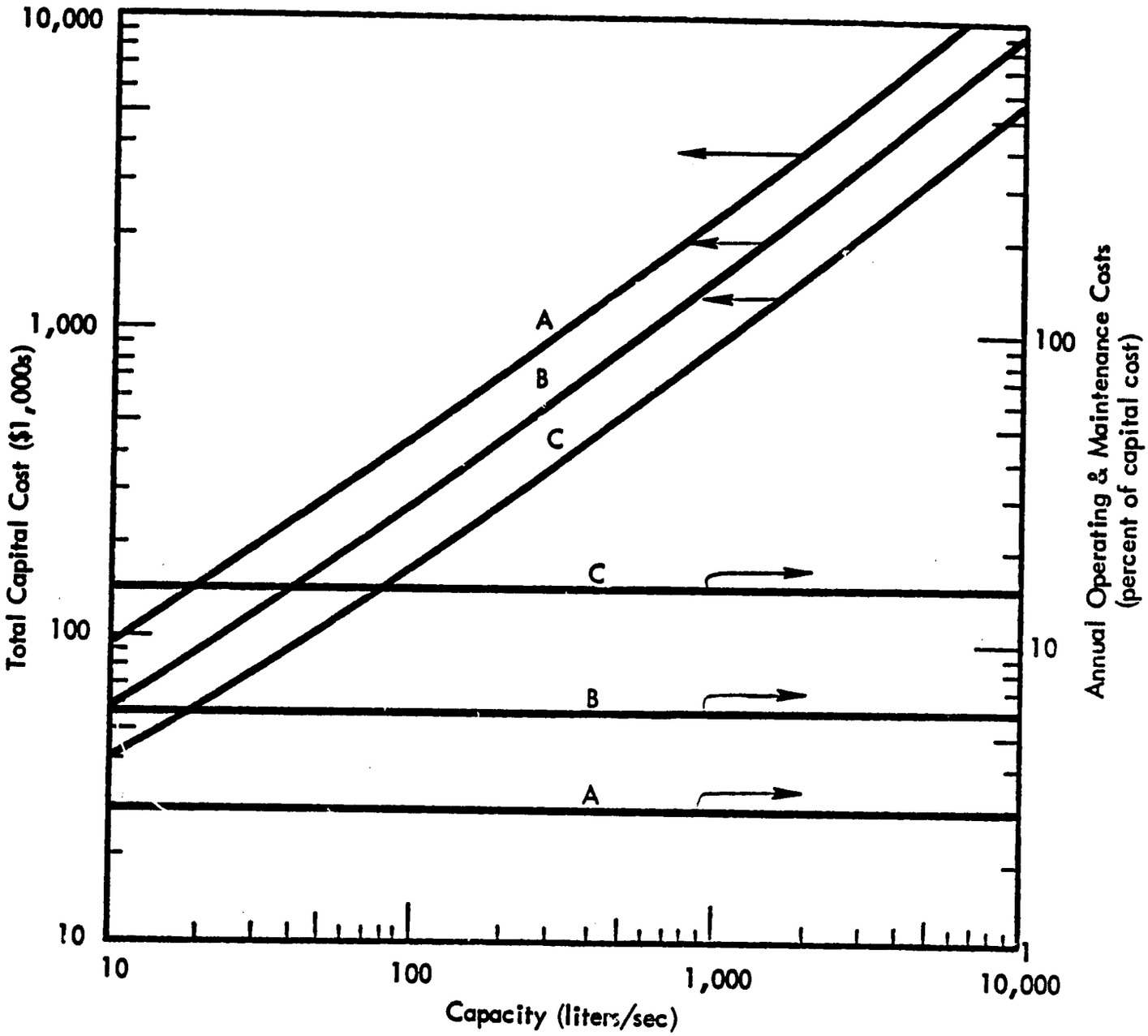
Cost Curve	BOD_5 Loading (kg/ha/day)
A	112
B	224
C	336

Power Cost (calculated at $.02/kwhr)

NOTE: Based on an estimated cost of excavation and embankment construction of $3.90/cu m, a lagoon depth of 4.6 m, a BOD_5 concentration of 200 mg/liter, and aeration at 5.8 w/1000 liters of lagoon volume.

Source: 72, 107.

FIGURE: 3-56
AERATED LAGOONS: ESTIMATED 1974 COSTS FOR VARIOUS BOD_5 LOADING RATES

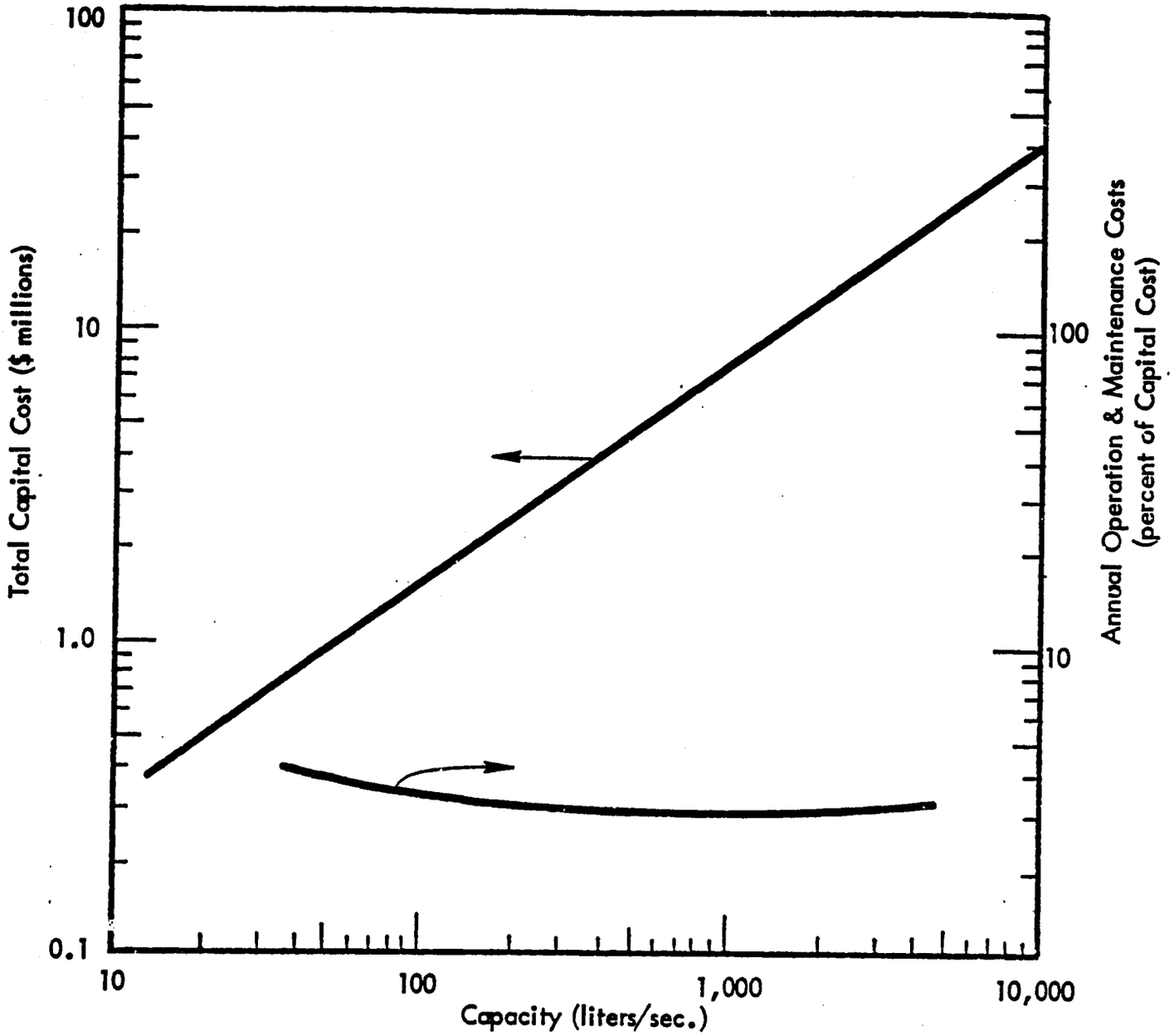


Cost Curve	BOD_5 Loading (kg/ha/day)
A	560
B	1,120
C	2,240

Note: Based on an estimated cost of excavation and embankment construction of $3.90/cu m and a lagoon depth of 4.5 m.

Source: 72.

FIGURE 3-57
ANAEROBIC LAGOON:
ESTIMATED 1974 COSTS



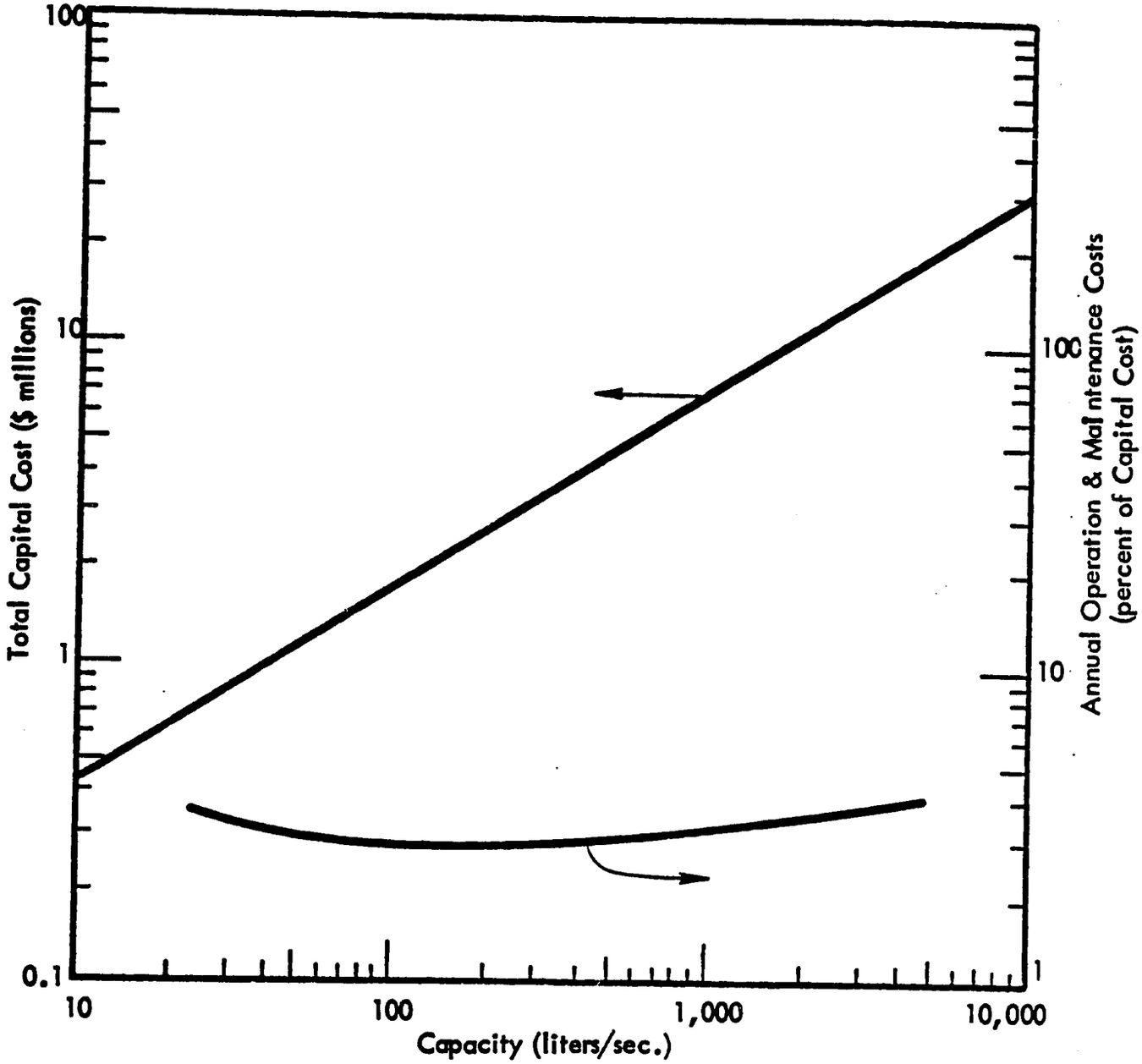
Estimating Parameters

Hydraulic loading = 4-16 million liters/day
Organic loading = 0.11-0.37 kg BOD_5/cu m-day

Costs include motor and drive, rack packing, setting packing, concrete, steel, instrumentation, electrical, insulation, paint, and prime contractor engineering and construction overhead

FIGURE 3-58
TRICKLING FILTER:
ESTIMATED 1974 COSTS

Source: 47, 87.



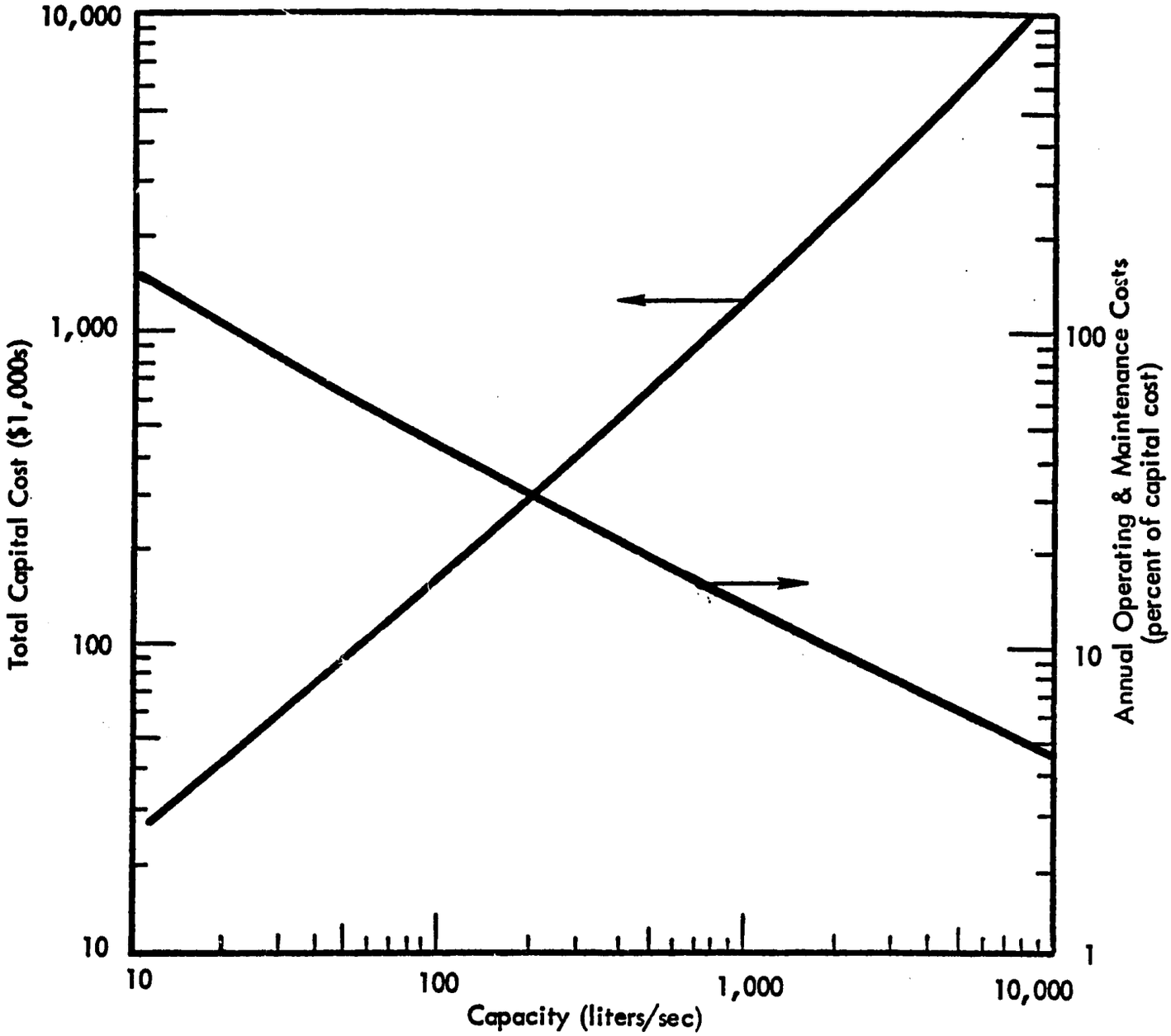
Estimating Parameters

Hydraulic loading = 40-160 million liters/day
Organic loading = 0.37-1.85 kg BOD_5/cu m-day

Costs include tank, underdrains, rock medium, and distributor

Source: 47.

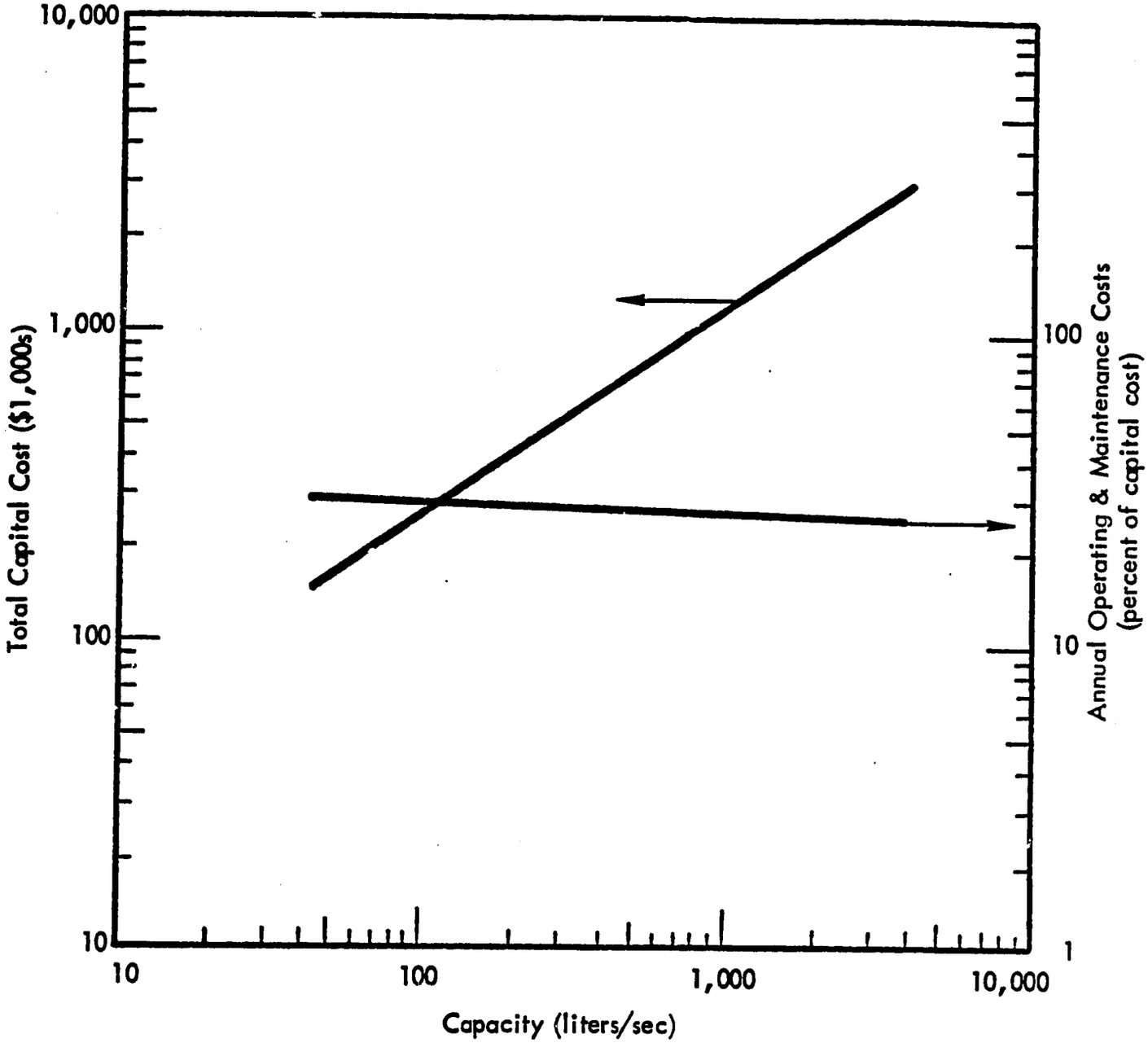
FIGURE 3-59
HIGH RATE TRICKLING FILTER:
ESTIMATED 1974 COSTS



Source: 5, 72.

FIGURE 3-60

MICROSTRAINING:
ESTIMATED 1974 COSTS



Source: 5, 72.

FIGURE 3-61

SAND FILTRATION:
ESTIMATED 1974 COSTS

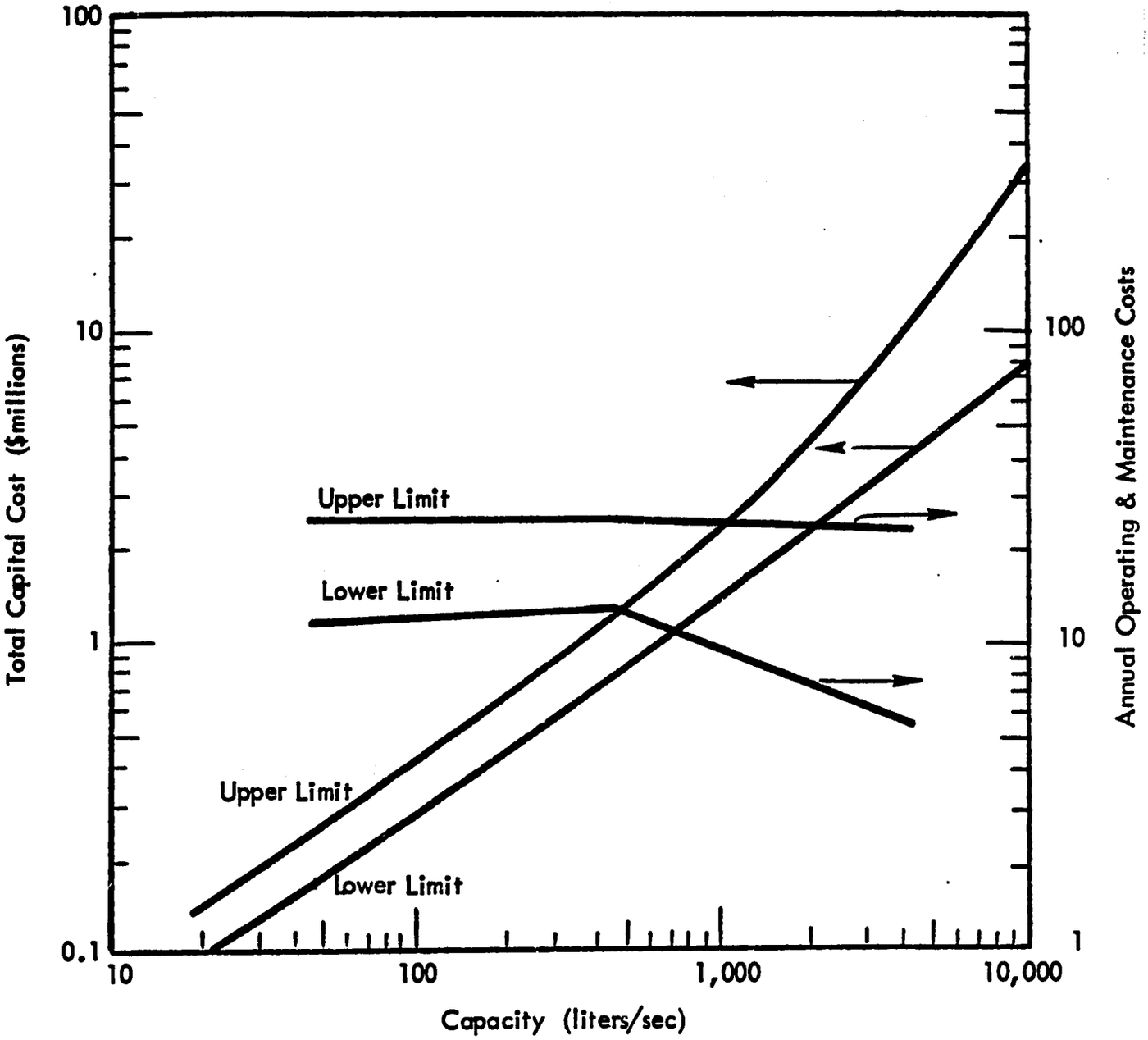
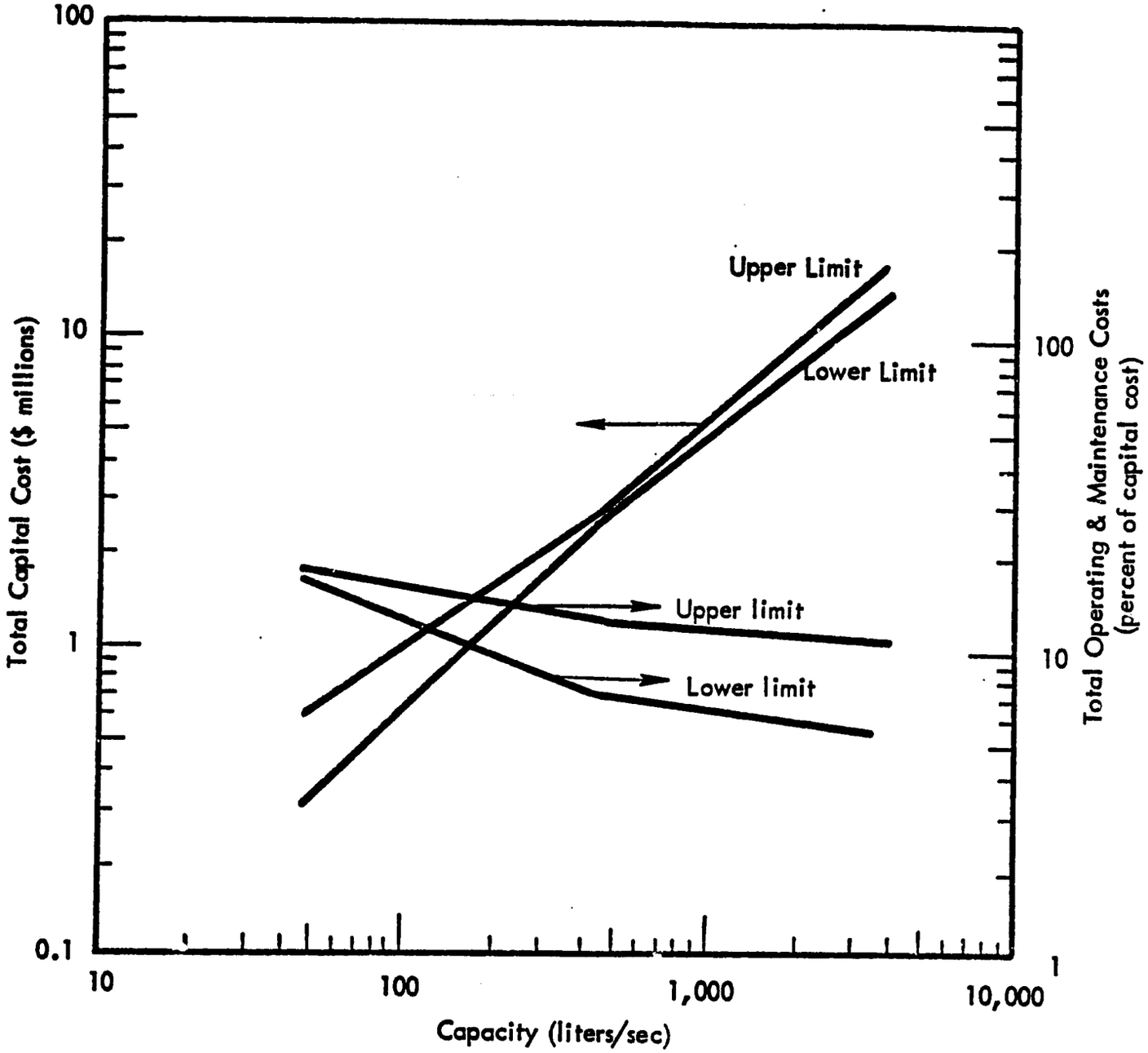


FIGURE 3-62

MIXED MEDIA FILTERS: ESTIMATED 1974 COSTS

Source: 46, 63.

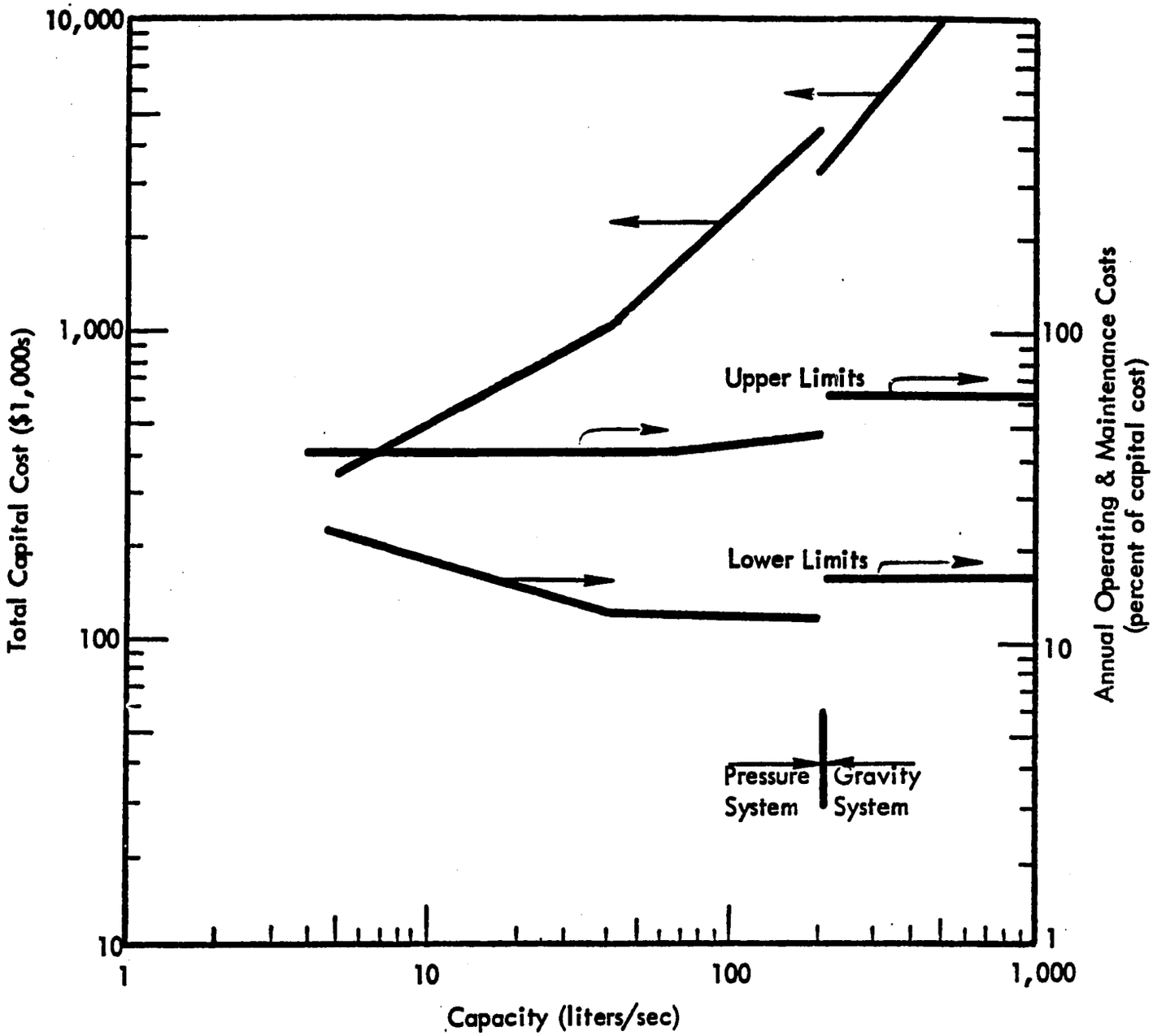


NOTE: Costs include tanks, activated carbon, and piping.

Source: 70, 87.

FIGURE 3-63

ACTIVATED CARBON ADSORPTION: ESTIMATED 1974 COSTS

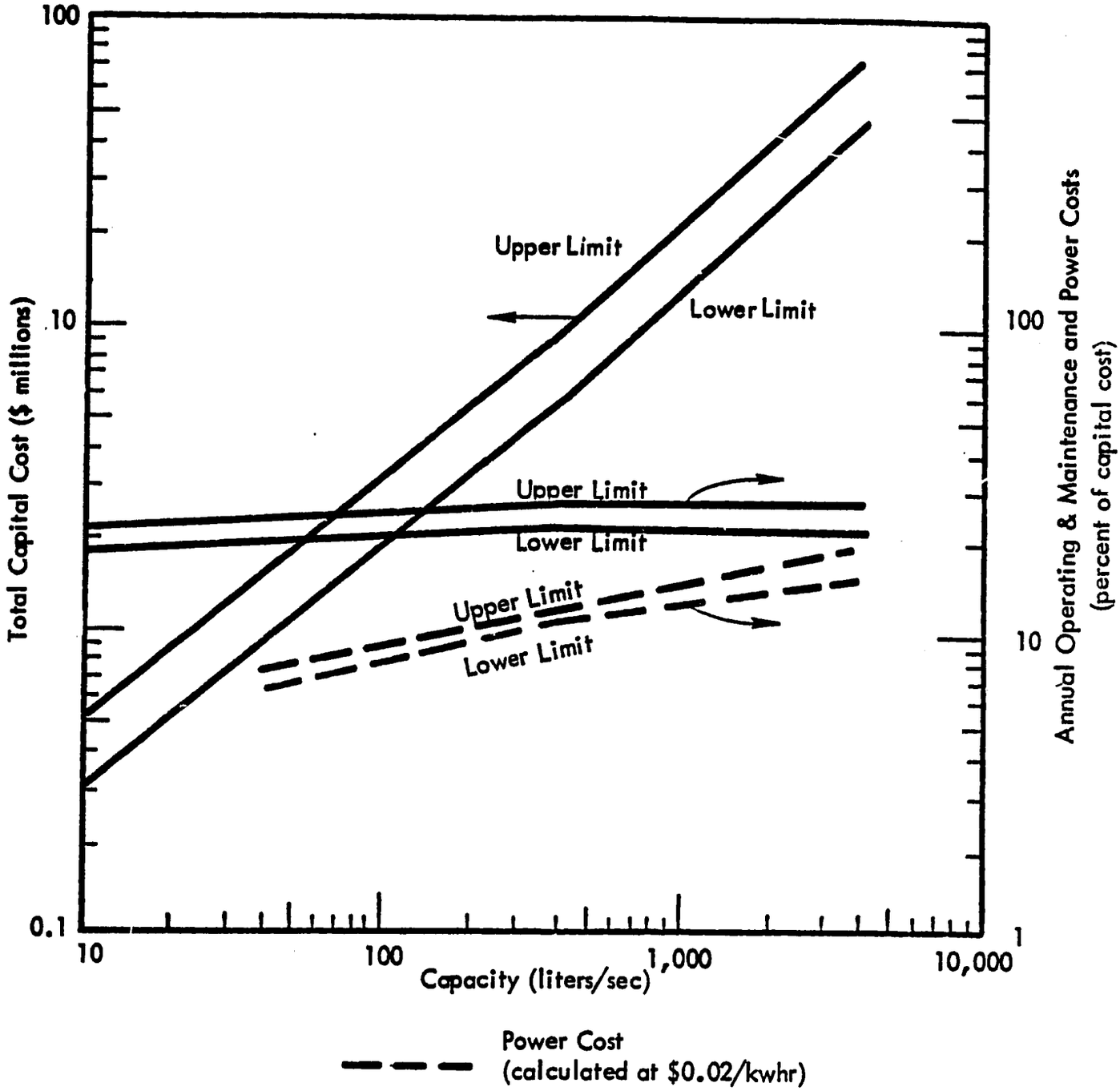


NOTE: Costs include resin, pump, water, storage tank, backwash storage, regenerant storage, underdrains, troughs, electrical, pumps, piping, fans, supports, etc.

Source: 20, 87.

FIGURE 3-64

ION EXCHANGE:
ESTIMATED 1974 COSTS



NOTE: Costs include the land and building, and the brine feed, pH control, filters, deaerator, product-water transfer, chlorinator, main pump, module pressure-vessel, and recovery turbine assemblies.

FIGURE 3-65

REVERSE OSMOSIS, LARGE INSTALLATIONS: ESTIMATED 1974 COSTS

Source: 70.

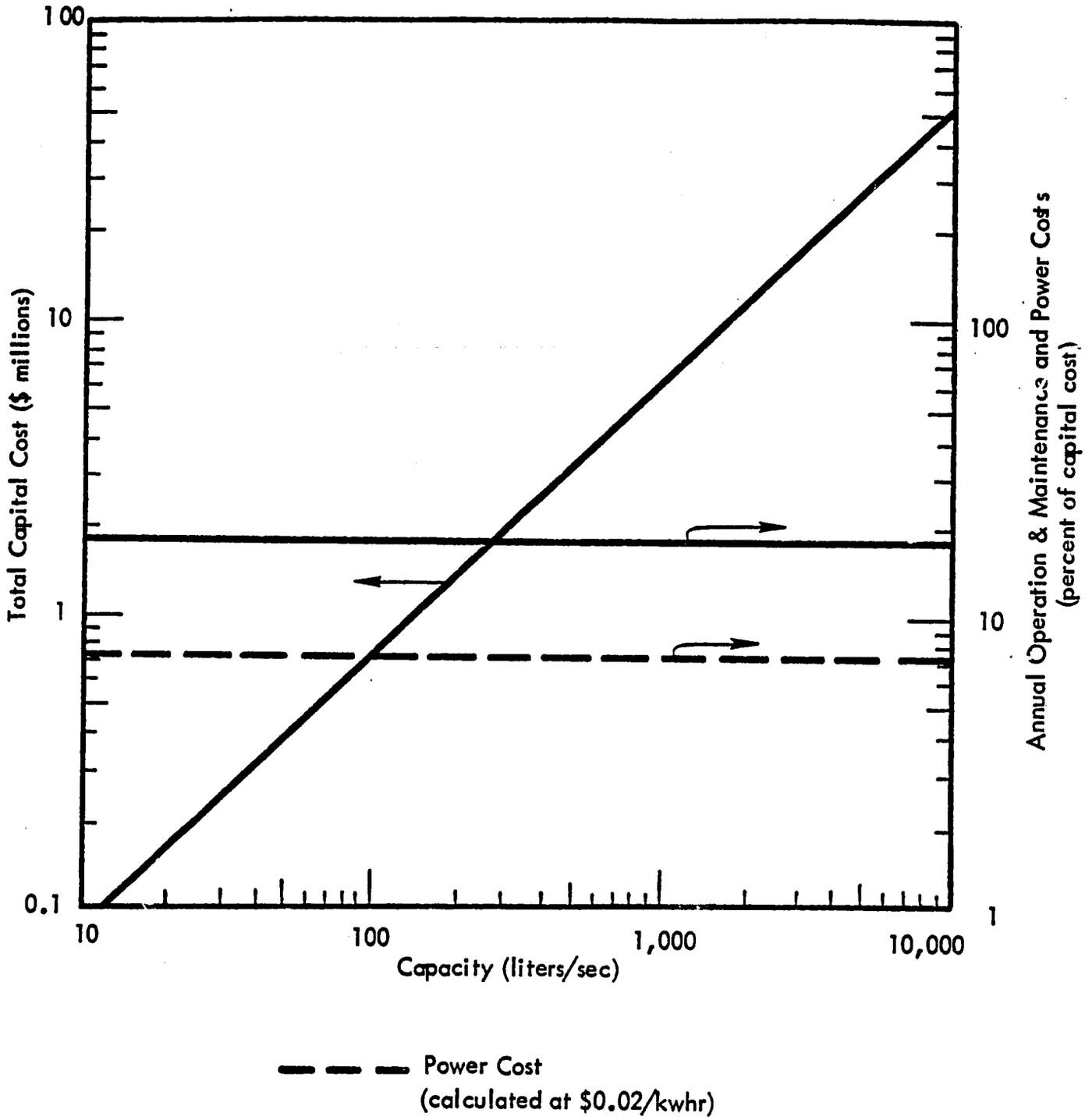


FIGURE 3-66

ELECTRODIALYSIS:
ESTIMATED 1974 COSTS

Source: 16, 47.

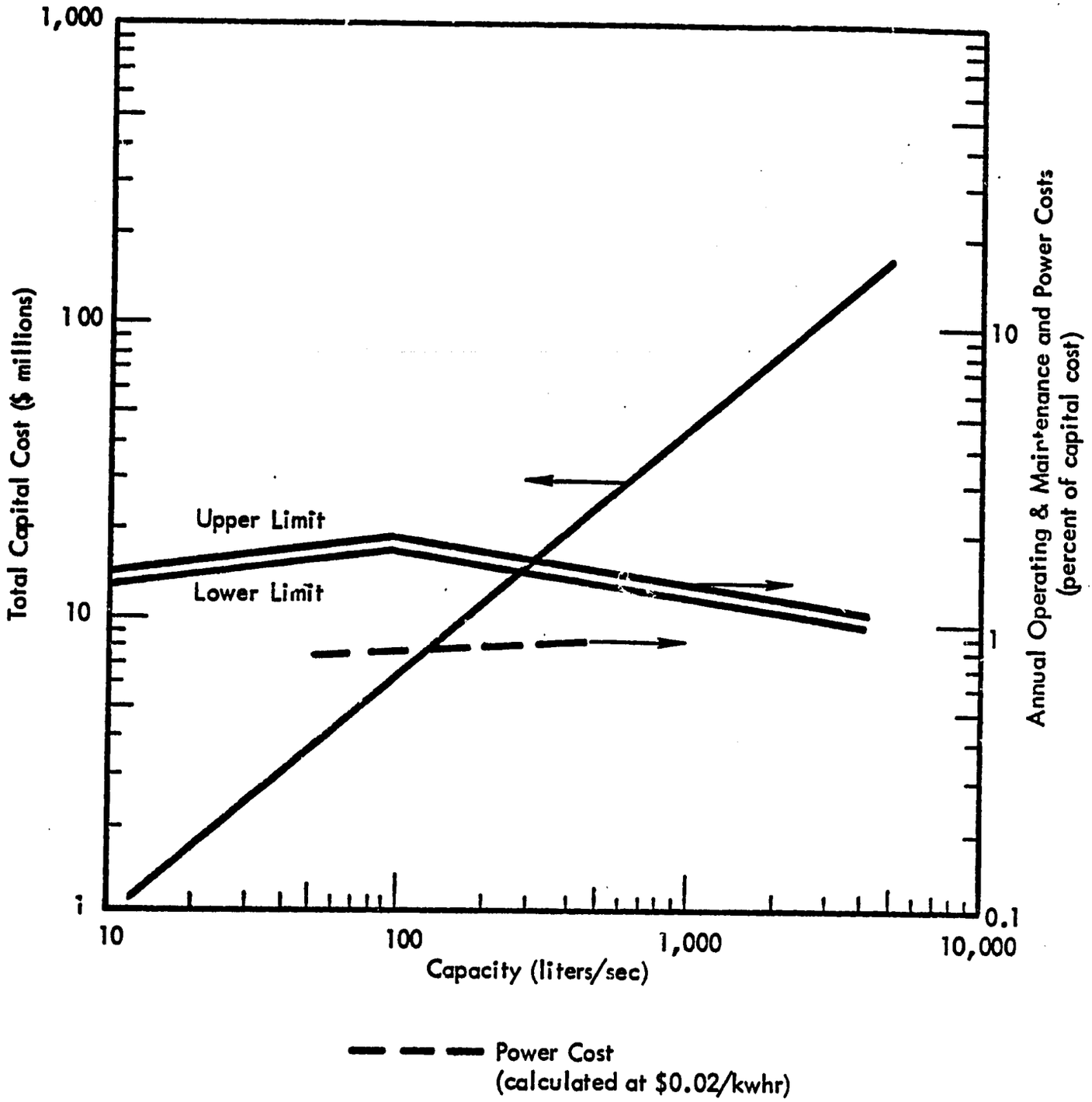


FIGURE 3-67

MULTI-STAGE FLASH EVAPORATION
(DESALINATION):
ESTIMATED 1974 COSTS

Source: 5, 72.

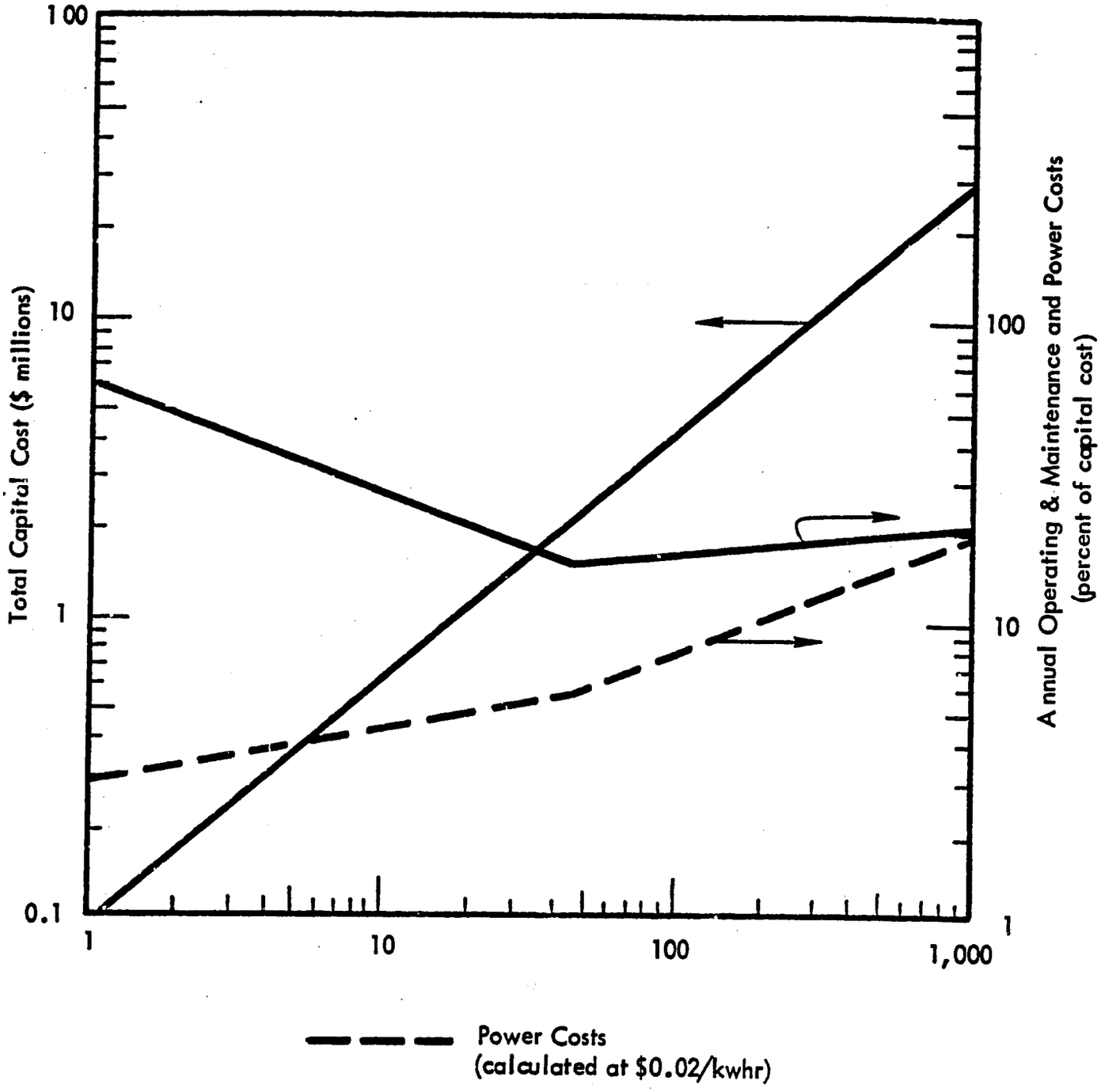
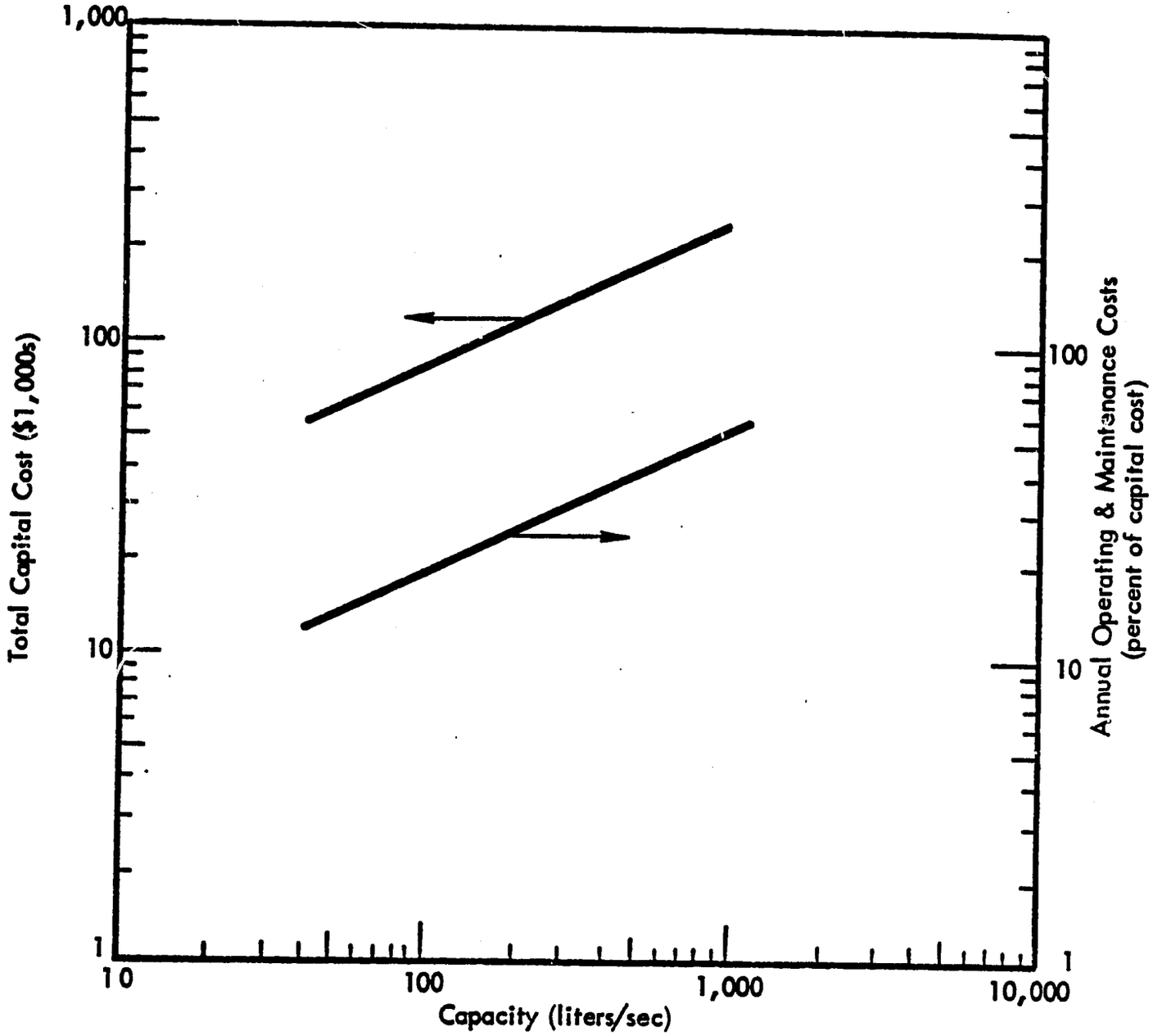


FIGURE 3-68

VAPOR COMPRESSION--VERTICAL TUBE EVAPORATION--MULTI-STAGE FLASH DESALINATION: ESTIMATED 1974 COSTS

Source: 10, 46.

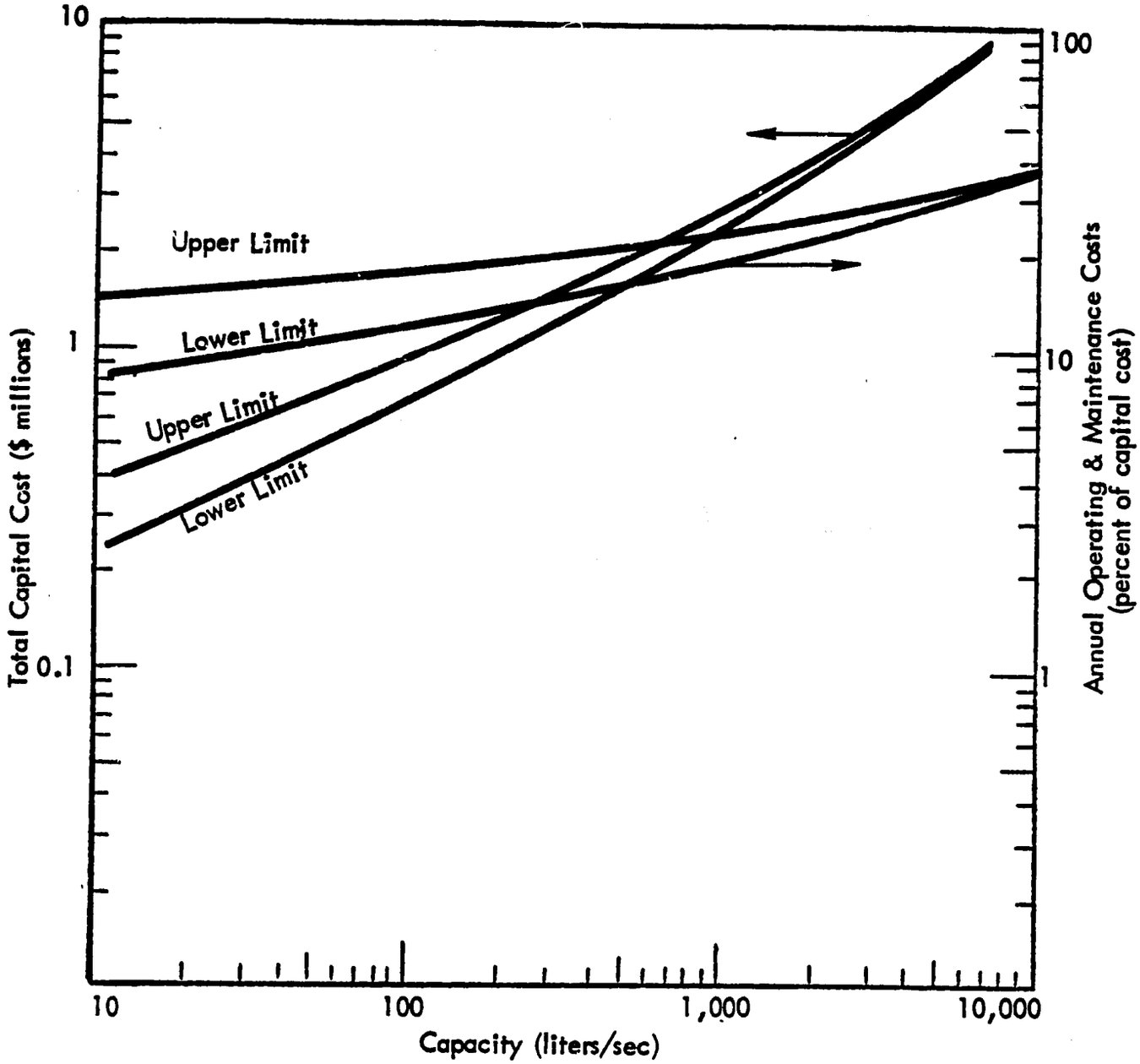


NOTE: Costs include tank, mixer, and feed equipment.

Source: 107.

FIGURE 3-69

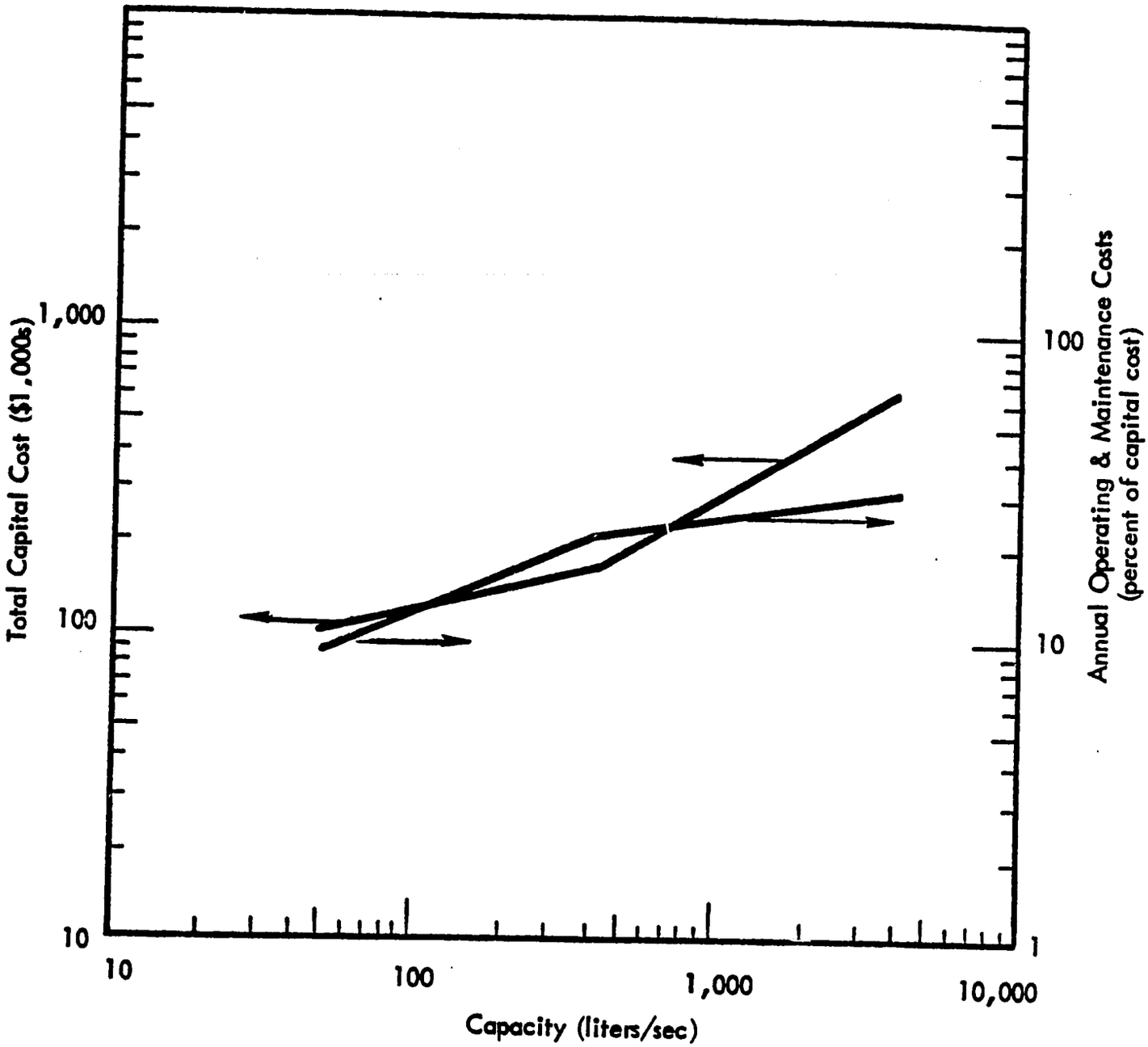
NEUTRALIZATION:
ESTIMATED 1974 COSTS



NOTE: Costs include chlorine feeding and handling equipment, scales, evaporators, structures housing the equipment, and chlorine storage space.

Source: 10, 63.

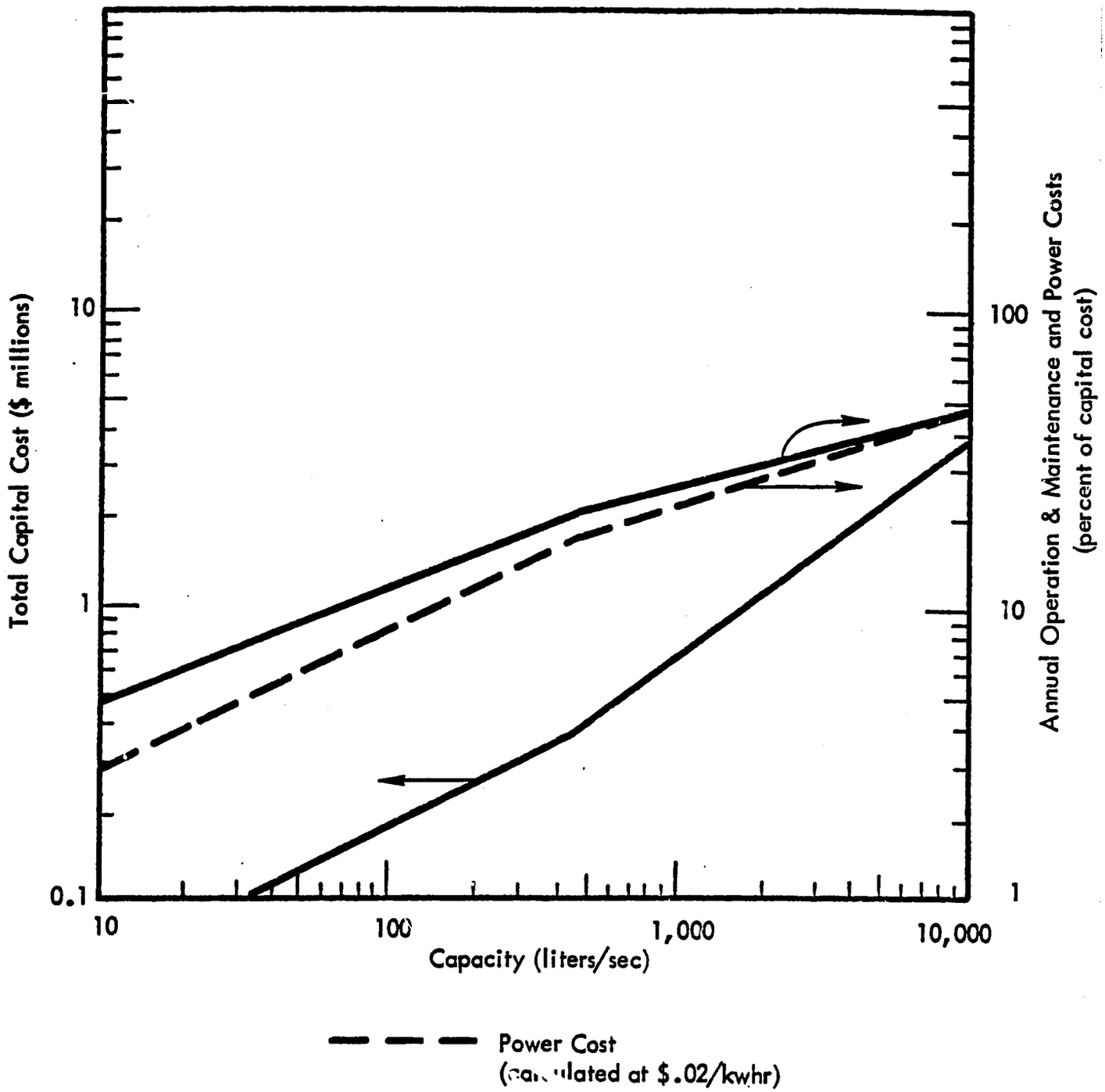
FIGURE 3-70
CHLORINATION:
ESTIMATED 1974 COSTS



NOTE: Costs include chlorine feeding and handling equipment, scales, evaporators, structures housing the equipment, and chlorine storage space.

Source: 63.

FIGURE 3-71
BREAKPOINT CHLORINATION:
ESTIMATED 1974 COSTS

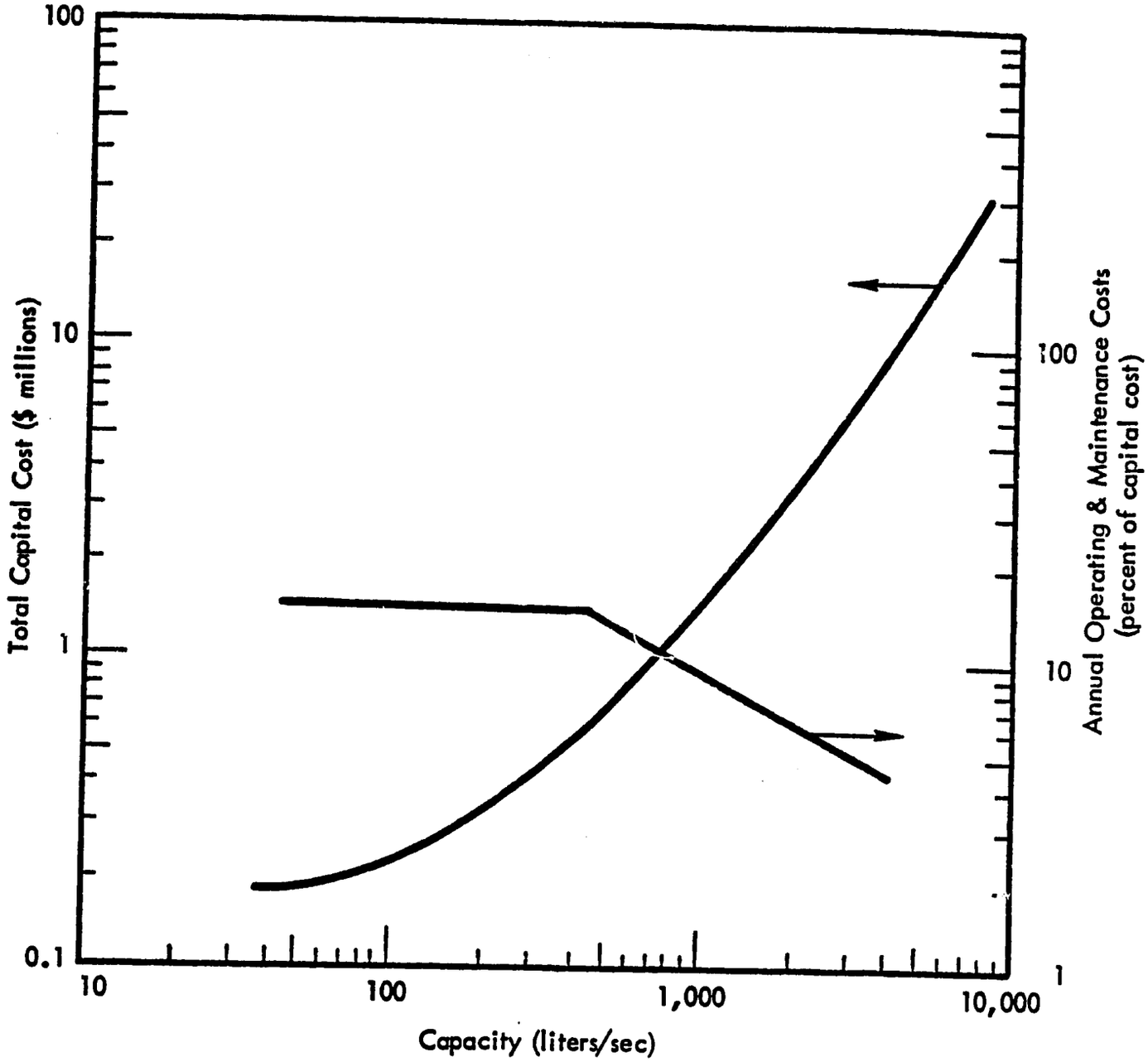


NOTE: Costs include building, contractor tank, ozonators, and driers.

Source: 10, 47.

FIGURE 3-72

OZONATION:
ESTIMATED 1974 COSTS



NOTE: Based on an estimated cost of excavation and embankment construction of $3.90/cu m.

FIGURE 3-73

SPREADING BASIN: ESTIMATED 1974 COSTS

Source: 5, 72.

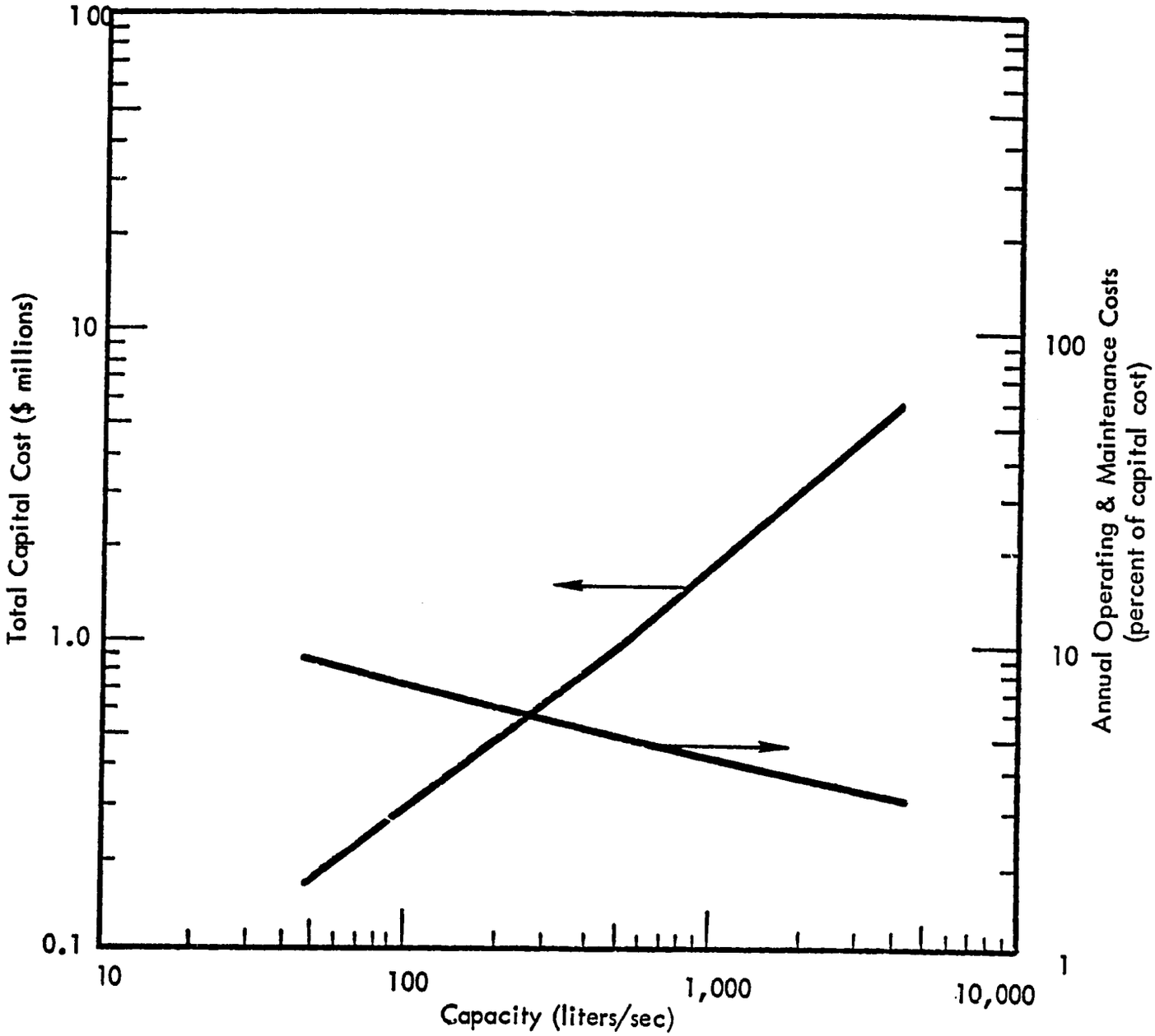
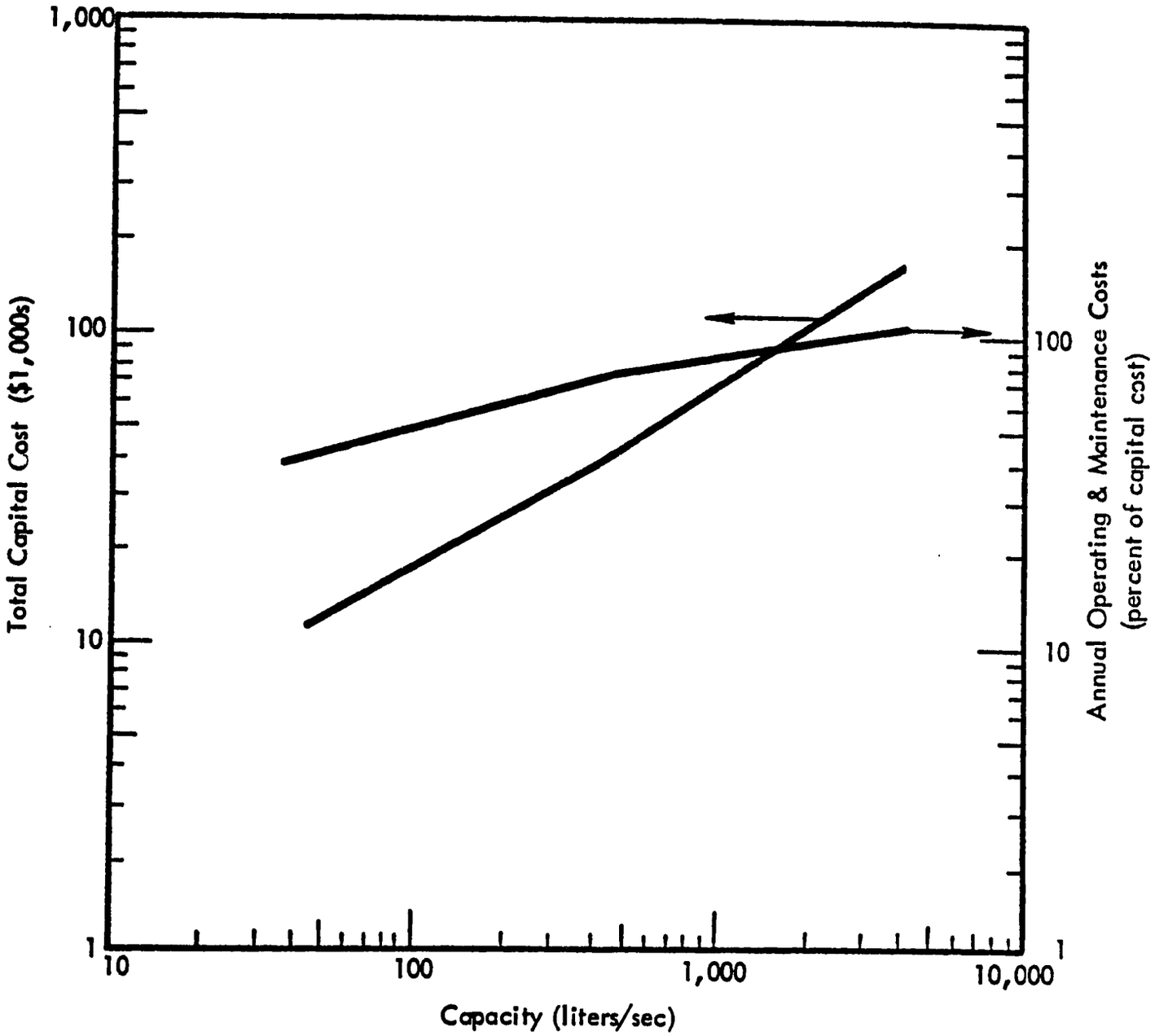


FIGURE 3-74

ANAEROBIC DIGESTION:
ESTIMATED 1974 COSTS

Source: 10.

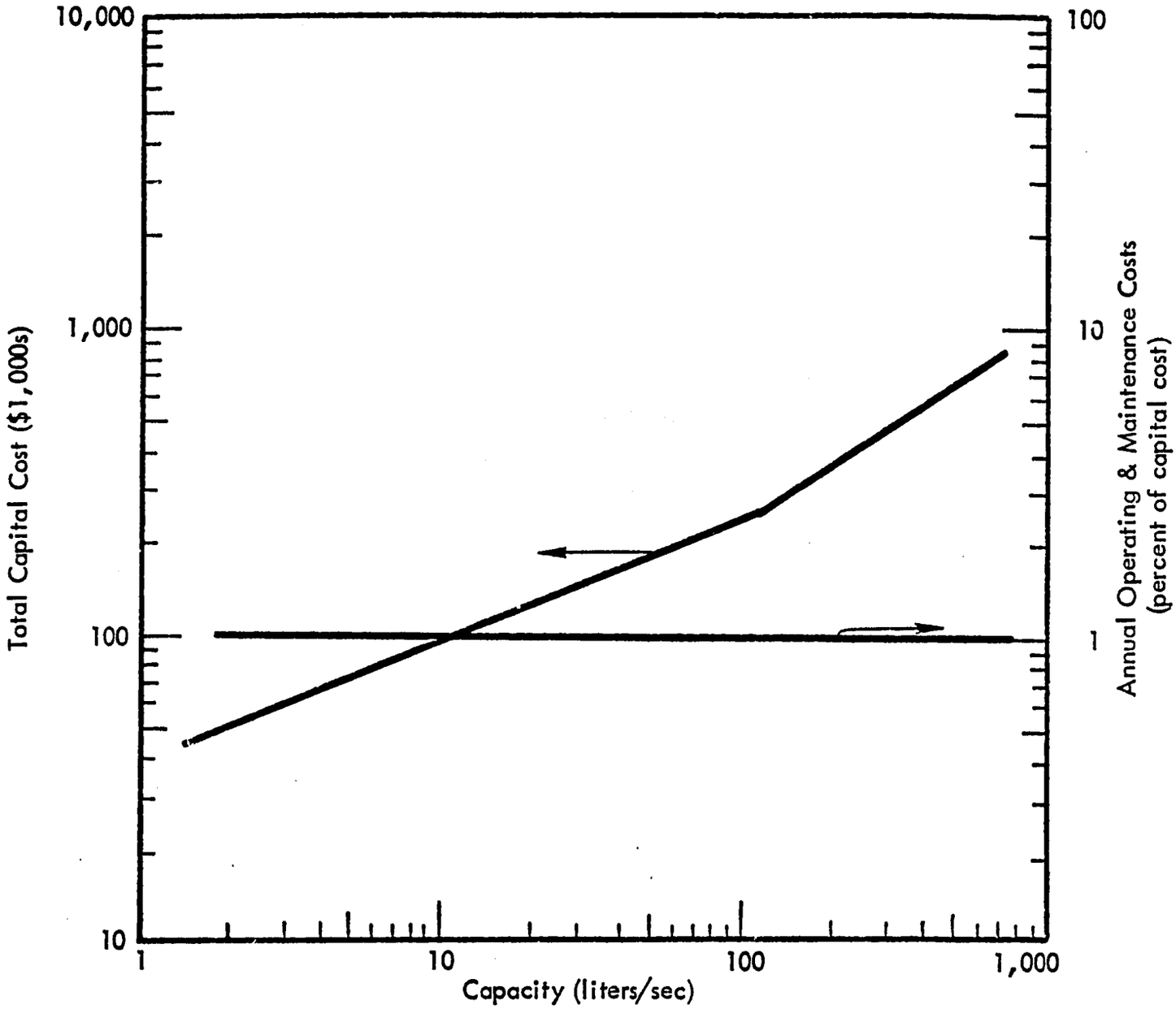


NOTE: Costs include land, excavation, dike construction, and sludge distribution piping.

Source: 10.

FIGURE 3-75

SLUDGE LAGOON:
ESTIMATED 1974 COSTS



NOTE: Costs include thickener.

Source: 87.

FIGURE 3-76

GRAVITY THICKENING:
ESTIMATED 1974 COSTS

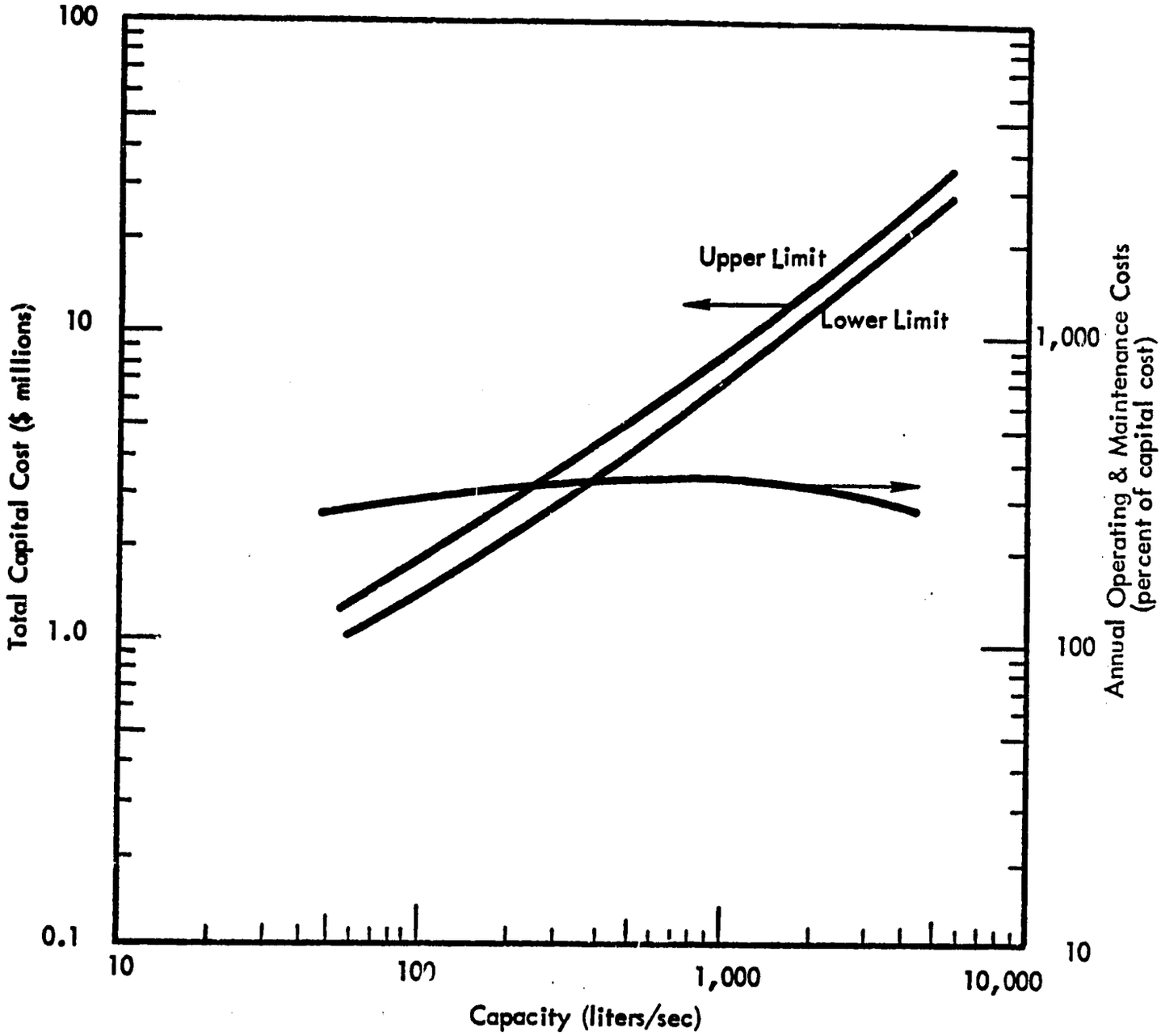
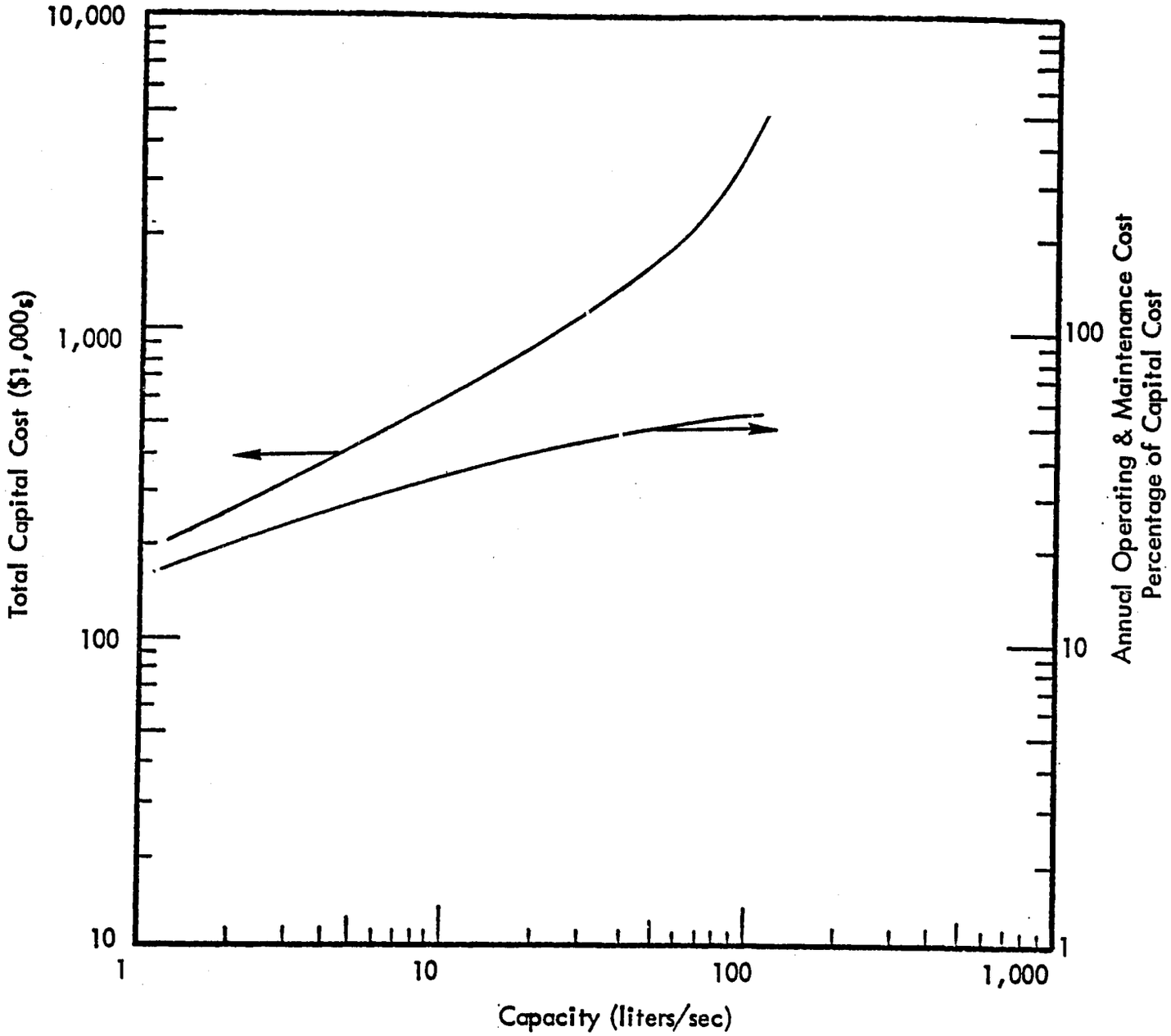


FIGURE 3-77

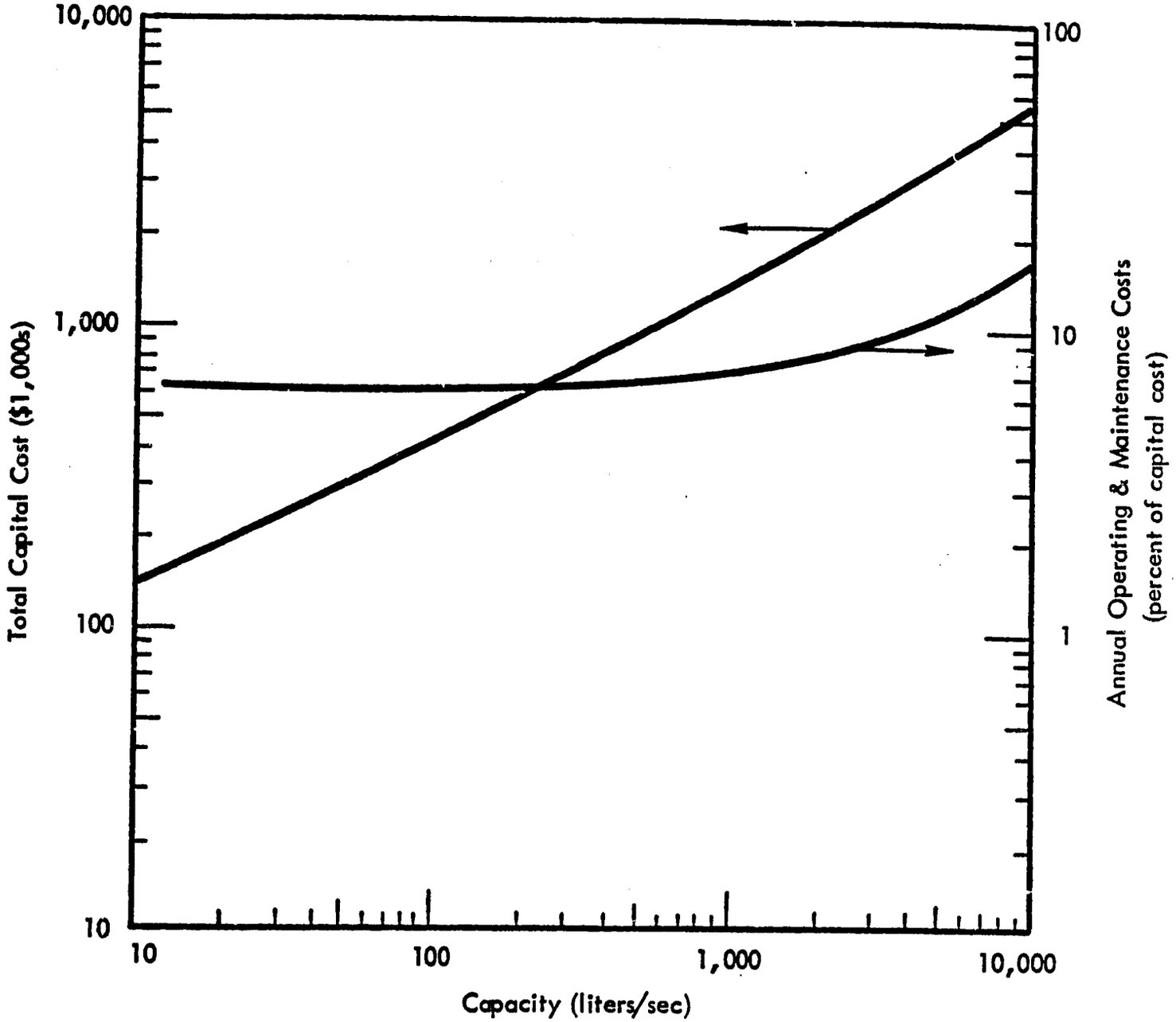
VACUUM FILTER:
ESTIMATED 1974 COSTS

Source: 10, 63.



Source: 5, 72.

FIGURE 3-78
CENTRIFUGE:
ESTIMATED 1974 COSTS



NOTE: Costs include multiple hearth furnaces, gas scrubber and exhaust, ash handling, fuel system, instrumentation, piping, electrical, and enclosing structure.

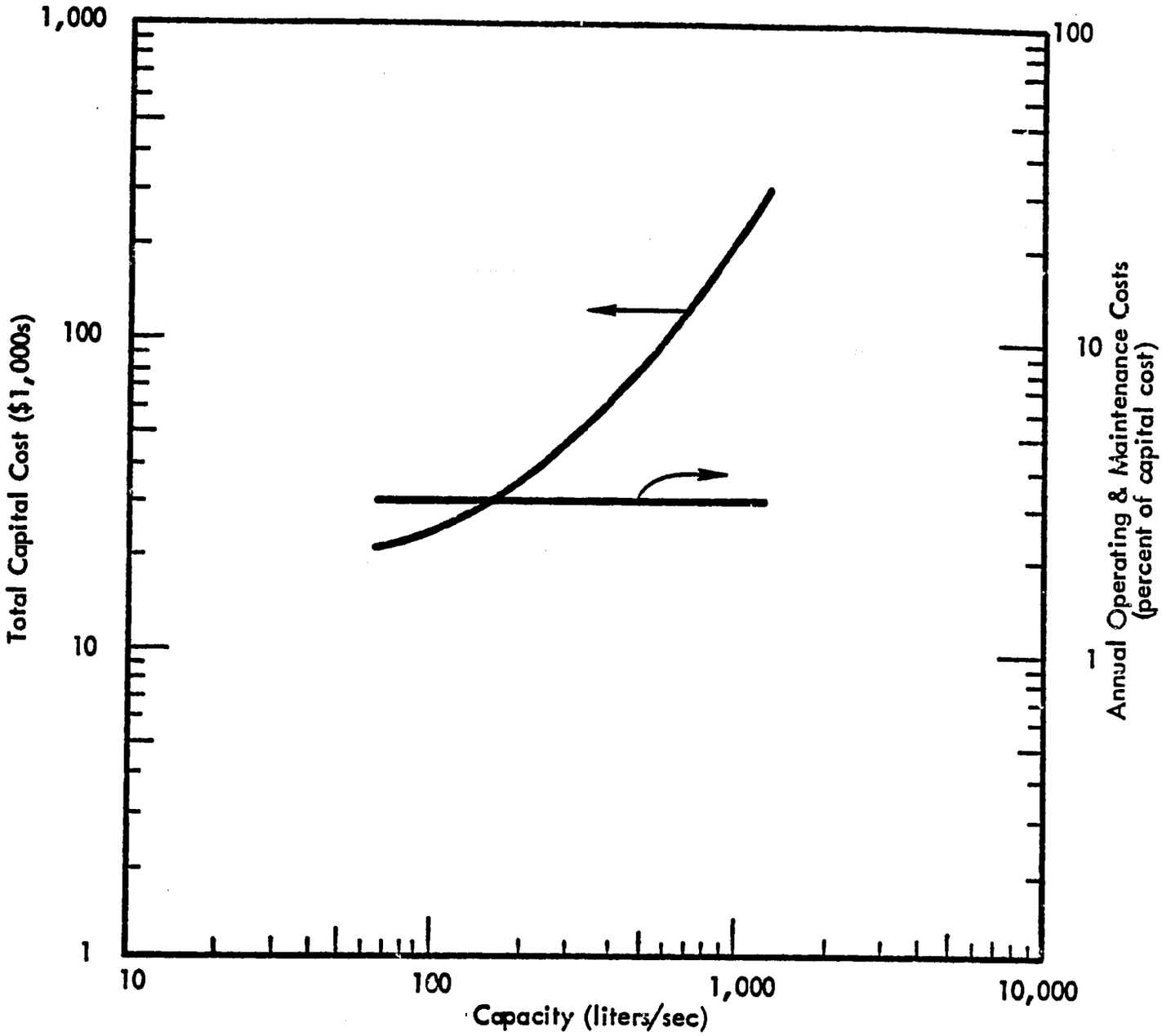
Source: 10, 72.

FIGURE 3-79

MULTIPLE HEARTH INCINERATION: ESTIMATED 1974 COSTS

THERMAL POLLUTION

EQUIPMENT COSTS



NOTE: Costs include cooling tower, basin, handling and settling, piping, concrete foundations and footings, instrumentation, paint, and prime contractor engineering and construction overhead.

FIGURE 3-80

COOLING TOWER: ESTIMATED 1974 COSTS

Source: 87 .