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9. ABSTRACT

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Pollution control for power generation, iron and steel, and food processing industries is discussed, and specific control effects of significant plants within those industries are described. Information on pollution control is also presented on case studies in four Latin American countries--on one waste composting plant and five industrial plants: Iron foundry, coffee roasting, spark plug manufacturing, pulp and paper milling, and ceramic manufacturing. Observations made during all the studies indicate that control cost per unit of product varies inversely with the size and rate of operation, and that control costs are generally a small percentage of total production costs. This information comprises chapter 4 of "Industrial Pollution Control, Technological Strategies," a larger work which discusses the effects and controls of industrial pollutants, and means of reducing their impact on the environment.

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INDUSTRIAL POLLUTION CONTROL

TECHNOLOGICAL STRATEGIES

APRIL 1977

RALPH STONE & CO., INC.
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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.

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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.

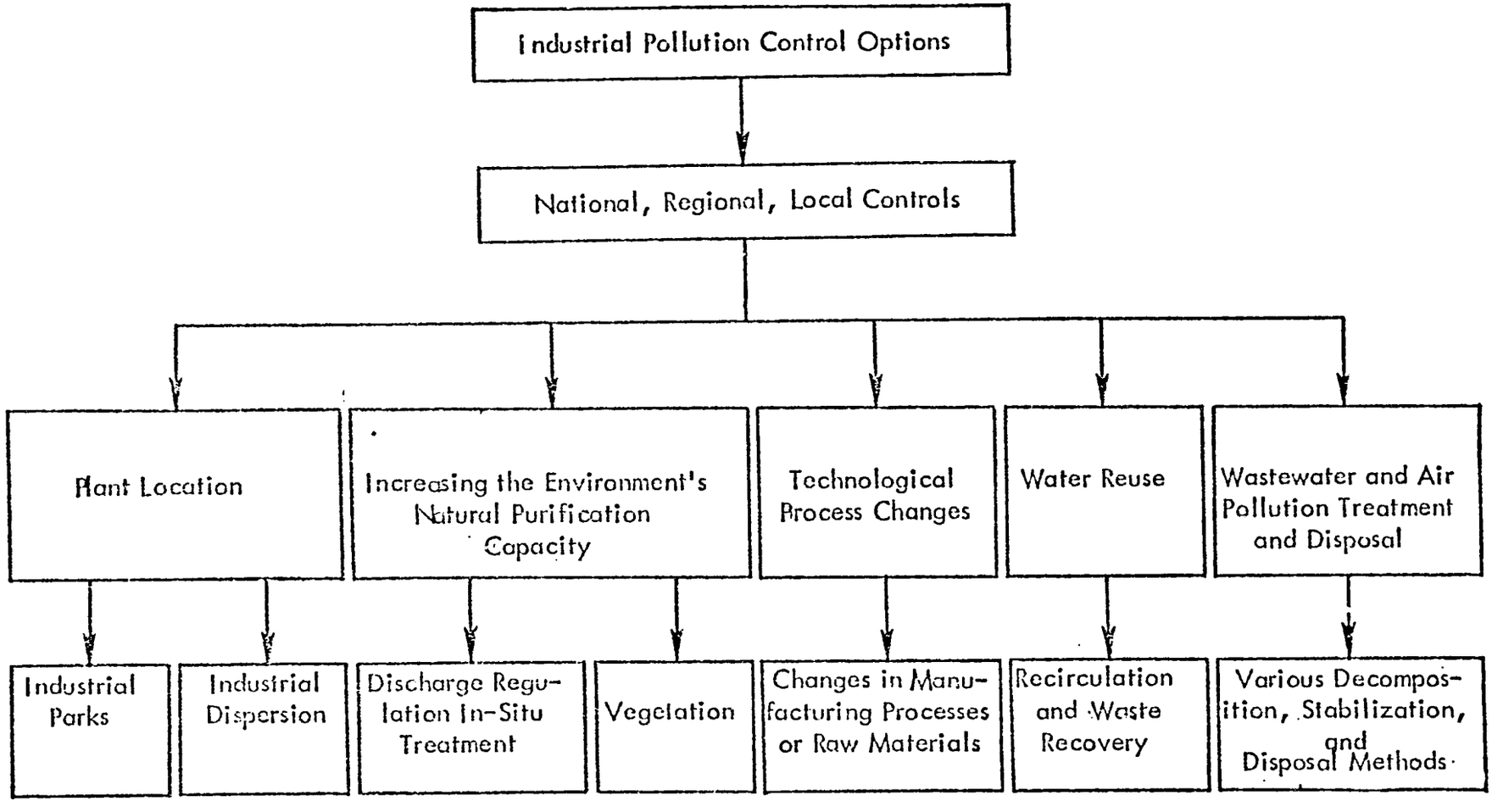

FIGURE 1-1
INDUSTRIAL POLLUTION CONTROL OPTIONS

POLLUTION CONTROL IN CASE STUDY INDUSTRIES: POWER GENERATION, IRON AND STEEL, FOOD PROCESSING, AND SELECTED PLANTS

April 1977

(Chapt. 4 of Industrial Pollution Control, Technological Strategies)

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CHAPTER 4

POLLUTION CONTROL IN CASE STUDY INDUSTRIES: POWER GENERATION, IRON AND STEEL, FOOD PROCESSING; AND SELECTED PLANTS

INTRODUCTION TO THE CASE STUDIES

Three industries were selected for detailed case studies: iron and steel, power generation, and food processing. They were chosen because they are important to economic development and have a high potential for environmental damage. Each of the detailed studies discusses (1) pollution control for the industry as a whole (industry overview), and (2) the pollution control efforts of significant plants within the industry. A final section of the chapter summarizes pollution control information gathered in field trips to industrial plants in four Latin American countries. On-site studies were made of the pollution control methods used in five industrial plants and of the reclamation operations at a solid waste composting plant. A final section of the chapter gives a brief description.

INDUSTRY OVERVIEW

Each overview describes the selected industry's production processes, types and quantities of pollutants generated, pollutant concentrations in the discharge stream, methods of achieving high, moderate, and low levels of air and water pollution control, and the costs of achieving each control level for a wide range of plant capacities.

Steel mill, power plant, and food processor options for controlling pollution include process modification, reuse/recycling, and end-of-pipe treatment. The industry cost studies, however, considered only end-of-pipe treatment for several reasons:(1) it is difficult to cost the other methods because they are frequently part of the regular production process rather than identifiable pollution control measures. At the Kaiser Steel case study plant, for example, it would be difficult to determine whether certain water recycling innovations were undertaken to control pollution, increase manufacturing operating efficiency, or reduce water costs. (2) Many control approaches are relevant only during the initial construction of the plant. (3) The intent of the cost analysis is to provide a common reference point for decision-making concerned with industry in which plants vary greatly in age and specific processes used. The cost and applicability of end-of-pipe treatment systems are generally less dependent on such differences than are other control options.

The main influence on the unit cost of a particular end-of-pipe treatment method is normally the scale (production capacity) of the plant: in general, the larger the plant's capacity, the lower the per unit costs of control. Control costs are therefore expressed as a function of plant capacity. The costs and control levels estimated for end-of-pipe methods do not necessarily represent the lowest possible cost for the given control level or the highest possible control level for the given cost. Where appropriate, process

modification and reuse/recycling methods should also be considered.

In general, air and water pollution control options are separate and independent; the adoption of a given air (water) pollution control method does not greatly affect either the pollution loading or choice of control method for water (air). Low, medium, or higher efficiency air and water pollution control systems can therefore be adopted in any combination desired. If, for example, environmental improvement resources are limited, and local conditions make air quality a much more critical factor than water quality, it may be advisable to adopt strict air pollution control standards and lower water pollution control standards. In some instances air and water pollution controls are not independent. Controlling particulate emissions with wet scrubbers, for example results in a transfer of pollutants from the air to the water. But in the industries considered, the effect on total pollutant loading is minimal (less than 10 percent), and the assumption of independence causes little environmental distortion.

Cost Analysis.

Estimating Pollution Control Costs. The suitability of treatment facilities depend on the production process, the resulting waste stream, and the proposed level of control. The method used to estimate control costs involved: (1) determining waste stream flow rates and pollutant concentrations, (2) developing a conceptual treatment system for plants of several different production capacities, (3) costing those systems, and (4) establishing (from the resulting cost-capacity points) the general relationship between capacity and treatment cost.

Conceptual treatment systems were designed for each case study industry. The treatment facilities were selected (based on United States Environmental Protection Agency and other data) to provide examples of the costs of attaining widely differing control levels. The choice of equipment, however, is not rigid; other equipment with comparable performance and costs can be substituted. The treatment systems were designed for low, medium, and high levels of control, respectively designated: primary, secondary, and tertiary treatment (with tertiary representing the highest level of control). For power generation, however, only the first two levels of control were designed for air pollution (in accordance with the industry's current practices).

Standard engineering sources and indexes were used to develop detailed capital cost information (updated to 1975), and published United States Environmental Protection Agency estimates largely provided the operating and maintenance (O & M) data. The O & M estimaes are based on a percentage of unit capital costs and include: labor, utilities, overhead, maintenance, supplies, administration, treatment chemicals, and insurance.

Annualizing Treatment Costs. To distribute long-term investment costs equitably, the case studies annualize the projected control equipment costs based on a 20-year useful life, an 8 percent interest cost, and the capital recovery method of calculating depreciation over the entire useful life period. Most authorities estimate that with normal maintenance, pollution control equipment has a useful life of about 20 years. This estimate compares well with information gathered during on-site, case-study investigations in the United States, Latin America, Europe, Africa, and Asia.

Actual costs for any one manufacturer or industry will vary according to the interest rates and other cost factors affecting the firm or industry at the given time and place. Since all the data and calculation methods are presented, however, the decision-maker can adjust the calculations as appropriate.

The capital recovery method of estimating depreciation uses an interest rate discounting approach to determine the hypothetical payment which, if made yearly, would be equivalent to the actual cost of periodically purchasing and replacing capital equipment. Based on a 20-year useful life and a given interest rate, one may solve for the equivalent annual payment with the equation

$$y = x + \frac{x}{(1+r)} + \frac{x}{(1+r)^2} + \cdots \frac{x}{(1+r)^{19}}$$

where

y = total capital cost

x = annual capital cost

r = interest rate.

Alternate depreciation methods which fairly distribute total capital cost over useful life may also be used. Accelerated depreciation, however, is not suitable for annualizing investment cost. Where allowed, it involves a rapid write-off of capital investment for income tax purposes. In environmental policy, its use is frequently permitted to encourage investment in pollution control equipment. The effect, however, is to overstate annual pollution control costs during the early write-off period, and understate them during the remainder of the equipment's useful life.

Cost Equations. Calculations, data, and the resulting cost equations and curves are presented at the end of the chapter. The equations make it possible to estimate the total cost for an existing plant to achieve a given level of control, assuming zero current control. For a given plant, such cost estimates would have to be modified to account for any control equipment already installed. In addition, control costs tend to be less for plants engineered in the planning stage than for existing plants which must be retrofitted because (1) the possibilities for using process modifications are greater before construction, and (2) it is cheaper to design a plant for controls than to retrofit an existing plant not designed for controls. The cost equations therefore give upper bounds for the costs of pollution abatement in existing plants which have neither pollution controls or pre-planned fittings. New plants, those with existing controls, and those capable of improving on the cost-effectiveness of the proposed treatment system would have lower costs.

SELECTED PLANT CASE STUDIES

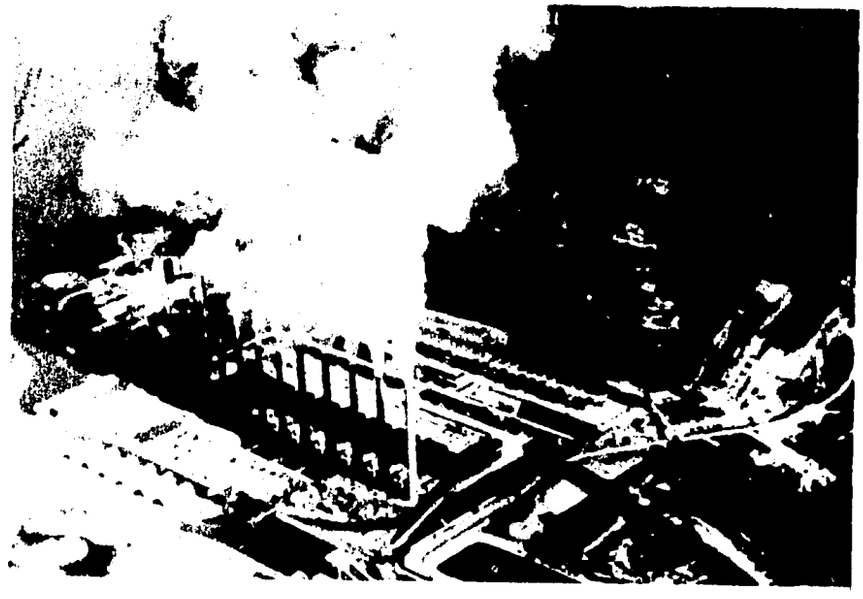
Each industry overview is followed by in-depth studies of either one or two specific plants that have effective pollution control programs in that industry. The plant case studies describe the selected plant's general characteristics, production methods, pollutant generation, pollution control methods and related available cost information. For this purpose, on-site field investigation was made of two power plants, one steel plant, and two canning plants. Information concerning the five plants is based on direct observation, interviews with management, and data supplied by the firm. The individual plant studies consider the environmental problems associated with the particular operation, control strategies in use and their effectiveness, and available cost data.

The selected case study plants are large, economically viable producers with excellent success records in pollution control and a willingness to cooperate in the case studies. The purpose of the individual plant studies is to present examples of pollution abatement under actual operating conditions and without undue financial burden on the manufacturer. The case study plants are not subsidized "showcases." They operate under the same rules as other plants in their industry and region, compete successfully with them, and are profitable. They are also highly successful in their pollution control efforts and in making those efforts consistent with profitable production. All of the detailed case study plants are located in an area where the lack of water and prevalence of temperature inversions make it difficult to comply with pollution control standards. Their levels of pollution abatement may therefore be considered minimum, readily attainable goals. Similar plants in less difficult environments should be able to achieve higher levels of control and/or lower pollution control costs.

POWER GENERATION

INDUSTRY OVERVIEW

The function of an electric power plant is to convert mechanical energy into electrical energy. The mechanical energy may be obtained from any of several sources, but the most common are hydroelectric, nuclear, and fossil fuel. (Geothermal and solar energy sources are little used at the present time.) Hydroelectric power plants use the energy of moving water to run electrical generators. In general, they consume no fuel, produce very little pollution, and discharge no significant amounts of heat to receiving waters. Since hydroelectric plants are not a prominent source of pollution, they will not be further considered here. Nuclear power plants use heat from atomic fission to produce steam and the steam to run electrical generators. Nuclear power plants release considerable thermal pollution, some small quantities of other pollutants, and generate highly dangerous radioactive waste products. The pollutants generated and the control problems created by nuclear power plants are unique and specialized and will not be considered here. (For those interested in nuclear power, however, a broad, published literature is available.) Fossil-fuel power plants are the major producers of electric power and generate large quantities of air and water pollutants. (See Photograph 4-1.) The remainder of this case study will be devoted to their consideration.



Photograph 4-1

Emissions from a steam electric power generating plant before installation of air pollution control devices.

Production Process

Fossil-fuel power plants burn coal or petroleum source fuels to produce steam and then use electrical generators to convert the mechanical energy in the steam into electrical energy. Figure 4-1 presents a process schematic of a typical power generating unit with cooling water recirculation. It identifies the major pollutants generated and their sources.

There are five unit processes:

- Storage and handling of fuel and related materials, both before and after use.
- Conversion of water into high pressure steam in a boiler using the heat obtained from burning fuel.
- Steam expansion in a turbine to drive the generator.
- Conversion of the rotating mechanical energy of the turbines into electrical energy by means of generators.
- Condensation of the steam leaving the turbine and its return to the boiler for reuse.

Three basic types of fuel are used: coal, natural gas, and oil. Fluid fuels are stored in tanks and handled by systems which prevent air exposure. Their storage seldom generates pollution. Possible corrosion of tanks and piping, however, is a problem. Coal is stored in piles open to the air and is handled by conveyance systems open to the air. Runoff from coal piles is similar in composition to acid mine drainage. Acids, dissolved solids, oil and tar, and suspended solids are contaminants. The pH may vary from as low as 2.5 for drainage from coal with high sulfur content to almost 7 for drainage from coal with low sulfur content.

Steam production is generally uniform, differing only in the mechanics of the actual heat production. The production of high-pressure steam involves the oxidative combustion of fuels and subsequent transfer of the heat of combustion to water by radiation and convection. The highest possible thermal efficiency requires transferring as much heat as possible from the combustion gases to the steam. Any heat left in the emitted gases represents waste heat and a loss of efficiency. Maximum efficiency is obtained through a series of steps. The feed water is heated to boiling by the gases exiting the boiler. The water is vaporized by radiant heat as it passes through tubes in the walls of the combustion zone of the boiler. The steam is superheated by convection of the gases in the superheater section of the boiler. Even the flue gas heat is used to preheat the incoming air so as to avoid the loss of efficiency caused by wasting energy to heat up the fresh inlet air entering the boiler.

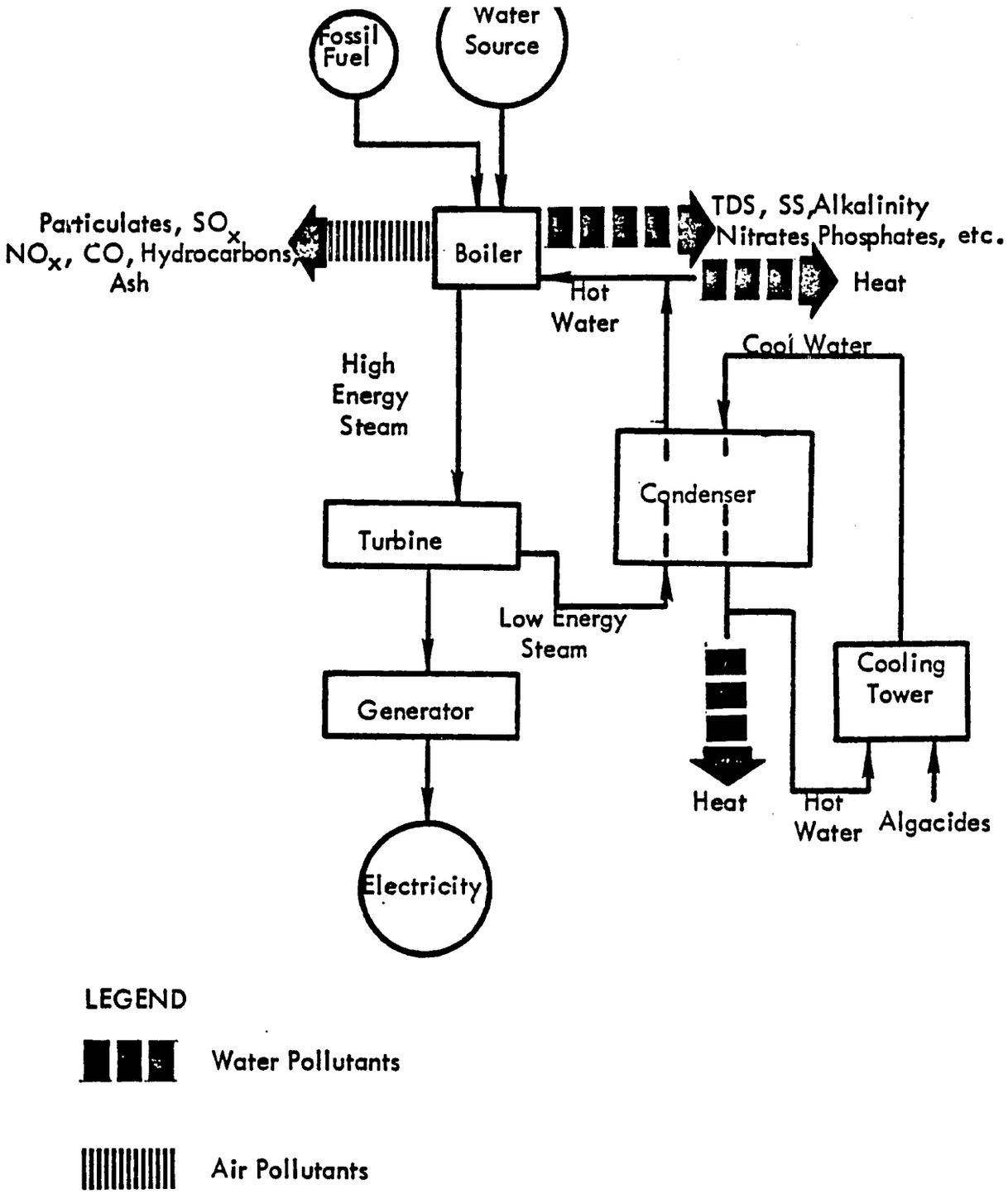


FIGURE 4-1
ELECTRIC POWER PRODUCTION

The superheated steam is passed through a series of turbines, releasing energy as it passes. A variety of moving and planetary, high and low pressure turbine arrangements may be used. In a process parallel to that for pre-heating incoming air, the hot water condensed from this steam in the latter portions of the cycle is used to pre-heat the fresh feed water.

Process steam must be condensed to maintain a low turbine exhaust pressure and maximum power generation efficiency. This is achieved through a series of condensers and cooling towers. Cooling is generally done by the water evaporation process, so any existing dissolved solids tend to increase and some blowdown wastewater and make-up treated fresh water are required to prevent scaling.

Pollution Control

Air Pollutants. Table 4-1 lists the types and quantities of atmospheric emissions from fossil-fueled power plants. It shows discharge quantities for a given quantity of each fuel and the equalized quantities for a constant heating value. Pollutant loads will vary depending on the type of fuel, the fuel source, and the combustion conditions. Coal produces the largest quantities of particulates, while natural gas produces little ash. The particulate emissions of hard and soft coal vary. Sulfur oxide emissions are directly related to the sulfur content of the fuel. The quantity of nitrogen oxides emitted is related to the temperature of combustion, oxygen content in the combustion chamber, bound nitrogen in the fuel, and other factors.

Particulates can be removed with centrifugal cyclones, mechanical filters, electrostatic precipitators, and wet or dry scrubbers. Selection depends on the type of particulate, the desired removal efficiencies, and economic constraints. Particulate emissions can also be reduced by substituting low-ash for high-ash fuel. This may be done by switching to a different type of fuel (oil produces fewer particulates than coal, and natural gas less than oil) or by using the same type of fuel with a lower ash content (anthracite coal has a lower ash content than bituminous coal, for instance). The type of burner mechanism can also influence particulate emissions (see Table 4-2).

Sulfur dioxide control by scrubbing (either wet or dry) is the most frequently used end-of-pipe treatment method. Dry absorbents include manganese oxide, hopcalite, cobalt oxide, nickel oxide, copper oxide, and calcium hydroxide. Removal efficiencies depend on specific operating characteristics and the best choice for a given situation must usually be determined through experimentation. Wet absorbents usually consist of dilute aqueous alkaline magnesium or calcareous salt solutions. Scrubber configuration can vary and includes packed-bed systems, spray towers, venturis, or combination units. Where available, substituting low-sulfur fuel can effectively reduce sulfur dioxide emissions without resorting to relatively expensive, technologically complex scrubber systems.

Hydrocarbon emissions can be controlled with adsorbents or afterburners. Adsorbent systems generally employ activated carbon, although several synthetic adsorbents are available. Afterburners burn off flammable hydrocarbon emissions as they leave the

TABLE 4-1

EMISSION FACTORS FROM FUEL COMBUSTION

Emission Source	Solids	SO_x	NO_x	Hydro-carbon	Organic Acids	Aldehydes	Ammonia
Coal	(kg unit of fuel[a])						
Bituminous	50	37.5	10	10	15	1	1
Anthracite	7	12.5	10	1.5	2.5	0.5	1
Fuel oil							
Residual #5 and #6	1.2	25.2	14.4	0.6	1.8	0.1	0.1
Oil distillate #1 and #4	1.2	10.2	8.4	0.6	1.8	0.2	0.1
Natural gas	160	10	2.883	1,121	961	160	8
	(equalized for constant heating value--kg/10^6 kcal)						
Coal							
Bituminous	6.62	4.96	1.32	1.32	1.99	0.13	0.13
Anthracite	1.00	1.79	1.43	0.21	0.36	0.07	0.14
Fuel oil							
Residual #5 and #6	0.12	2.52	1.44	0.06	0.18	0.01	0.01
Oil distillate #1 and #4	0.13	1.09	0.90	0.06	0.19	0.02	0.01
Natural gas	0.02	0.001	0.32	0.13	0.11	0.02	0.001

[a] Per kkg coal, 1,000 liters fuel oil, and 10^6 cu m natural gas.

Source: 12.

TABLE 4-2

PARTICULATE EMISSION FACTORS FROM COAL COMBUSTION[a]

Type of Combustion Unit	Particulate Generation (kg/kkg of coal burned)
Pulverized	
General	640
Dry bottom	723
Wet bottom without fly-ash reinjection	423
Wet bottom with fly-ash reinjection	1,440
Cyclone	10
Spreader stoker	
Without fly-ash reinjection	423
With fly-ash reinjection	1,000
All other stokers	63

[a] Assuming no control measures are taken.

Source: 12.

stack. A variation of this system involves injecting these gases into a boiler or other combustion unit. This system reduces hydrocarbons and lowers fuel costs.

Nitrogen oxide (NO_x) forms when fossil fuels are burned in air. Nitrogen in the combustion air and bound in the fuel source combines with oxygen in the air to form NO_x in the reaction

$$N_2 + O_2 \rightleftarrows 2NO_x$$

This reaction will eventually reach equilibrium, with the final concentration of NO_x dependent on several factors, including flame temperature, gas concentrations, and gas movement through areas of different temperatures, pressures, and concentrations.

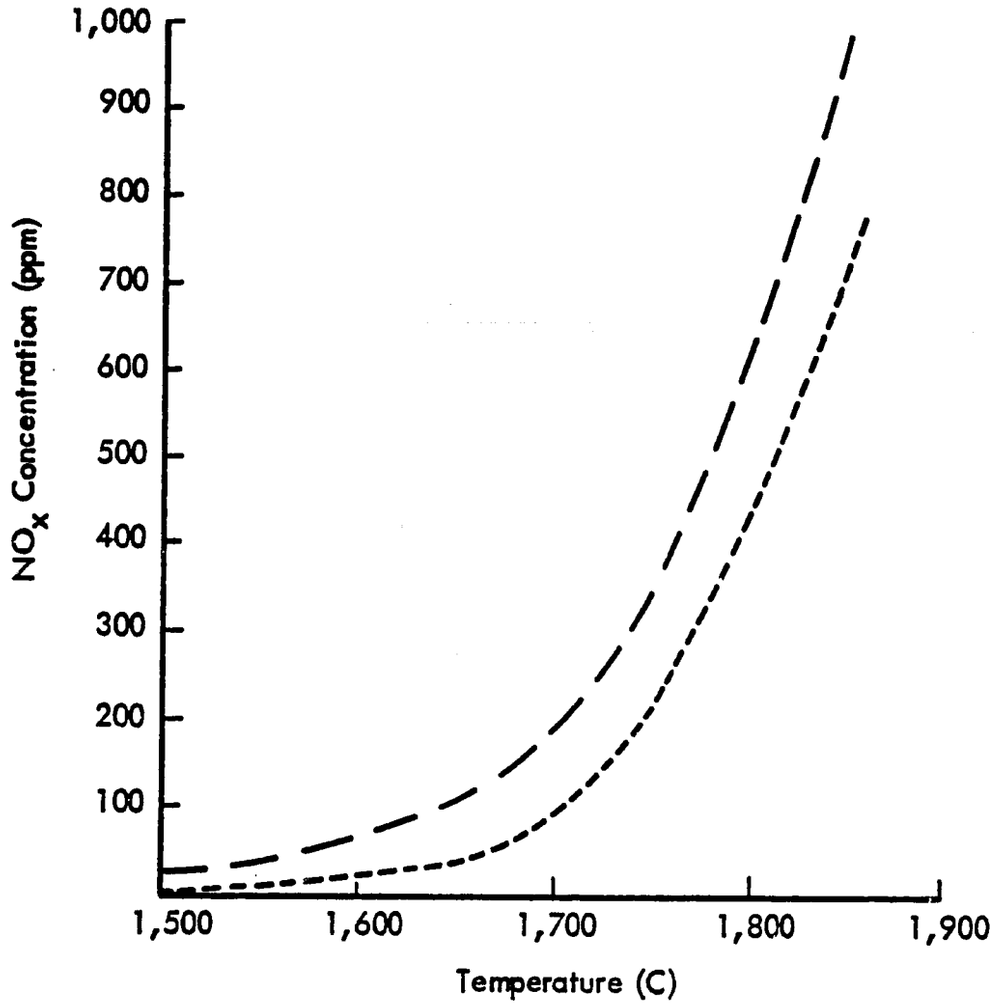
Once formed, however, NO_x decomposes (to nitrogen and oxygen) very slowly, and therefore will persist after it leaves the combustion zone.

The major determinants of NO_x formation in a boiler are: flame temperature, time vs temperature profile, amount of excess air present in the combustion zone, and amount of bound nitrogen in the fuel.

Figure 4-2 illustrates, for oil- and gas-fired generating units, the relationship between temperature and NO_x formation. The relationship is similar for coal-fired units, except that NO_x generation is higher. Table 4-3 shows the importance of residence time in NO_x formation. Not only does the equilibrium concentration of NO_x rise with temperature, but the residence time necessary to form as much as 500 ppm NO_x declines rapidly. The relationship between excess air and NO_x generation is shown in Figure 4-3 (percentage oxygen in the flue gas is used in this figure as a proxy for percentage of excess air). Excess air is the amount of air present above that theoretically necessary for complete fuel combustion (called the stoichemetric quantity). This oxygen is therefore available for combination with nitrogen. The location of maximum temperature zones and the excess air in those zones is more significant in NO_x generation than average temperature or average excess air. This is one reason it is difficult to predict NO_x generation from a given unit: many factors influence the distribution of temperature zones and excess air concentrations.

Once nitrogen oxides are formed, they are difficult to remove from the waste gases. Much less effort has gone into developing removal devices for NO_x than for SO_x. In fact, the methods available for NO_x control remove NO_x as a by-product of SO_x control, generally achieving 20 percent or less nitrogen oxides removal. The only commercial process reported to remove nitrogen oxides is Combustion Engineering's lime - SO_2 scrubbing process. Other processes under study for SO_x control that have shown some ability to remove NO_x are the Reinluft Char Process and the Tyco Laboratories' Modified Lead Chamber Process.[79]

Effective process modification appears to be a promising control approach. It works by modifying one of the factors in NO_x generation (temperature, excess air, etc.).



Legend

— — Oil-fired

----- Gas-fired

Note: Based on comparable excess air presence and 0.5 sec residence time.

Source: 79

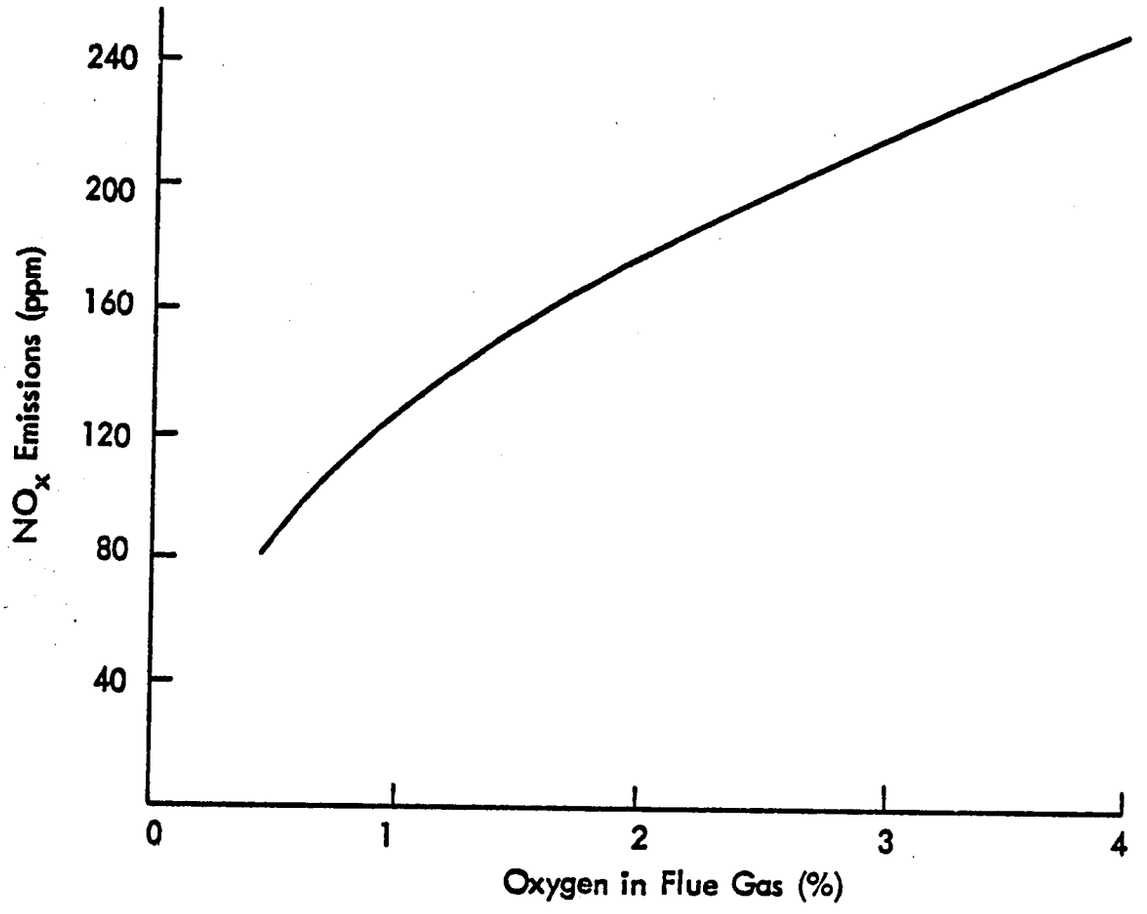
FIGURE 4-2
EFFECT OF TEMPERATURE ON NO_x FORMATION

TABLE 4-3

EFFECT OF TIME ON NO_x FORMATION

Temperature (C)	Equilibrium Concentration NO_x (ppm)	Time to Form 500 ppm NO_x (sec)
1,080	180	
1,300	550	1,370
1,525	1,380	16.2
1,745	2,600	1.1
1,970	4,150	0.12

Source: 12.



Source: 79.

FIGURE 4-3
EFFECT OF EXCESS AIR ON
NO_x FORMATION

The following process modifications and input substitutions have been used for NO_x control: flue gas recirculation, low excess air firing, two-stage combustion, over-fire air ports (NO_x ports), burner improvement modifications, by-passing the air preheater, and fuel substitution.

Figure 4-4 illustrates the effects of flue gas recirculation. Table 4-4 shows the effects of low excess air, two-stage combustion, and flue gas recirculation for different types of fuel. Figure 4-5 shows the effects of preheating the combustion air to different temperatures. The impact of burner configuration is illustrated in Table 4-5.

Water Pollution. Figure 4-1 shows the major water pollutants generated by each step in the production process. Table 4-6 presents average wastewater flow rates from coal, oil, and natural gas generating units.

Because of evaporation, total dissolved solids build up in the boiler water. These solids are soluble salts that are essentially constituents of the feed water. The concentrated brines can have deleterious environmental and health effects. Their treatment varies. Many power plants simply dilute the waste down to acceptable solids levels with extra feed water. This is only possible when adequate water is available, as is normally the case with once-through cooling systems. Other plants remove some of these excess solids through chemical precipitation or one of the more sophisticated polishing techniques (ion exchange, reverse osmosis, electrodialysis).

Power plant wastewater may also contain a variety of chemicals which have been added at the plant. Biocides are generally added to prevent biological growths in cooling systems, for instance. Depending on the choice of chemicals, their presence may or may not be a problem in the wastewater. Since non-hazardous biocide chemicals are available which can effectively accomplish the desired purpose, there is no need to discharge hazardous chemicals.

Residue accumulations, scale build-up, and corrosion require periodic cleaning. Depending on the particular surface to be cleaned, water or acid is used. The wash water will be high in the residual dissolved metals and particulates. Generally, treatment must be provided to neutralize the acid wastes, and settling tanks are necessary to remove the suspended matter. Dissolved solids are either discharged or subjected to the treatment methods mentioned earlier.

Air pollution control devices may also generate some water pollutants. Wet scrubbers produce wastewaters high in suspended matter and, if high-sulfur fuels are being used, sulfates, nitrates, and other related chemicals. These can be treated as discussed above.

Thermal pollution of natural waterways occurs if warm or hot water is discharged at sufficient volumes and temperatures to raise the temperature of the natural water body so as to alter its ecological balance. Potential thermal pollution may be reduced by process change, recovery of waste heat, and cooling before discharge.

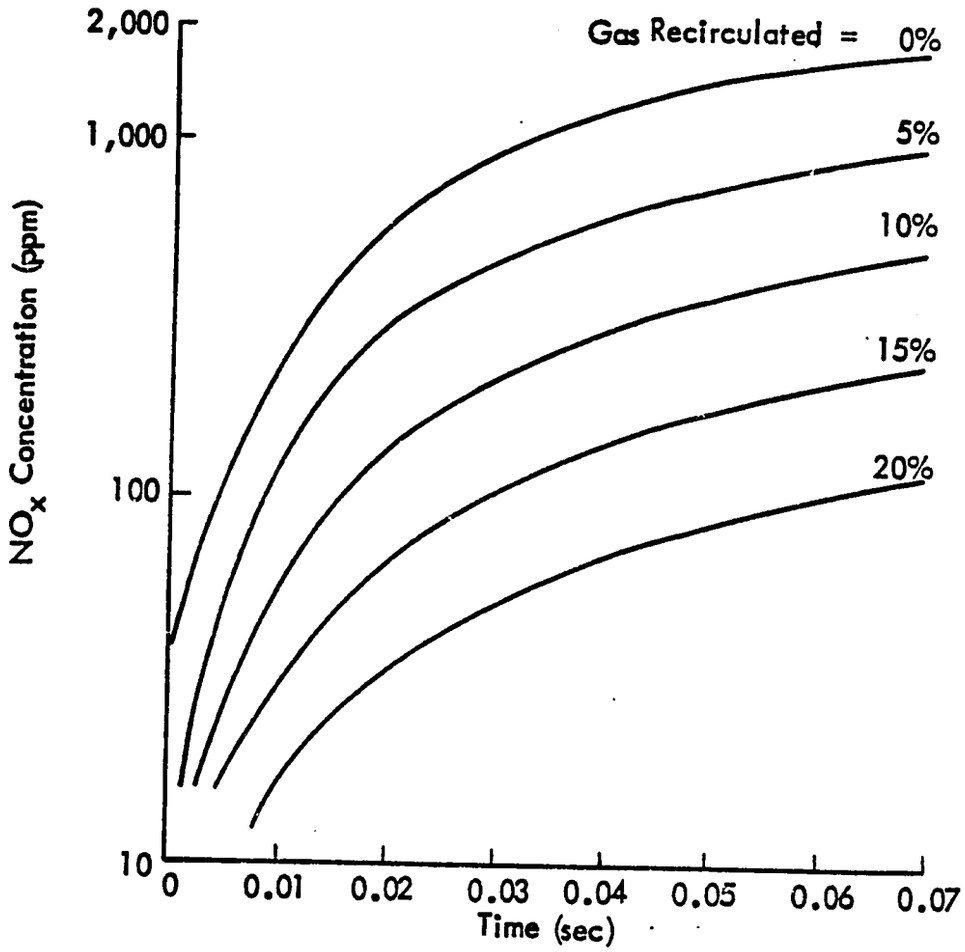


FIGURE 4-4
EFFECT OF FLUE GAS
RECIRCULATION ON NO_x
GENERATION

Source: 85.

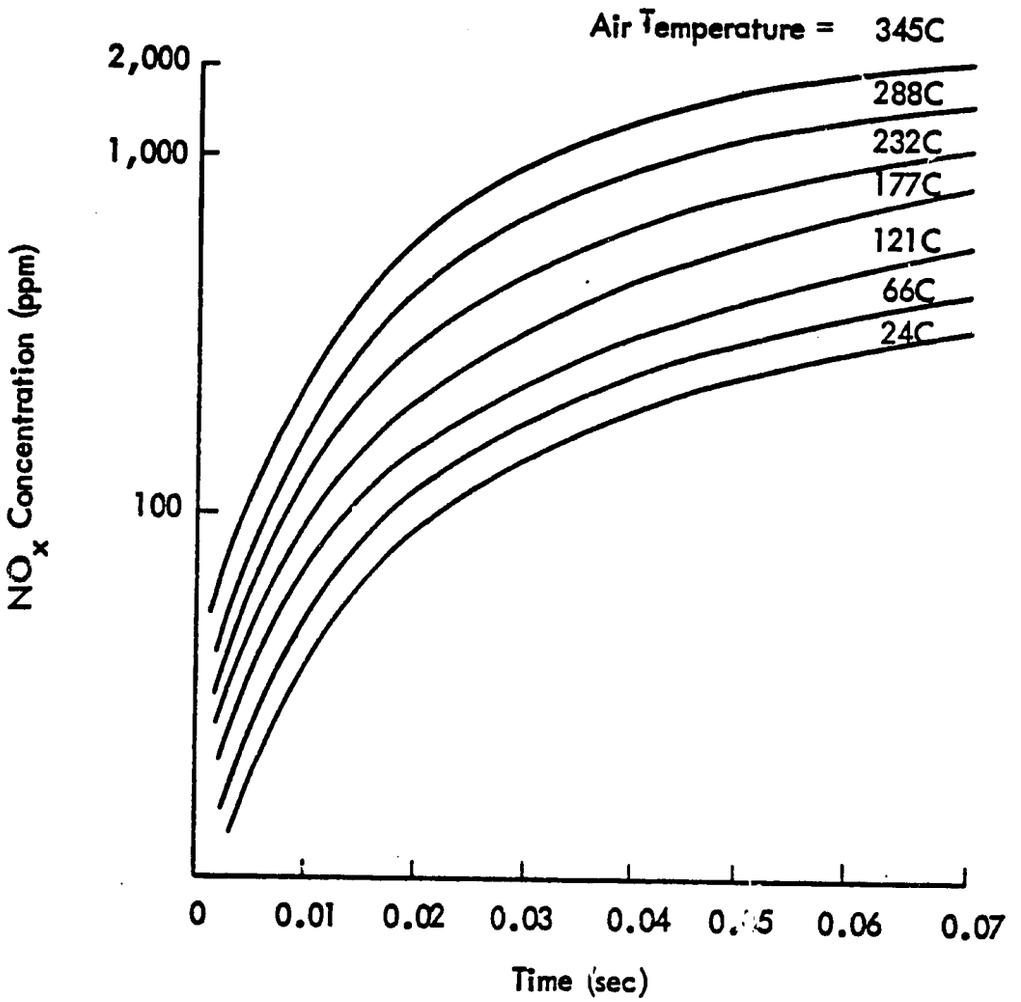
TABLE 4-4

NO_x CONTROL METHODS: COST AND EFFICIENCY[a]

Control Method	NO_x Reduction (%)	Fuel	Control Cost[b] ($1,000s/yr)	NO_x Reduction (kkg/yr)	NO_x Control Costs[b] ($/kkg)
Uncontrolled	0	Gas	0	48,100[c]	0
	0	Oil	0	27,200[c]	0
	0	Coal	0	27,200[c]	0
Low excess air	33	Gas	-95	15,900	-5
	33	Oil	-297	9,000	-27
	25	Coal	-79	6,800	-10
Two-stage combustion	50	Gas	0	24,000	0
	40	Oil	0	10,900	0
	35	Coal	299	9,500	26
Low excess air plus two-stage combustion	90	Gas	-95	43,300	-2
	73	Oil	-297	19,900	-13
	60	Coal	220	16,300	11
Flue gas recirculation	33	Gas	202	15,900	11
	33	Oil	202	9,000	18
	33	Coal	202	9,000	18
Low excess air plus flue gas recirculation	80	Gas	107	38,500	3
	70	Oil	-95	19,100	-5
	55	Coal	123	15,000	7

[a] For a 1,000 Mw boiler used 6,120 hours/year.
[b] Minuses (-) indicate cost savings.
[c] Total emissions without controls.

Source: 79.



Source: 79.

FIGURE 4-5
EFFECT OF AIR PREHEAT
ON NO_x GENERATION

TABLE 4-5

EFFECT OF BURNER CONFIGURATION ON NO_x GENERATION

Test	Burner Type	NO_x Generation (kg/1000 kcal)	
		Before Fly-Ash Collector	After Fly-Ash Collector
Full load	Vertical	0.68	0.99
	Corner	1.71	1.28
	Front wall	1.22	1.71
	Spreader-stoker	1.17	1.37
	Cyclone	4.50	3.96
	Horizontally opposed	1.17	1.06
Partial load	Vertical	0.50	0.56
	Corner	1.31	1.03
	Front wall	1.48	1.33
	Spreader-stoker	1.31	1.22
	Cyclone	3.42	3.24
	Horizontally opposed	1.19	1.01

Source: 12.

TABLE 4-6
AVERAGE WASTEWATER FLOW RATES:
POWER GENERATION

Wastewater Source	Letter Code[a]	Wastewater Flow Rate (liters/Mwhr)		
		Coal	Oil	Natural Gas
Ion exchange	A	15	93	91
Evaporator blowdown	B	313	295	284
Boiler blowdown	C	8	4	3
Laboratory and sampling	D	2	2	1
Boiler tube	E	1	13	8
Cooling water blowdown	F	813	795	795
Boiler fireside cleaning	G	1	1	1
Air preheater	H	6	11	10
Coal pile runoff	I	108	--	--
Scrubber blowdown	J	227	193	--
Ash pond overflow	K	607	227	--
All	--	2,101	1,633	1,193

[a] Used to identify wastewater sources shown on the water treatment flow diagrams (Figures 4-8 through 4-10).

Source: 104.

Process changes to reduce heat waste will also increase plant efficiency. Such changes include increasing boiler temperature and pressure, addition of reheat or regenerative cycles, reducing turbine exhaust pressure, and using air-cooled turbines. Recovery of waste heat involves diverting a waste stream to allow it to pre-heat incoming boiler feedwater. This reduces the amount of fuel needed, and also lowers the temperature of the water effluent.

Irrigation for growth-intensive agricultural or aquacultural "farms" is an attractive method for utilizing warm water. The warm water induces rapid growth, and the large irrigated surface area improves cooling. The effluent water can return to the natural water systems after overland runoff or groundwater recharge.

Plant cooling systems are of two basic types: open cooling systems and closed cooling systems. Open cooling systems may not be effective year-round due to seasonal change in atmospheric temperature, but they do not affect turbine back-pressure as closed systems may.

Once-through systems do not recycle any plant waste heat and discharge directly into a natural water body. They are used where year-round water supply is more than adequate and the receiving body of water is of sufficient volume and flow to receive and dissipate waste heat. Supplemental cooling is sometimes employed, but is usually nothing more than allowing the hot effluent to cool by storage in reservoirs or flowing down drainage ditches to the point of discharge.

Reuse of residual hot gases or condensed steam reduces thermal pollution and also increases plant efficiency. Feedwater can be preheated before boiling by counter-current exchange with condensed steam or residual hot gases.

Coal Storage Drainage. For coal-fired generating units, outside storage of coal at or near the site is necessary. Contact with air and moisture results in the oxidation of the metal sulfides in the coal to sulfuric acid. Precipitation falling on the piles dissolves sulfates which oxidize into an acid waste requiring neutralization. Covering the storage piles can reduce the acid drainage waters.

Solid Waste. Although chemical precipitation creates some solid waste, the overwhelming bulk of the solid waste consists of fly ash and bottom ash, both dry, and as a slurry or sludge. The large quantities generated may be a problem except that this material also has a variety of uses. It functions well as a soil builder, as an additive for concrete or asphalt, and in a host of other applications (see Table 4-7). If a local market can be found and exploited, there should be no significant solid waste disposal problem; otherwise, the residue may be disposed for landfilling.

Cost of Pollution Controls

Representative treatment systems were designed as discussed under "Cost Analysis" at the beginning of the chapter. Tables 4-8 and 4-9 list the selected control equipment for air and water respectively. Figures 4-6 through 4-10 are schematics of the proposed treatment systems for primary, secondary, and tertiary (highest level of control) air and water treatment. (Only two levels of control were designed for air pollution.) Tables 4-10 and 4-11 list their approximate pollutant removal efficiencies.

TABLE 4-7

ASH BY-PRODUCT USE IN 1972

Application	Quantity Used (1,000 kkg)		
	Fly Ash	Bottom Ash	Boiler Slag
Cement			
In type 1-P cement (As a pozzolan mixed with cement)	66		
As a raw material for cement clinker	105	27	100
As a partial replacement of cement	466	21	
Road base stabilization	139	22	4
Lightweight aggregate	121	21	
Fill material for roads, construction, etc.	531	681	433
Filler in asphalt mix	127	13	39
No cost removal from utility	1,356	739	1
Miscellaneous	387	836	637

Source: 34.

TABLE 4-8
AIR POLLUTION CONTROL EQUIPMENT:
POWER GENERATION

Fuel	Control System	
	Primary	Secondary
Coal	Cyclone Wet scrubber	Cyclone Wet scrubber Electrostatic precipitator Flare up
Oil	Cyclone Wet scrubber	Cyclone Wet scrubber Baghouse filter Flare up
Natural gas	Flare up	Cyclone Flare up

TABLE 4-9

WATER POLLUTION CONTROL EQUIPMENT: POWER GENERATION
(COAL, OIL, AND NATURAL GAS)

Control System		
Primary	Secondary	Tertiary
Equalization basin Holding tank (with skimmer) Neutralization tank	Equalization tank Holding tank Clarifier Neutralization tank Filter	Equalization tank Holding tank Clarifier Neutralization tank Aeration basin Secondary clarifier Coagulator and flocculator Filter

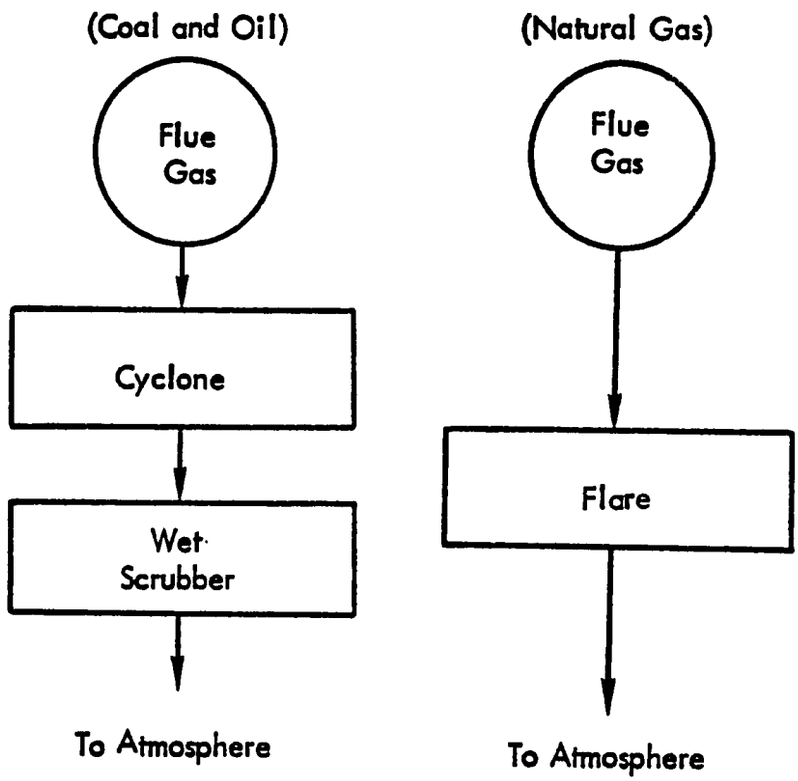


FIGURE 4-6
PRIMARY AIR POLLUTION TREATMENT SYSTEM: POWER GENERATION (COAL, OIL, NATURAL GAS)

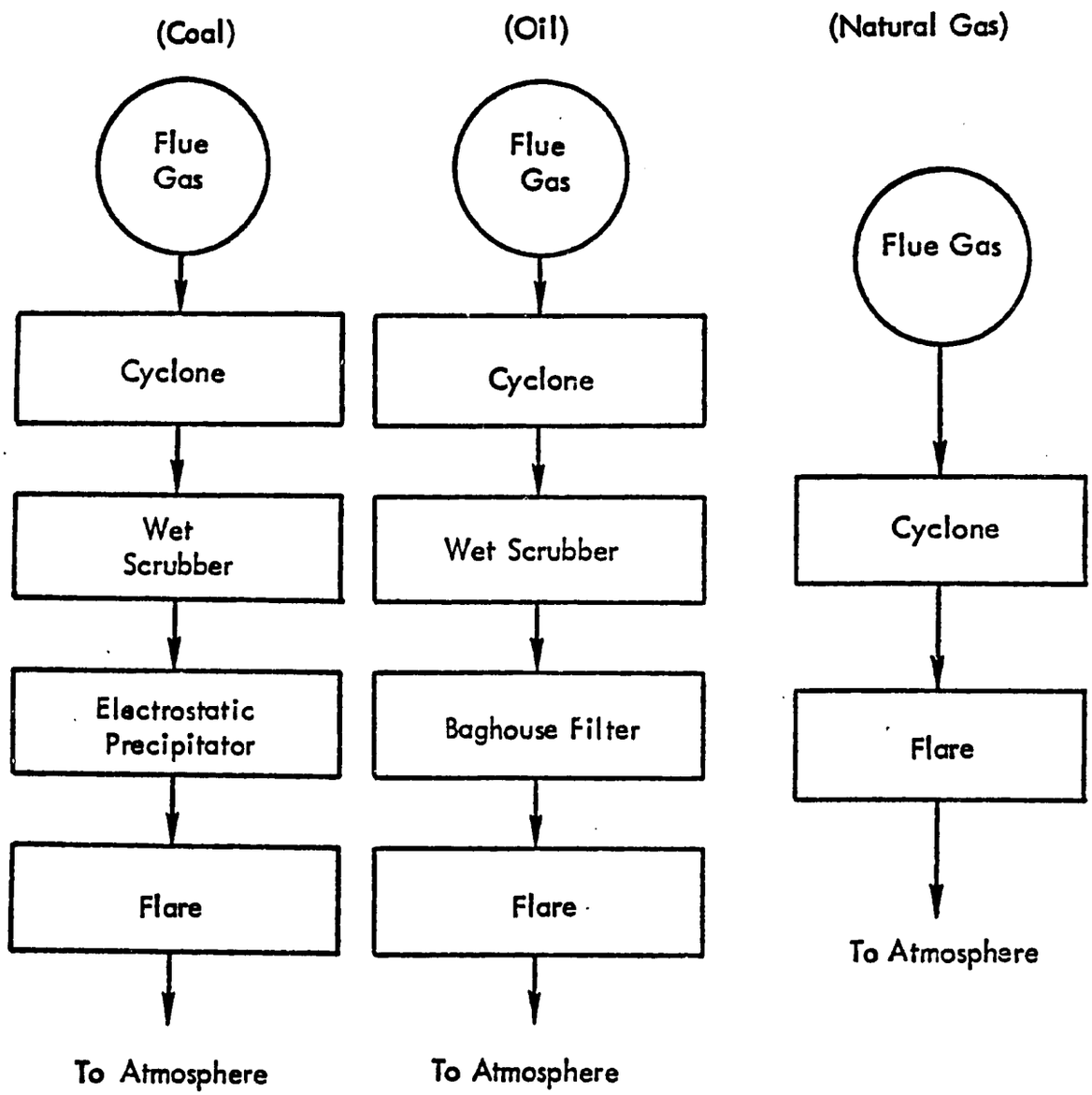
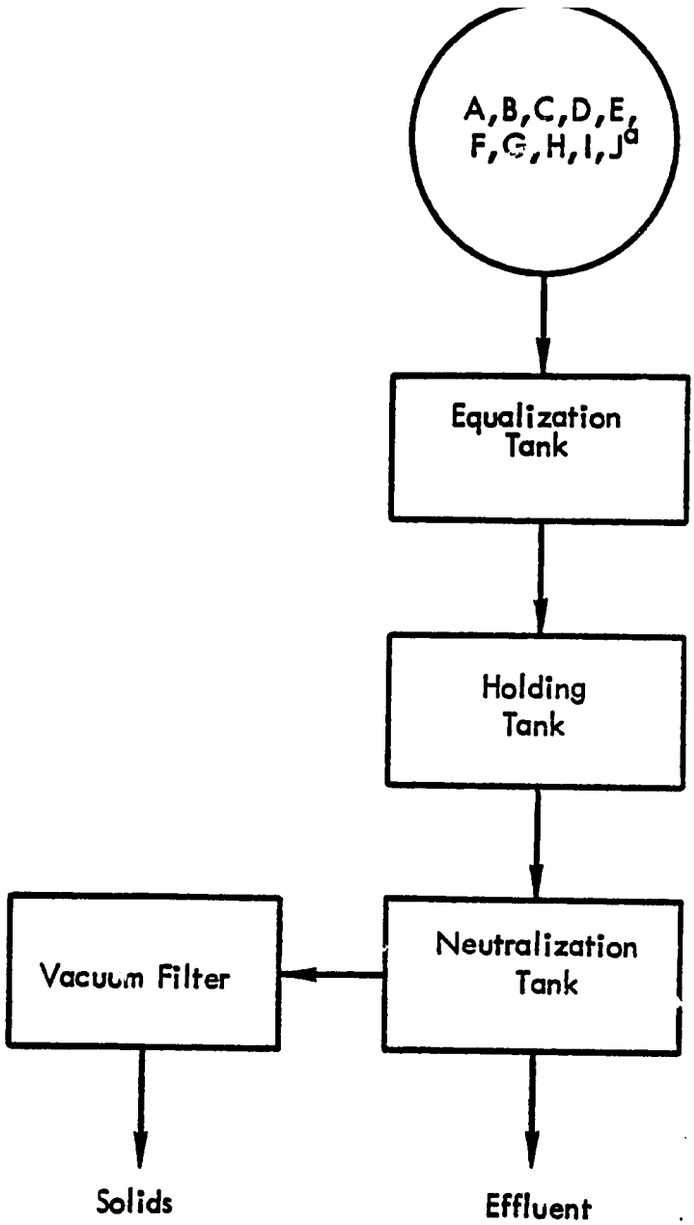
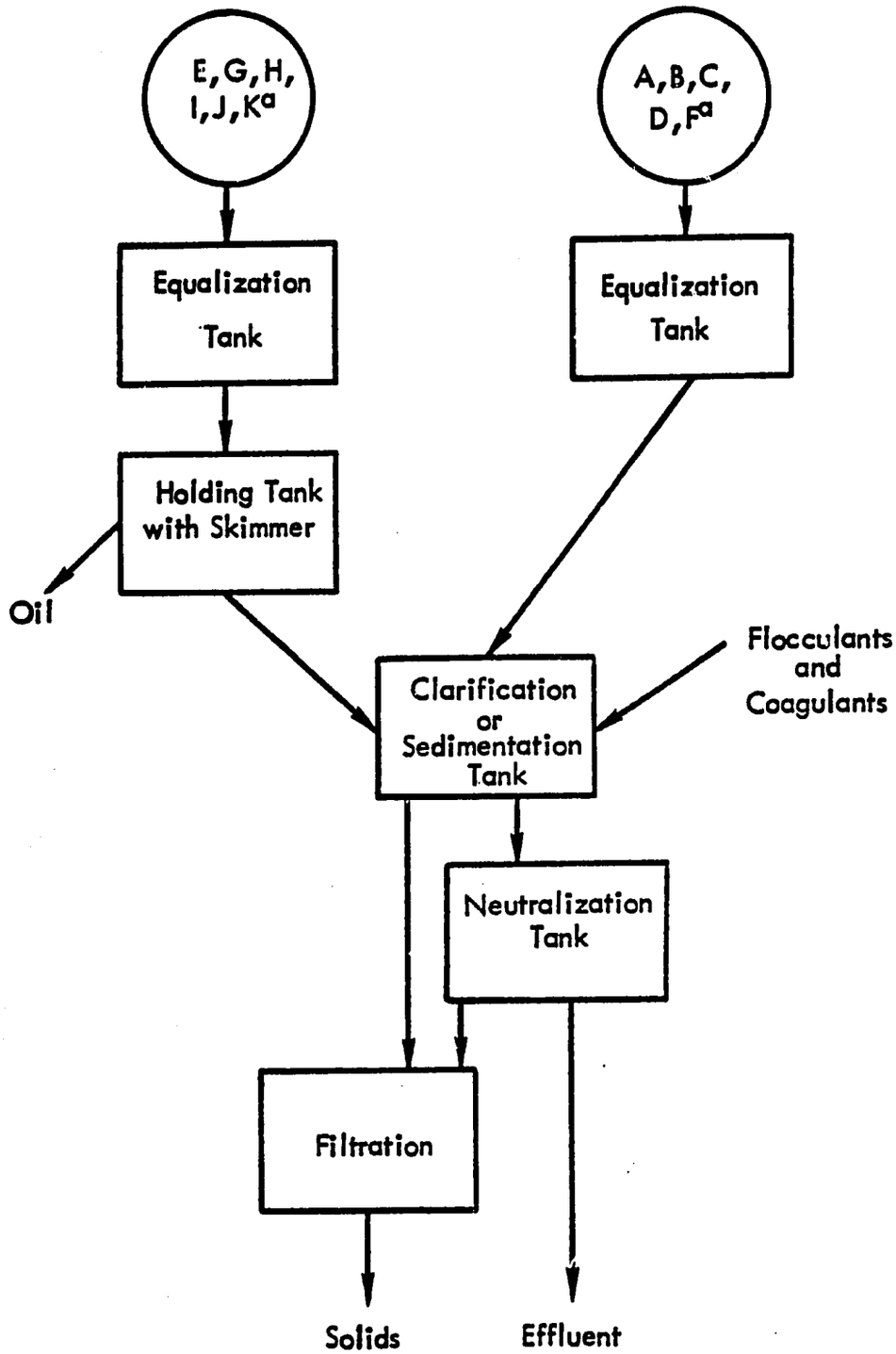


FIGURE 4-7
SECONDARY AIR POLLUTION TREATMENT SYSTEM: POWER GENERATION (COAL, OIL, NATURAL GAS)



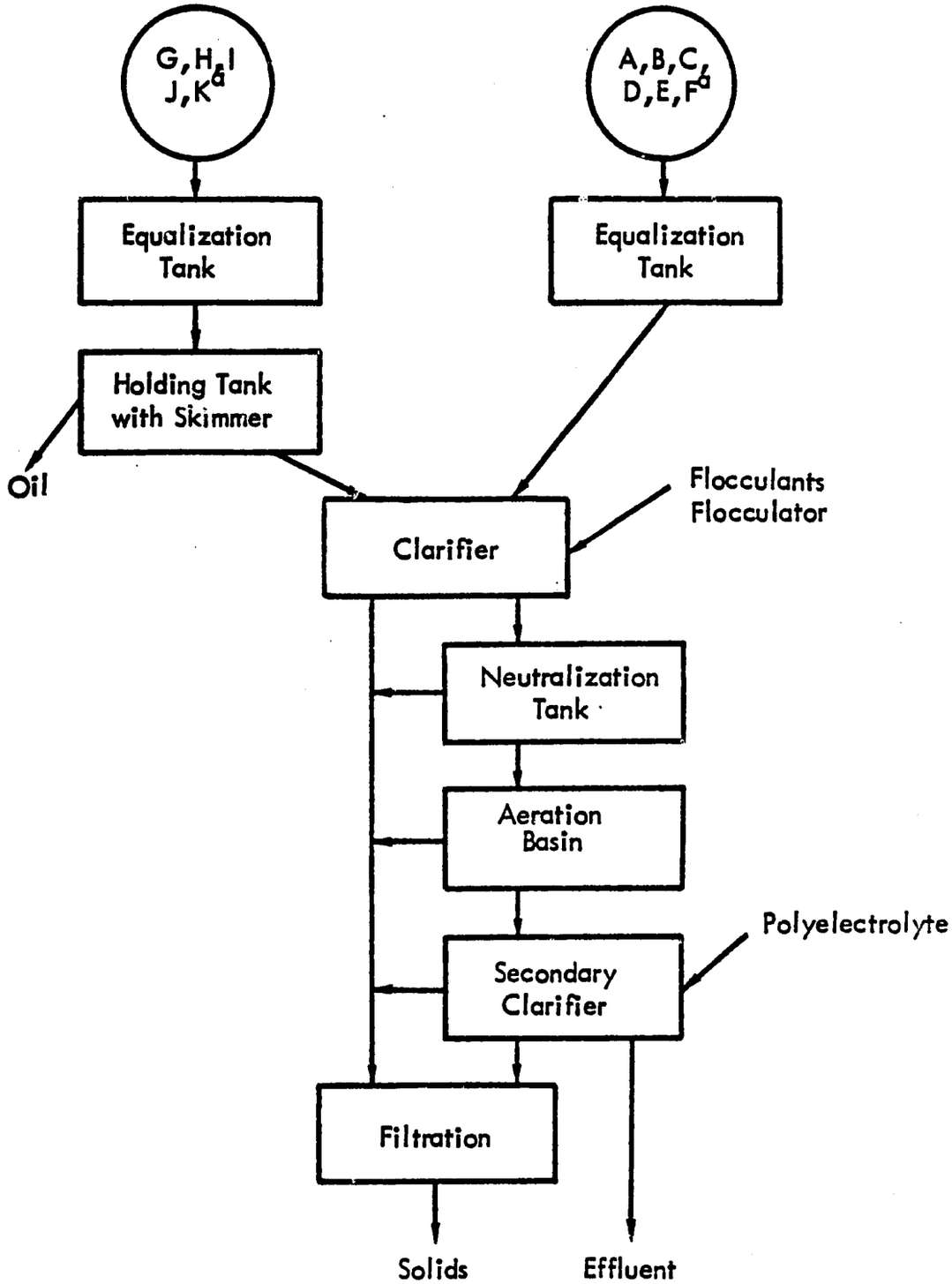
[a] Letters refer to wastewater sources as identified on Table 4-6 .

FIGURE 4-8
PRIMARY WASTEWATER TREATMENT SYSTEM: POWER GENERATION



[a] Letters refer to wastewater sources as identified on Table 4-6 .

FIGURE 4-9
SECONDARY WASTEWATER TREATMENT SYSTEM: POWER GENERATION



[a] Letters refer to wastewater sources as identified on Table 4-6 .

FIGURE 4-10
TERTIARY WASTEWATER TREATMENT SYSTEM: POWER GENERATION

TABLE 4-10

AIR POLLUTANT REMOVAL EFFICIENCIES OF THE SELECTED TREATMENT SYSTEMS: POWER GENERATION

Subcategory	Pollutant	Removal Efficiency (%)	
		Primary	Secondary
Coal and oil	Particulates	30-50	90-95
	Sulfur dioxide	50-70	90-98
	Nitrogen oxides	30-40	≈ 90
	Hydrocarbons	30-40	90-95
	Organics	30-50	90-95
	Aldehydes	--	≈ 90
	Ammonia	--	≈ 95
Natural gas	Particulates	--	85-95
	Sulfur dioxide	≈ 50	80-95
	Nitrogen oxides	40-50	≈ 90
	Hydrocarbons	40-60	90-95
	Organics	40-60	90-99
	Aldehydes	40-50	80-95
	Ammonia	--	--

Source: 72.

TABLE 4-11
WATER POLLUTANT REMOVAL EFFICIENCIES OF THE SELECTED TREATMENT SYSTEMS: POWER GENERATION

Fuel	Pollutant	Removal Efficiency (%)		
		Primary[a]	Secondary[b]	Tertiary
Coal	BOD	55	80	98
	COD	45	75	95
	Acidity (as ($CaCO_3$)	70	85	99
	Iron	--	85	97
	Oil & grease	45	90	99
	Sulfate	35	85	98
	Chloride	40	90	99
	Chromium	--	90	99
	Zinc	30	80	95
	Manganese	--	73	95
	Total dissolved solids	25	90	98
	Aluminum	--	80	94
	Nickel	--	78	94
	Total suspended solids	50	85	99
Oil	BOD	60	85	98
	COD	45	78	99
	$CaCO_3$ (as total hardness)	80	90	99
	Iron	45	75	98
	Oil and grease	55	88	99
	Sulfate	40	80	95
	Chloride	55	80	97
	Chromium	--	85	99
	Zinc	25	77	96
	Nickel	--	75	95
	Sodium	30	85	99
	Total suspended solids	50	85	99
Natural gas	BOD	55	80	99
	$CaCO_3$ (acidity)	80	90	98
	Iron	20	78	99
	Sulfate	35	75	95
	Chloride	40	80	97
	Nickel	--	80	95
	Sodium	30	85	97
	Total suspended solids	55	85	99

[a] Removal efficiency may vary ± 5%.
[b] Removal efficiency may vary ± 3%.

Source: 104, 87, 53,109,112.

The cost calculations and data are presented in Table 4-41, the resulting cost equations in Table 4-42, and (graphically) in Figures 4-34 through 4-47. These tables and figures are found at the end of the chapter.

ELECTRIC POWER PLANT A

Description

This is a large oil/gas fired power plant operating three generating units with a total rated capacity of 700,000 kilowatts. The plant is located in a coastal area of the United States within a major metropolitan area. Because it is near a heavily populated area, the plant's management has long been sensitive to environmental problems. The site itself is in a mixed residential/industrial/recreational area: single family dwellings, apartments, parks, beaches, schools, a major airport, a power plant operated by another utility, miscellaneous industrial plants, a sewage treatment plant, and a petroleum refining complex are located within a five-mile radius of the power plant. The presence of other air and water pollution sources tends to mask plant A's specific contribution to the area's environmental problems. From field inspection of the site, however, this general impression seems justified: in relation to the industry as a whole, this is a "clean" operation. Although some environmental problems remain, steps are being taken to correct most of them.

The plant was designed and built for greater capacity than was allowed by subsequent air pollution regulations. The newest generating unit represents about one-half the total rated capacity of the plant. This unit has been shut down for several months because (1) it is designed to use natural gas only and none is available, and (2) pollution control regulations make it difficult to convert the unit to oil. Even when natural gas is available, the unit cannot be currently operated at more than 75 percent of design capacity. This reduces the peak capacity of the system and forces utilization of older, less efficient units. It also means that one-third the capacity of the plant is unusable because of stringent pollution regulations.

The plant produced 1.8×10^6 Mwhr of electricity in 1975, employs 120 people, was constructed at a cost of $165 million (in as-built prices), and costs about $30 million per year to operate. It uses ocean water for cooling, and discharges used cooling water and effluent from various processes to the ocean.

The plant is subject to stringent air and water pollution control requirements with which it complies (see Tables 4-12 and 4-13). New, more stringent standards will take effect in the future, and much of the current air and water pollution control activity relates to designing methods to meet the proposed new standards.

TABLE 4-12

AIR POLLUTION EMISSION STANDARDS:
ELECTRIC POWER GENERATION

Source	Pollutant	Air Discharge Standard
Stack	Smoke/color	a) Not to exceed shade No. 1 Ringelmann chart for more than 3 minutes in any one hour; or b) obscure an observer's view greater than (a), above.
	Nuisance	No discharge of materials causing any health or safety nuisance.
Transport, handling, construction, storage	Fugitive dust	Not to be visible in air beyond property line of plant source.
		Not to exceed 100 μg/cu m above the difference between upwind and downwind dust, when instant and average wind speeds exceed 40 km/hr and 24 km/hr, respectively.
	Carbon monoxide	Maximum of 2,000 ppm averaged over a minimum of 15 minutes.
Stack from fuel burning	Gas calculated to 12 percent carbon dioxide	Maximum of 0.23 g/cu m.
Stack	Oxides of nitrogen	Fuel — No_x (ppm): Gas — 125; Liquid or solid — 225
	Combustion contaminants	0.23 g/cu m.

TABLE 4-13

NPDES[a] WASTE DISCHARGE REQUIREMENTS: POWER PLANT A

Plant/Process Source	Discharge		Effluent Limitations	
	Type	Source	Pollutant	Max. Concentrations
Electric Power Generating Plant	Combined: Condenser water, surface and building roof drainage, maintenance wash water, oil separator, chemical feed, filter softener, blowoff tank evaporator descaling and flush, cooling tower blowdown, condenser pit drains, and start-up wastewater	Ocean outfall pipeline	Grease, oil, oil slick	None visible
			Objectionable color	None visible
			Solids	None visible
			Odors	None
			Toxic materials	Below toxicity levels
			Sludge bank formation	No interference with marine life
			Dissolved oxygen	Not to fall below 5 mg/l in receiving waters
			pH	6.0 to 9.0 range in discharge
			Temperature	Not to rise to level affecting marine life

NOTE: This facility must also meet state water resources control board limitations.

Air Pollution Control

Air pollution abatement measures have been taken to control particulates, sulfur oxides (SO_x), and nitrogen oxides (NO_x). In addition, relatively insignificant quantities of hydrocarbons and carbon monoxide are generated. Available air pollutant generation rates for the entire plant are shown in Table 4-14. Three control approaches are used: process modification, input substitution, and end-of-pipe treatment.

Low sulfur fuels (natural gas when available and fuel oil with a sulfur content less than 0.5 percent) are used to control sulfur oxides generation; no scrubbers or other end-of-pipe treatment methods are used. The plant currently meets applicable discharge standards for SO_x. But since more stringent standards are anticipated, it is investigating various scrubber systems for treating the flue gas. The agency responsible for setting SO_x standards has been encouraging the adoption of scrubber systems for its control. Even if the air pollution standards remain unchanged, it may become necessary to adopt additional controls if the price or availability of low-sulfur fuel oil requires switching to higher sulfur fuel. This would make it necessary to use scrubbers or some other additional control method. To avoid this possibility, the power plant is investigating an oil-desulfurization process being developed by one of the major international oil companies.

The low-sulfur fuel being used is low in ash content. This reduces particulate generation. The reduction is greatest for natural gas, but ash is significant with fuel oil. Mechanical dust collectors on the flue gas ducts provide additional control. The mechanical collectors remove large particles but are ineffective for small ones- those with the maximum potential for health impacts. The collectors are only about 10 percent efficient by weight. Scrubbers, if eventually adopted for SO_x control, may remove particulates with an efficiency above 90 percent.

The following methods of NO_x control are being used at this plant: flue gas recirculation, off-stoichemetric firing, tangential firing, low excess air firing, and over fire air ports.

In the past, recirculating a portion of the flue gas to the bottom of the boiler has often been used as an operating measure to control steam temperatures. Moving the reentry point to the burners resulted in a reported 50 percent reduction in NO_x emissions on fuel gas operation. The high cost of NO_x control ($2 million) was primarily due to boiler redesign. Some units in fact, could not be retrofitted because of space or design access limitations.

Off-stoichemetric firing is essentially the same as two-stage combustion. At this power plant, the effectiveness of the method was found to depend on burner pattern. Optimal results were achieved by turning off the flow of fuel to the top burners and increasing the fuel flow to the bottom ones. The effect is to increase the total fuel/air ratio, by creating substoichemetric air conditions in the hottest part of the combustion zone and providing excess air above that primary zone (where the temperature is lower). Off-stoichemetric firing has the advantages of requiring only small changes in existing

TABLE 4-14

AIR POLLUTANT GENERATION RATES[a]

Pollutant	Generation Rate	
	(kg/day)	(kg/Mwhr)
Particulates	577	0.12
Sulfur oxides	4,680	0.95
Nitrogen oxides	3,910	0.79
Hydrocarbons	212	0.04

Note: Total flue gas flow is 31,000 cu m/min.

[a] At maximum capacity.

equipment and little initial expense. However, it (1) raises fuel consumption (> 1%) (2) makes the combustion process less stable, thus requiring closer control, and (3) cannot be accepted by some (mainly older) units. The plant engineer reported capital expenditures of $75,000 to make the conversion on two older boilers and a control efficiency for the method of 25 percent for fuel oil and 50 percent for natural gas. Research and development, and engineering costs were not included in the $75,000.

Low excess air firing reduces NO_x generation by reducing the amount of oxygen in the combustion zone available for combining with nitrogen to form NO. The goal is to lower excess air as much as possible without creating major combustion operating difficulties. A tangentially fired boiler is being used. It works by lowering the peak temperatures attained in the combustion zone.

Water Pollution Control.

Power plant A is designing a wastewater treatment plant in anticipation of the new, more stringent discharge standards taking effect in 1977 and 1983. The treatment plant has an estimated capital cost of $3 million. Table 4-15 presents the type, source, and concentration of major water pollutants generated. Current wastewater treatment consists of removal of settleable solids prior to discharge to the ocean.

The six major types of waste generated are: metal cleaning waste (heat exchanger cleaning, air preheater and fireside boiler wash); boiler blowdown; cooling tower blowdown; circulating cooling water discharge; low volume waste (ion exchange, evaporator, draining from oil-water separator); and waste heat.

The agency responsible for water pollution control requires new generating units to meet stringent thermal discharge standards unless one of the following two conditions exists: no land is available for the necessary cooling towers, and no environmental harm would result from the thermal discharges. Since power plant "A" was able to demonstrate the lack of sufficient land available for the construction of a closed cycle cooling system, it only needs to meet the less stringent requirement which requires elevated temperature wastes to comply with limitations necessary to assure protection of the beneficial uses and areas of special biological significance. The plant has no difficulty in meeting this requirement. Diffusers are not used when discharging the cooling water effluent.

To meet 1977 standards for iron and copper, it is planned to segregate waste flows, collect them in separation basins, and provide treatment in batches. Boiler blowdown normally contains more than 1 ppm iron and copper only during the boiler start-up period (lasting 8-12 hours per start-up). Cooling tower blow-down is unlikely to present a problem with average free chlorine content (an algacide-bactericide), but chrome (used as a rust inhibiter), may require removal. Oily waste from equipment goes to mechanical oil-water separators. The treated effluent is discharged, with the skimmed oil trucked off for landfill disposal. When properly maintained, the system meets very high statutory environmental standards.

TABLE 4-15

WATER POLLUTANTS: SOURCE AND CONCENTRATION

Pollutant	Source	Quantity
COD	Demineralizer and water softener regeneration, fireside boiler and air preheater wash, and filter backwash	n/d[a]
SS	Same as for COD	7,000 mg/liter
pH	Same as for COD	3 units
TDS	Air preheater wash and demineralizer regeneration	23,500 mg/liter
Heat	Condenser	Δ11C
Fe	Air preheater and boiler fireside washes	3,000 mg/liter
Cu	Air preheater and boiler fireside washes	30 mg/liter

[a] No data given.

The proposed treatment plant is being designed to use equipment which is as maintenance-free as possible. Manpower requirements are estimated at only 1 to 2 man-days per operating day. There will be minimal power requirements, but significant chemical requirements (e.g., approximately 12 grams of lime per liter of wastewater).

ELECTRIC POWER PLANT B

Description

This is a large oil-fired power plant operating 8 generating units with a total rated capacity of 1,606 Mw. The plant is located in a coastal area of the United States within sight of Power Plant A (discussed above); the same general considerations therefore apply.

Plant B is also "clean" by industry standards. It uses ocean water for cooling, and discharges used cooling water and effluent from various processes to the ocean. It generally complies with the present stringent air and water pollution control requirements (see Tables 4-12 & 4-16), and is designing methods to meet the stricter standards which will take effect in the future. Energy generating capacity and output of Plant B are given in Table 4-17; pollutant generation is shown in Table 4-18.

Air Pollution Control

To control particulates, sulfur oxides, and nitrogen oxides (the only air pollutants controlled), Plant B uses process modification and input substitution. These have reduced discharges below current discharge limitations. No scrubbers, cyclones, or other end-of-pipe treatment methods are used. Particulates and sulfur oxides are controlled with low-sulfur (less than 0.5 percent), low-ash fuel oil. Particulates are also controlled with combustion controls (i.e., modifying operating procedures to reduce generation). The remaining particulate generation comes mainly from boiler surfaces, where it was part of the boiler structure itself, rather than from the fuel.

Because the pollution standards for particulate emissions made it necessary to stop soot blowing at Power Plant B, the boiler is wet-cleaned every 6 to 8 weeks to maintain its efficiency. Since this cleaning is a wet process, it generates some water pollutants. Even with the frequent shutdowns for cleaning, boiler efficiency declined significantly between cleanings and overall efficiency was less than with soot blowing. As an alternative to wet-cleaning, it might be possible to install treatment equipment and continue soot blowing. However, plant management feels that the cost in terms of equipment, power, operating and maintenance, and reduced boiler operating efficiency would be greater than that for periodic washdowns.

Although no end-of-pipe particulate control measures are used at this plant, the company has experimented with a baghouse and an electrostatic precipitator at two of its other oil-fired power plants. (Its coal-fired plants all have particulate control devices.) These research and development projects both encountered normal problems. The oil in

TABLE 4-16

NPDES WASTE DISCHARGE REQUIREMENTS: POWER PLANT B

Plant/Process Source	Discharge		Effluent Limitations	
	Type	Source	Pollutant	Max. Concentrations
Electric Power Generating Plant	Combined: Condenser, demineralizer, boiler acid wash, boiler alkaline wash, superheater and reheater wash, air-heater wash, citric acid and water rinse, boiler and demineralizer wash wastewater	Ocean outfall pipeline	Grease, oil, oil slicks	None visible
			Objectionable color	None visible
			Solids	None visible
			Odors	None
			Toxic materials	Below toxicity levels
			Sludge bank formation	No interference with marine life
			Dissolved oxygen	Not to fall below 5 mg/l in receiving waters
			pH	6.0 to 9.0 range in discharge
			Temperature	Not to rise to level affecting marine life
	Condenser, evaporator, blowdown zeolite softener wastes, yard drainage wastewater, plant floor and deck drainage wastewater	Ocean outfall pipeline	Same as above	Same as above

TABLE 4-17
CAPACITY AND OUTPUT: POWER PLANT B

Generating Unit	Capacity (Mw)	1975 Output (10^3 Mwhr)	Capacity Utilization (%)
1-4	296	218	8.4
5 & 6	350	1,434	46.8
7 & 8	960	3,469	41.3

TABLE 4-18
POLLUTANT GENERATION: POWER PLANT B

Pollutant	Generation Rate	
	(kg/day)	(kg/Mwhr)
Air		
Particulates	2,703	0.19
Sulfur oxides	21,945	1.56
Nitrogen oxides	11,902	0.08
Hydrocarbons	961	0.07
Carbon monoxide	neg.	neg.
Water		
Iron	1,700	0.31
Copper	9.5	7×10^{-4}
Chrome	0.77	5×10^{-5}
Grease and oil	2,150	0.15

the particulate stream caused the baghouse to be easily fouled, thereby increasing cleaning periods and causing a significant head loss. The electrostatic precipitator was operated for only a short period because, after it was built, the plant was required to shift to low-ash fuels, thus eliminating the need for additional particulate control (for meeting current 1976 statutory standards). Several problems were encountered while it was in operation, however. Plate fouling and ash handling were more difficult than anticipated. Electrostatic precipitators are being used successfully at the company's coal-fired plants.

The company has been one of the leaders in research and development on process modifications to reduce nitrogen oxide generation. The following methods of NO_x control have been tried at this or other plants in the system: off-stoichemetric firing, flue gas recirculation, tangential firing, low excess air firing, by-passing the air preheater, and over-fire air ports. Off-stoichemetric firing, gas recirculation, and low excess air firing are the only methods currently used at Plant B. The best results were with off-stoichemetric firing with the third row of burners out of service. To retrofit existing units for recirculation costs an estimated $2 million per unit and achieves approximately a 15 percent reduction in NO_x generation. In contrast to Power Plant A, this company's experiments indicated that by-passing the air preheater didn't reduce NO_x generation. Although tangential firing does work, the units at Power Plant B were not designed for it and have not been converted.

The company's research into NO_x control provided two other interesting conclusions. First, small differences in plant design and operation can result in large differences in nitrogen oxide pollution generation. At one of their power plants there are two supposedly identical boilers operating under the same conditions, but one produces up to 20 ppm more NO_x. Second, the proportion of fixed nitrogen in the fuel has a substantial effect on NO_x generation. Reducing fuel nitrogen content from 1.0 to 0.25 percent, for example, significantly reduces NO_x generation.

The "identical" units mentioned above have design capacities of 750 Mw. They were designed to meet existing air pollution standards, but during construction new, more stringent control standards were imposed. As a result, the completed units could only be operated at 600 Mw (80 percent capacity) and still meet NO_x standards. After six years of work with process and other modifications, NO_x emissions have been reduced only enough to allow operation at 630 Mw. Interestingly, the unit with the lower NO_x emissions before modifications now has the higher emission rate.

The company's experience with over-fire air ports for NO_x control has been mixed: it works on some units but not on others. Design characteristics of the particular boiler appear to be responsible for the differences. Overall, the retrofitting air pollution control measures have resulted in a net loss in operating efficiency. It is impossible to specify the precise loss from any single measure or the sum from all of them because they were all begun at approximately the same time and nearly simultaneously with the loss of natural gas (a cleaner fuel) for boiler firing. However, over this period it is known that heat rates (the industry's measure of energy conversion efficiency) have risen about

4 percent, from 35,500 to 36,900 kcal/kwhr. This means that it takes about 1,400 kcal more heat (and correspondingly more fuel) to produce one kwhr of electricity.

Water Pollution Control

Increased wastewater treatment facilities are being planned for Power Plant B in anticipation of stricter future control requirements. Current control measures consist mainly of a retention basin for settling and skimming (2 to 3 days storage time, depending on flow rate), and dilution into the cooling water effluent.

In the retention basin, iron (Fe) and copper (Cu) largely settle out and oil is skimmed from the top. An oil-water separator is also used. Effluent from the retention basin is metered out to be discharged with the once-through cooling water. The discharges are metered so that standards for receiving water discharge concentrations are not exceeded. As iron concentration is closest to the limit, it is the determining factor in the discharge rate from the basin. Iron concentration in the effluent cannot exceed 1 ppm; the plant has little trouble in meeting this standard. The dilution ratio is approximately 4,000 to 1, at which there is also little concern with nickel or chrome. In fact, there is less than 1 ppm in the retention basin (before dilution). Oily waste skimmed from the retention basin is transferred and stored in another basin until it is full and then is trucked to a Class A (safe for toxic wastes) sanitary landfill for disposal. So little oily waste is generated that the basin needs to be emptied only every 4 to 5 years.

Sodium hypochlorate is used for slime control. It is applied in an intermittent "shock" feed approximately twice a day for 30 minutes each application. Quantities and dilutions are chosen with the intent of keeping within 0.5 ppm total residual chlorine in the effluent.

Wastes from the metal washing operations have substantially increased since soot blowing was stopped. Acid rinses hold metals in solution (which is the reason for their use), and are a major pollution source (for example, maximum copper concentration wash effluent is 200 ppm). Because the metals are in solution they do not settle out. Even so, there is adequate cooling effluent dilution so that applicable discharge standards are met. These wastes are not currently segregated, although that may become necessary in the future. The plant is now conducting tests on their treatment.

Much current effort is being directed toward expanded and improved pollution impact monitoring. The effects of wastewater discharges to the ocean, including thermal and chemical wastes, are being extensively studied. Plans for future wastewater treatment tentatively include lime treatment and a continuous belt oil skimmer.

IRON AND STEEL

INDUSTRY OVERVIEW

The iron and steel industry produces finished steel from the basic raw materials of coal, ore and scrap iron, and limestone. Few plants perform all the steel making operations from raw materials to finished product; those which do are called integrated producers. This case study considers the entire process. Photograph 4-2 illustrates the potential hazard of polluted air emissions from a steel mill.

Production Process

Steel is produced by using various raw materials to reduce iron ore to ferrous metals of specific composition. The main processes are:

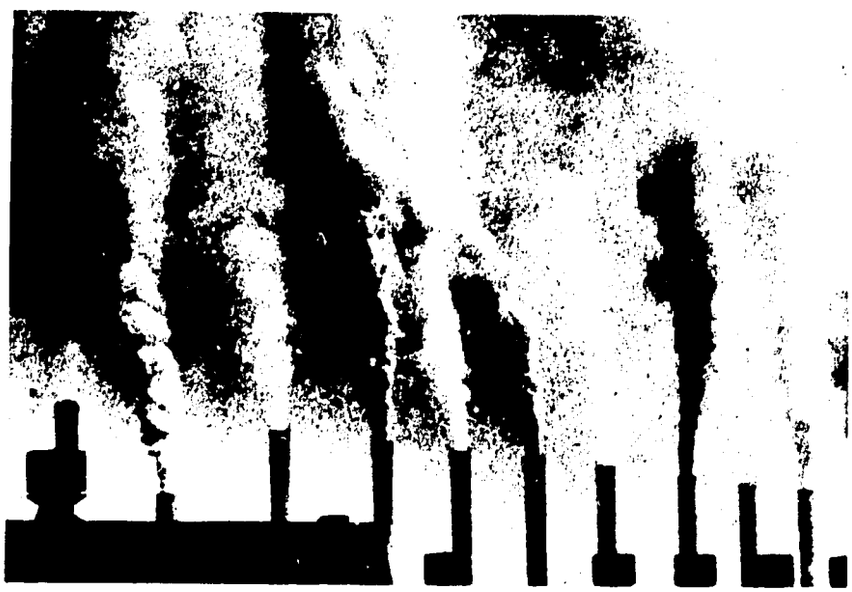
- Reduction of coal to coke (pure carbon), an input in steel making.
- Purification of iron by combining iron ore with coke and limestone in a blast furnace.
- Conversion of iron to steel in an open hearth, basic oxygen, or electric furnace.
- Refining, casting, and finishing operations.

Figure 4-11 is a process flow diagram of a typical integrated steel mill; it includes the major air, water, and solid pollutants generated and identifies their sources.

Coal can be converted to coke through either the beehive or by-product process, although nearly all is produced by the latter process. In the beehive process, coal is burned slowly to burn off volatile compounds, reducing the coal to coke, the only product recovered. In the by-product process, coal is heated in the absence of air. Because of the lack of oxygen, volatiles are vaporized rather than burned and can be recovered and used (e.g., in producing light oils and tars). Water is often used as a coolant for condensation of the volatiles and for quenching (cooling by direct water contact) the finished coke.

Before being refined in a blast furnace, the iron ore is crushed, sintered, and quenched. Crushing is necessary to achieve uniform distribution of iron within the unpurified ore. The ore is sintered by heating with coke to agglomerate the fine iron particles produced by crushing. Sintered ore is easier to handle in subsequent operations.

A blast furnace is used to produce the molten iron used for steel making. Iron ore, limestone, and coke are charged into the top of the furnace, and heated air is blown into the bottom. Coke combustion provides the heat necessary for the reaction. The limestone forms a liquid slag and combines with impurities in the ore. To produce 1.0 kkg of iron requires about 2.0 kkg of ore, 0.5 kkg of limestone, and 0.5 kkg of coke and generates about 0.5 kkg of slag. The impurities removed by the limestone float to the surface of the molten mixture and are skimmed off. The molten iron and coke mixture (known as pig or cast iron) is bled off the bottom of the furnace. Large amounts of water are used for cooling, quenching, and cleaning. Flue gas from the blast furnace has considerable heating value and is burned to preheat the air blast to the furnace.



Photograph 4-2

These steel plant emissions contributed to an industrial city's greatest single health emergency; a government restraining order temporarily closed twenty-three manufacturing plants (including the above plant) to protect the public health.

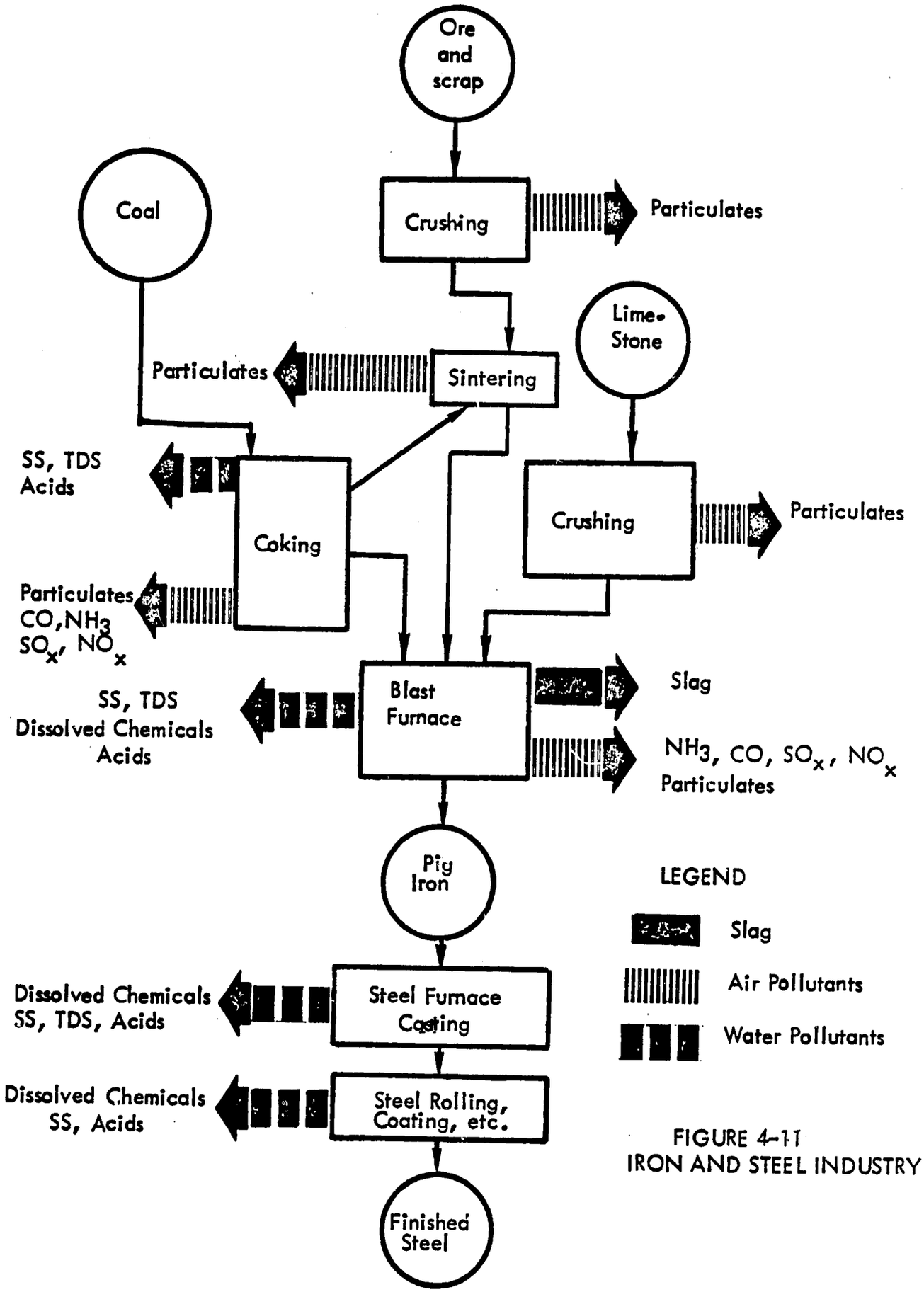


FIGURE 4-11
IRON AND STEEL INDUSTRY

Steel production from cast or pig iron adjusts the carbon content of the pig iron to a lower and predetermined amount. Steel is less brittle than pig iron, due to the slight amounts of carbon present in the final product. There are three types of steel making furnaces: open hearth, electric arc, and basic oxygen. All refine the iron from the blast furnace and blend it with scrap and alloying materials. The air pollutant quantities emitted differ for the different furnaces. Water pollution parameters are generally similar for all three types.

Open hearth furnaces are shallow, rectangular hearths constructed of refractory brick. The flame travels the length of the furnace above the charge. Oxygen is frequently injected during a burn to shorten heat time and speed reactions. Open hearth furnaces can produce from 100 to 300 tons of steel per heat cycle, each heat requiring 8 to 12 hours. Particulates emitted by open hearth furnaces are 50 percent iron oxides, with lesser amounts of fluxes and other additives. Small amounts of fluorides are emitted if fluorspar is used as a flux.

Electric arc furnaces are similar to open hearth furnaces, but heat is supplied by an electric arc. The sizes of electric arc furnaces range from 7 to 30 feet in diameter, and production ranges from 2 to 200 tons of steel per heat cycle. Each heat requires 1.5 to 4 hours.

The basic oxygen furnace (BOF), the latest advance in steel making, is rapidly replacing other furnaces. The basic oxygen furnace is a vertical cylinder in which scrap and molten pig iron are admitted at the bottom. A water-cooled lance is lowered in the melt when it comes from the furance, to supply oxygen. The resulting reaction burns off the impurities. After this, alloys are added and the melt is tapped. The BOF advantages include high production capacity (from 200 to 300 tons per hour) and close control of steel quality by means of variation in oxygen introduced.

The steel is either cast into ingots for storage or poured and allowed to partially cool for continuous processing and finishing. Alloying metals may be added before casting (if this was not done during the furnace operation). Water is used as a coolant to speed casting. Milling involves shaping the steel into a final form. The great variety of milling processes available are extremely specialized. Reheating is often necessary if the temperature of the steel falls below workable limits.

Cleaning is the next step in steel production. The type of cleaning needed depends on surface impurities. There are five major cleaning methods: (1) Pickling removes surface oxides with solutions of inorganic acids; it is extensively used since most steel is oxide coated and pickling is cheap and efficient. (2) Solvent cleaning involves wiping or scrubbing to remove surface oils, grease, and dirt. (3) Alkaline cleaning removes fats and oils with soaking solutions of alkaline silicates, caustic soda, soda ash, or phosphates. (4) Blast cleaning uses abrasive action, such as sand blasting. (5) Scarfing removes impurities and irregularities from the surface of steel ingots by subjecting the steel to a stream of oxygen while the steel is at orange heat.

Steel finishing is the final step before marketing. It is generally done by cold-rolling, tin-plating, or galvanizing. Cold-rolling gives steel a smooth finish. Tinplating and galvanizing are used where steel is expected to be exposed to corrosion.

Pollution Control

Air Pollutants. Coke making generates air pollutants from coke furnaces. These include particulates, hydrocarbons (HC), carbon monoxide (CO), ammonia (NH_3), and nitrogen oxides (NO_x). Sulfur oxides (SO_x) emissions depend on the sulfur content of the coal processed. Quenching with direct water contact to cool the coke releases volatiles, which can contribute air pollution unless collected and treated. Photograph 4-3 shows polluting emissions from a coke manufacturing plant.

Crushing iron ore and limestone for the blast furnace produces iron ore and calcium carbonate particulates. Sintering the crushed iron ore produces particulate and hydrocarbon air pollutants.

Common air pollutants from blast furnaces include particulates (35 to 50 percent iron, 4 to 14 percent carbon, 8 to 13 percent silicon dioxide, and small amounts of trace metal oxides) and carbon monoxide.

The three types of steel making furnaces differ in air pollutants produced. Open hearth furnaces emit particulates which are about 50 percent iron oxides with lesser amounts of fluxes and additives. Small amounts of fluorides are emitted if fluorspar is used as a flux. Because the melt in electric arc furnaces is subjected to high temperatures, oxides of impurities in the melt are produced in large quantities. The amount and types of oxides depend on the content of the melt, the amount of oxygen used, and the length of time of the heat. Particulates and carbon monoxide are emitted in moderate amounts. Basic oxygen furnaces generate more particulates per unit of product than open-hearth furnaces because of high levels of turbulence in the furnace caused by the high-pressure introduction of oxygen. Carbon monoxide is also generated (about 70 kg/kkg of steel).

Air pollutants are not an important problem in milling processes, but the next step, cleaning, produces air pollutants, mainly iron oxides. Air pollution is a lesser problem in finishing operations.

Particulates can be controlled by filters, electrical precipitators, scrubbers, or mechanical collectors, such as baffles or cyclones. Filters and precipitators are efficient in terms of particulate removal, as well as being of comparatively moderate cost. Mechanical means have the lowest removal efficiency, but are the cheapest and may be adequate if control laws are not strict, or if few particulates are emitted because of small plant size. Scrubbers are the most expensive control method; however, they also act to remove sulfur oxides and other gases, and are virtually the only means of controlling these emissions. Photograph 4-4 illustrates the effectiveness of air pollution control measures.

Residue Reuse. Two residues from air pollution controls which are economically feasible for reuse are carbon monoxide and iron particulates. CO is diverted back to a burner after all other pollutants have been removed from the waste stream. Burning the CO

Photograph 4-3

Air pollution from a coke manufacturing plant located on a river. Plant wastewater is treated before discharge.

Photograph 4-4

Smokestack at operating steel mill before and after installation of air pollution control equipment.

converts it to CO_2 (a harmless emission) and liberates 2,430 kcal of heat energy per kg of CO burned. Iron particulates may be recycled in the blast furnace after sintering.

Process/Fuel Modifications. Air pollution emissions can be minimized by process modifications and use of low sulfur fuels. Where oxygen injection into the melt is used, as in the BOF and some open hearth furnaces, the quantity of particulates produced is raised. However, oxygen injection results in more efficient use of fuel and greater steel production. The cost advantages of these factors far outweigh the cost disadvantages of installing air pollution control equipment.

Water Pollutants. In coke making, water pollution is created in cooling, quenching, and drainage waters. Coal supplies are stored in the open, and the resulting drainage is similar to acid mine wastewater. Heat is introduced in cooling waters; the difference between influent and effluent temperature can be as much as 5C. Quenching waters cool the coke by direct contact, thereby accumulating suspended solids, hydrocarbons, ammonia, cyanides, chlorides, and sulfates, along with significant amounts of heat. Cleaning the coke furnace adds ammonia, phenol, acids, and other cleaning chemicals to the washwater stream. The major water pollutants emitted from coke processing are suspended solids, phenols, oils, and heat.

Sintering crushed iron ore produces suspended solids and heat as water pollutants.

Water used as blast furnace coolant heat exchanger may contain few pollutants other than heat if there is no direct contact with the molten heat exchanger material. Quenching, however, may add high but variable amounts of suspended solids, some minor amounts of dissolved solids, and significant amounts of heat to the wastewater. Washwaters may contain 1 to 10 g/liter of total dissolved solids after each wash, along with variable but significant amounts of acid, base, and other cleaning agents. Thermal pollution is not a problem with washwaters.

Milling processes use large amounts of cooling and heating waters. In casting and milling operations, water is used as a coolant and as a medium to remove surface scale and oils. Oils are floatable and the size of the scale particles varies from microns to centimeters. Peak effluent volumes range from 8,000 liters per minute to 450,000 liters per minute, depending on mill size and process.

Finishing operations produce waterborne wastes. Wastewater from cold-rolling mills may contain as much as 200 mg/liter of oils. Effluent volumes are on the order of 4,000 to 6,000 liters per minute per mill. Tin plating and galvanizing operations emit wastewater high in zinc salt, sodium hydroxide, sodium acetate, and heat. Volumes are of the order of 12,000 liters per minute.

Treatment of waterborne wastes often consists of sedimentation and coagulation with chemical addition, as most of the pollutants produced are particulates and oils. These are cost-effective means of treatment, with removal efficiencies of up to 95 percent. Cleaning wastes may have to be neutralized with chemical additives. In some cases,

especially in special alloy production and electroplating operations, heavy metals are also pollutants. These can be removed by lime precipitation.

Water reuse and recycling can reduce water consumption and facilitate water pollution control (see Photograph 4-5). Recovery of cleaning chemicals from cleaning wastes is attractive, especially if their raw material costs are high. Recovering lime from processes where it is used as a neutralizing agent (especially acid wastes) can reduce demand for limestone to remove impurities from molten iron in blast furnaces.

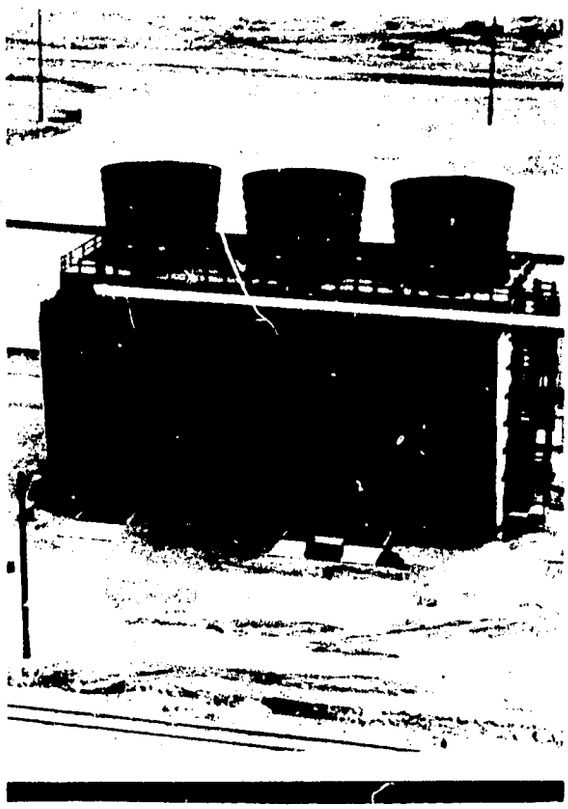
Water wastes from steel making have risen with the introduction of new technology which often increases suspended solids. In some processes, however, newer technology or process change may decrease loads of certain pollutants. New technology in hot rolling reduces oil waste loads, although suspended solid loads may be increased. Use of hydrochloric acid instead of sulfuric acid in pickling operations reduces waste acid loads by about 20 percent and makes recovery easier. Continuous casting instead of ingot casting reduces waste loads by eliminating some rolling mills.

Waste residues. The end products of many pollution control facilities are solid and liquid wastes. These residues often have commerical value. Tables 4-19 and 4-20 summarize reuse potential for various by-products which can be recovered from steel manufacturing and pollution control waste residues.

Cost of Pollution Controls.

Representative treatment systems were designed as discussed under "Cost Analysis" at the beginning of the chapter. Tables 4-21 and 4-22 summarize the air and water pollutants generated by an integrated steel mill. Figures 4-12 through 4-17 are schematics of the proposed air and water pollution treatment systems. Tables 4-23 and 4-24 list equipment for different levels of air and water pollution control. Tables 4-25 and 4-26 indicate for air and water pollutants, respectively, the approximate pollutant removal efficiencies of the indicated treatment systems.

Table 4-43, and Figures 4-48 through 4-53 demonstrate air and water pollution control cost as a function of plant capacity; these are found at the end of the chapter.



Photograph 4-5

This forced draft water cooling tower is part of a steel plant's pollution abatement system. The plant cools, clarifies, and reuses water many times before returning it to the river cleaner than when taken from it.

TABLE 4-19

BY-PRODUCT RECOVERY POTENTIAL
OF STEEL PRODUCTION WASTEWATERS

Wastewater	By-Product	Quantity	Value	Reduction of Pollutant Load(%)
Coke plant ammonia liquor	Phenol	10.5 kg/ton coke	$0.22/ton coke	40
	Ammonia sulfate	12 kg/ton coke	$1.10/ton coke	50
	Ammonia	4 kg/ton coke	$0.24/ton coke	50
	Napthalene, benzene, xylene, and cresols	10 kg/ton coke	$2.20/ton coke	≅100
Pickle liquor	Iron oxide	25-25 kg/ton iron	$.11-.22/ton iron	≅100
	Gypsum	20-25 kg/ton iron	$.11-.22/ton iron	≅100
	Sulfuric acid	15-20 kg/ton iron	$.66-.88/ton iron	≅100
	Hydrochloric acid	15-20 kg/ton iron	$.66-.88/ton iron	≅100
Blast furnace scrubber waters	Mill scale	10-25 kg/ton iron	Minor	60-80

Source: 68.

TABLE 4-20
REUSE POTENTIALS FOR SOLID WASTE RESIDUES
PRODUCED BY POLLUTION TREATMENT PROCESSES

Manufacturing Process and Pollutant	Type of Manufacturing Facility	Treatment Process	% Reuse	Description/Disposal Residue
Coking - particulates	Beehive-by product	None	-	-
Coking - ammonia	All	Sulfuric acid scrubbing	30	$(NH_4)_2 SO_4$ sale or disposal
Reduction - particulates	Blast furnace	Filters and precipitators	80	Recycle to sinter or dispose to landfill
		Scrubbers	80	Suspended solids
Steel-making furnaces-particulates	Open hearth	Precipitators	80	Recycle to sinter or dispose to landfill
		Scrubbers	80	Suspended solids
	Basic oxygen furnace	Precipitators	80	Recycle to sinter or dispose to landfill
		Scrubbers	80	Suspended solids
	Electric arc furnace	Precipitators	80	Recycle to sinter or dispose to landfill
		Scrubbers	80	Suspended solids
Sintering - particulates	Blast furnaces & sinter plants	Scrubbers	90	Suspended solids
- suspended solids		Sedimentation	80	Recycle to sinter or dispose to landfill

TABLE 4-20 (Cont.)
REUSE POTENTIALS FOR SOLID WASTE RESIDUES
PRODUCED BY POLLUTION TREATMENT PROCESSES

Manufacturing Process and Pollutant	Type of Manufacturing Facility	Treatment Process	% Reuse	Description/Disposal Residue
- suspended solids		Coagulation and sedimentation	80	Recycle to sinter or dispose to landfill
		Recirc. and sedimentation	80	Recycle to sinter or dispose to landfill
		Recirc., sediment., and coag.	80	Recycle to sinter or dispose to landfill
Scarfing (smoothing)- particulates	Abrasion or cutting	Dry treatments	70	Recycle to sinter or dispose to landfill
		Wet treatments	70	Suspended solids
Material handling - particulates	Truck vehicles, cranes, and belts	Dry treatments	60	Recycle to sinter or dispose to landfill
		Wet treatments	60	Suspended solids
Rolling mill - suspended solids	Rollers	Sedimentation, coagulation and sedimentation	70	Recycle to sinter or dispose to landfill
			70	Recycle to sinter or dispose to landfill
		Recirculation and sedimentation	70	Recycle to sinter or dispose to landfill
		Recirc., sediment., and coag.	70	Recycle to sinter or dispose to landfill

TABLE 4-20 (Cont.)
REUSE POTENTIALS FOR SOLID WASTE RESIDUES
PRODUCED BY POLLUTION TREATMENT PROCESSES

Manufacturing Process and Pollutant	Type of Manufacturing Facility	Treatment Process	% Reuse	Description/Disposal Residue
Pickling-$FeSO_4$	Tanks	Lime neutralization with sedimentation	70	Iron oxide - recycle Calcium sulfate - sale or disposal
		Evaporation - crystallization	70	Ferrous sulfate crystals
		Crystal roasting	90	Iron oxide to blast furnace. Liquid SO_2 - sale
Pickling-H_2SO_4	Tanks	Lime neutralization with sedimentation	70	Calcium sulfate - sale or disposal Iron oxide - recycle
		Evaporation - crystallization	70	Sulfuric acid in original solution
		Dialysis	90	H_2SO_4 - regenerate

Source: 68.

TABLE 4-21

AVERAGE AIR EMISSION PARAMETERS: IRON AND STEEL

Emission Characteristics	Process Step			
	By-Product Coking A[a]	Blast Furnace B	Sintering Machine C	Basic Oxygen Furnace D
Stack loading before control, g/m^3	22	20	≈17	≈15
(kg/kkg of product)	(115)	(100)	(≈20)	(≈22)
Pollutants (kg/kkg)				
Particulates	3 - 4	1 - 2	0.5	1
CO	1 - 5	0.5 - 1	0.05	0.5 - 1
NH_3	-	0.5 - 1	0.1 - 0.2	0.5
SO_x	3 - 5	1 - 3	0.1 - 0.5	1 - 2
Fe_2O_3	0.1 - 0.5	0.15 - 0.3	0.2 - 0.3	0.5 - 0.9
Manganese	0.01 - 0.1	0.1 - 0.3	0.05 - 0.1	0.044

[a] Letters are used to code the air discharge sources on Figures 4-26 through 4-28.

Source: 105, 96,51,60,73,83,42.

TABLE 4-22

AVERAGE WASTEWATER PARAMETERS: IRON AND STEEL

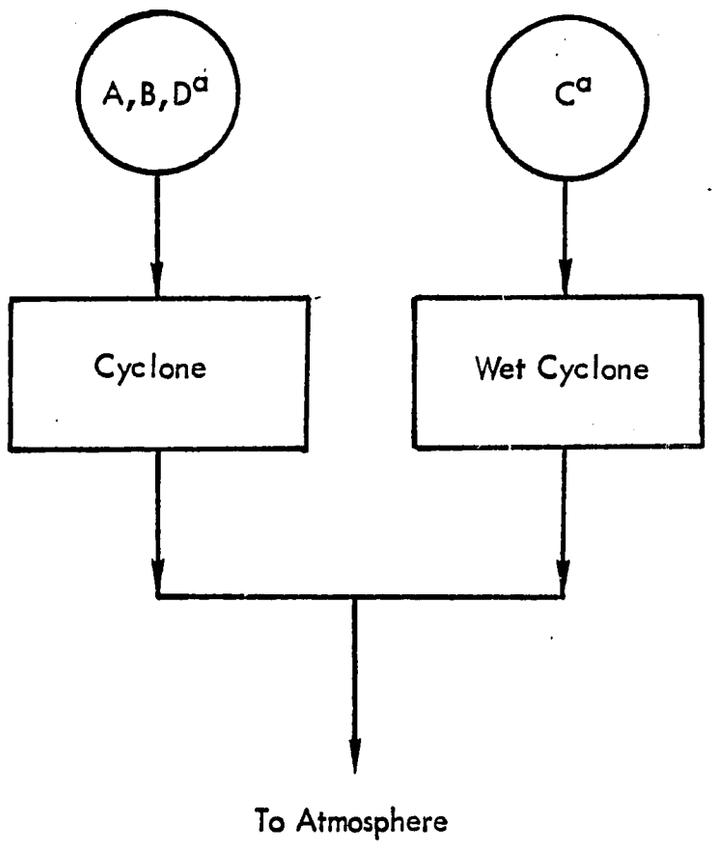
Wastewater Characteristic	Process Step						
	By-Product Coking (A)[a]	Sintering (B)	Blast Furnace (C)	Basic Oxygen Furnace[c] (D)	Vacuum Degassing (E)	Continuous Casting (F)	Primary Hot Forming (G)
Flow rate (liters/kkg[b])	730	1,045	16,285	2,505	2,340	17,535	2,505
pH	6-9	8-10	7-9	6-9	5-10	6-9	6-9
Pollutants (mg/kkg[b])							
Ammonia	2,000		10				
BOD_5	1,200						
Cyanide	200		2				
Fluoride		30	5	30			
Lead					3		
Manganese					20		
Nitrate					80		
Oil and grease	120	600				30	75
Phenol	360		1				
Sulfide	400	200	20				
Suspended solids	90	8,000	1,600	2,000	200	50	150
Zinc					30		

TABLE 4-22 (Cont.)

Wastewater Characteristic	Process Step						
	Cold Rolling (H)[a]	Hot Coating: Galvanizing Operations (I)	Acid Pickling (J)	Hot Coating: Terne Operations (K)	Utility Blowdown, O & M, etc. (L)	Pipes and Tubes (M)	All
Flow rate (liters/kkg[b])	105	5,010	420	5,010	105	10,440	64,035
pH	6-9	2-6	1		6-9	6-9	
Pollutants (mg/kkg[b])							
Ammonia							2,010
BOD_5							1,200
Cyanide							202
Fluoride							65
Lead				2			5
Manganese							20
Nitrate							80
Oil and grease	600	50		50	50	75	1,650
Phenol							361
Sulfide							620
Suspended solids	200	160	300	160	200	150	13,260
Zinc		108					138

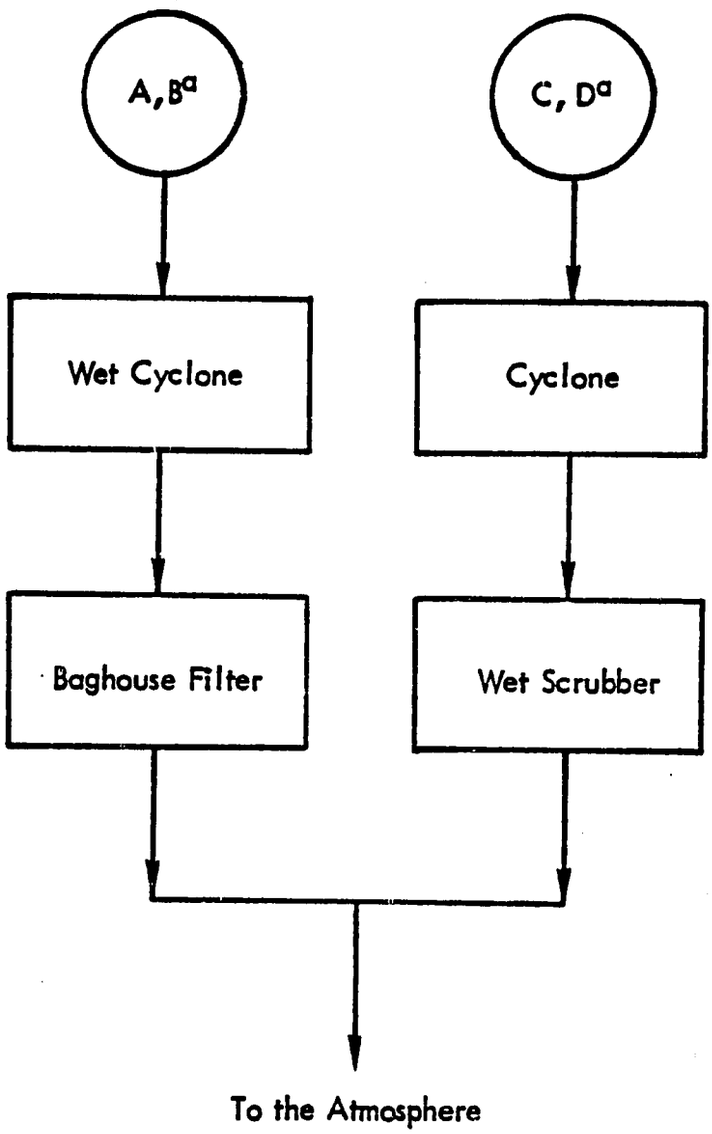
[a] Letters are used to code the wastewater sources shown on the water treatment flow diagrams (Figures 4-12 through 4-17)
[b] Per kkg of steel.
[c] A source of water pollution because wet air pollution control methods are normally used here.

Source: 12, 96,105.



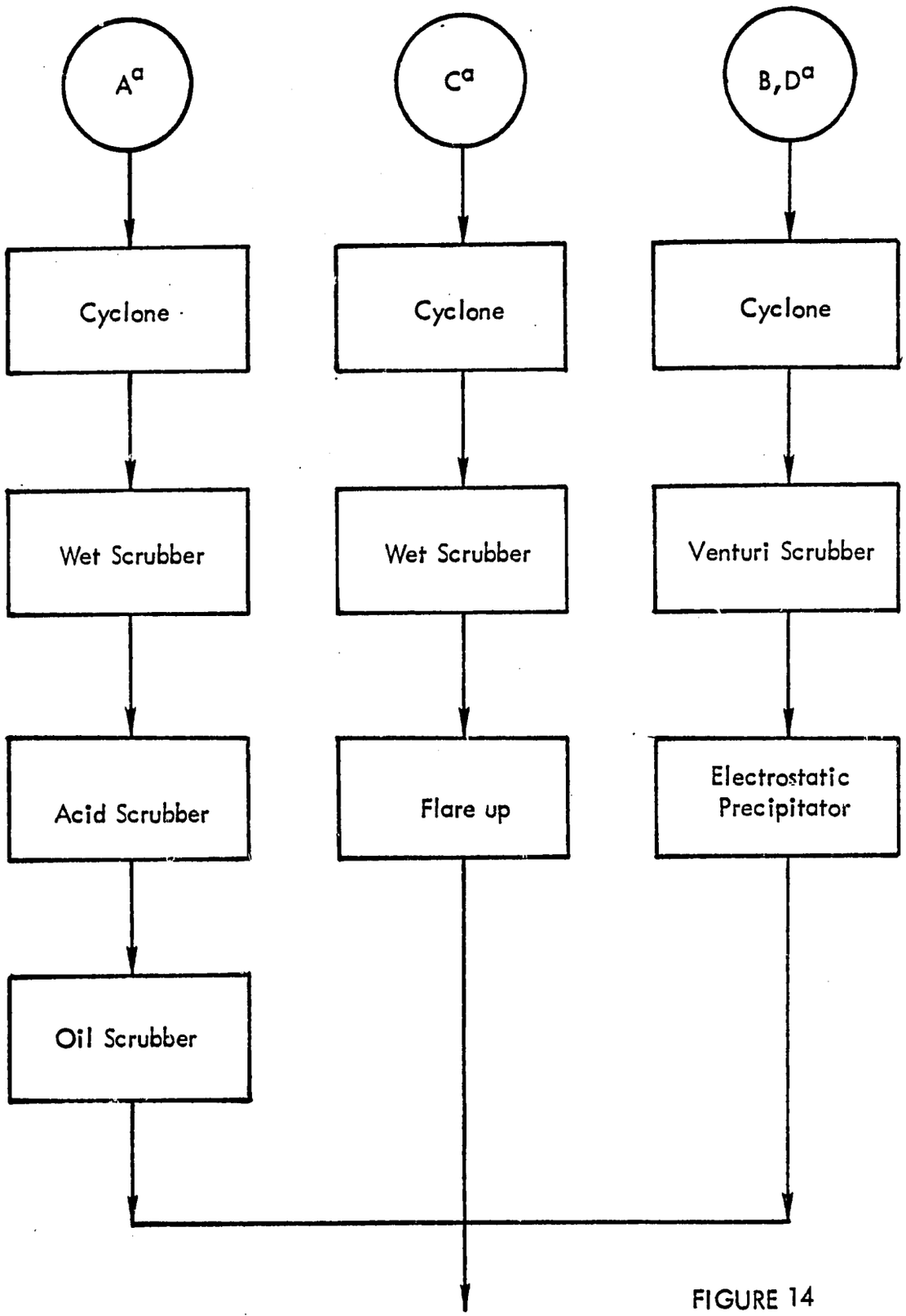
[a] Letters refer to air discharge sources as identified on Table 4-21.

FIGURE 4-12
PRIMARY AIR POLLUTION TREATMENT SYSTEM: IRON AND STEEL



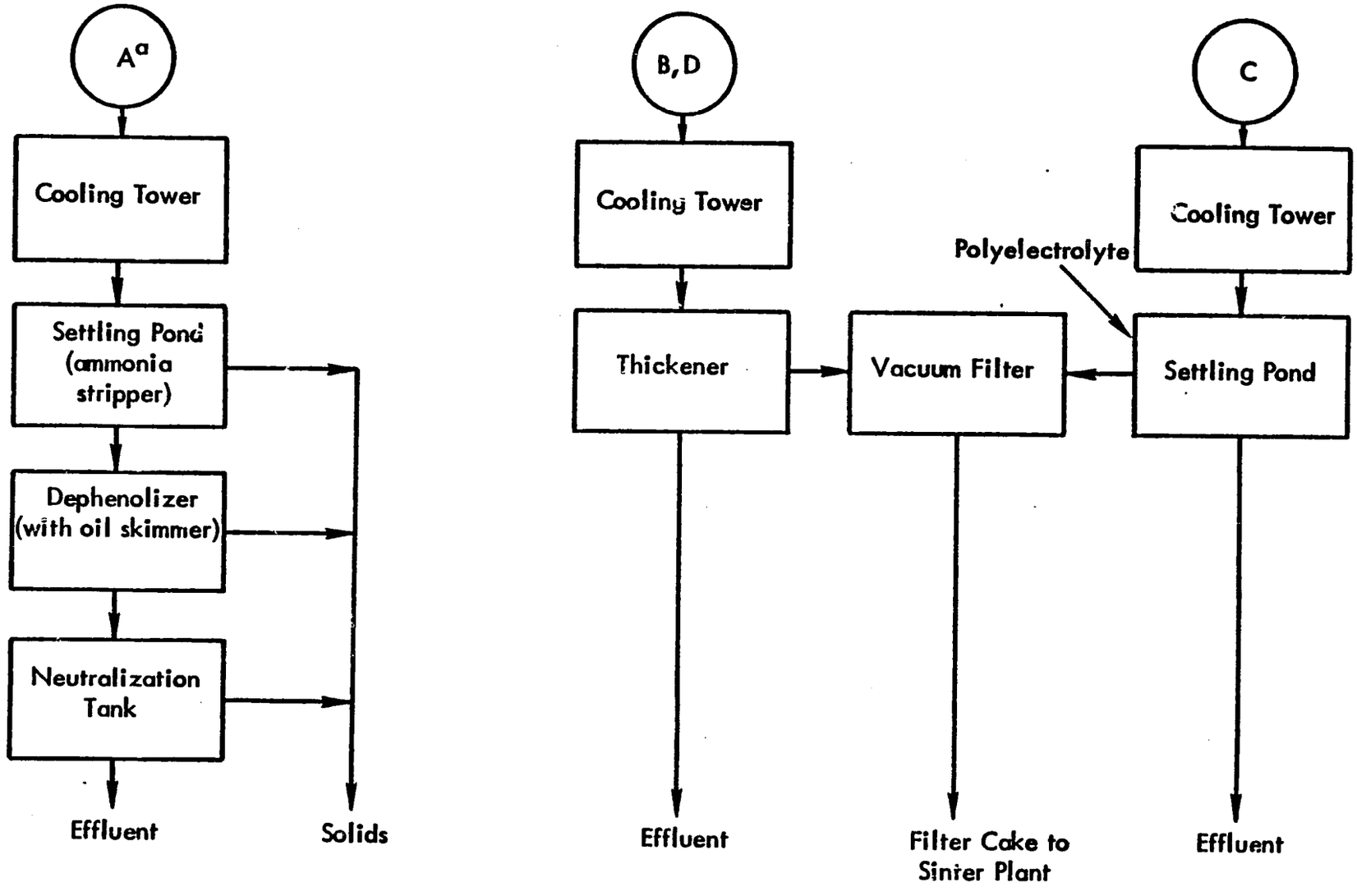
[a] Letters refer to air discharge sources as identified on Table 4-21.

FIGURE 4-13
SECONDARY AIR POLLUTION TREATMENT SYSTEM: IRON AND STEEL



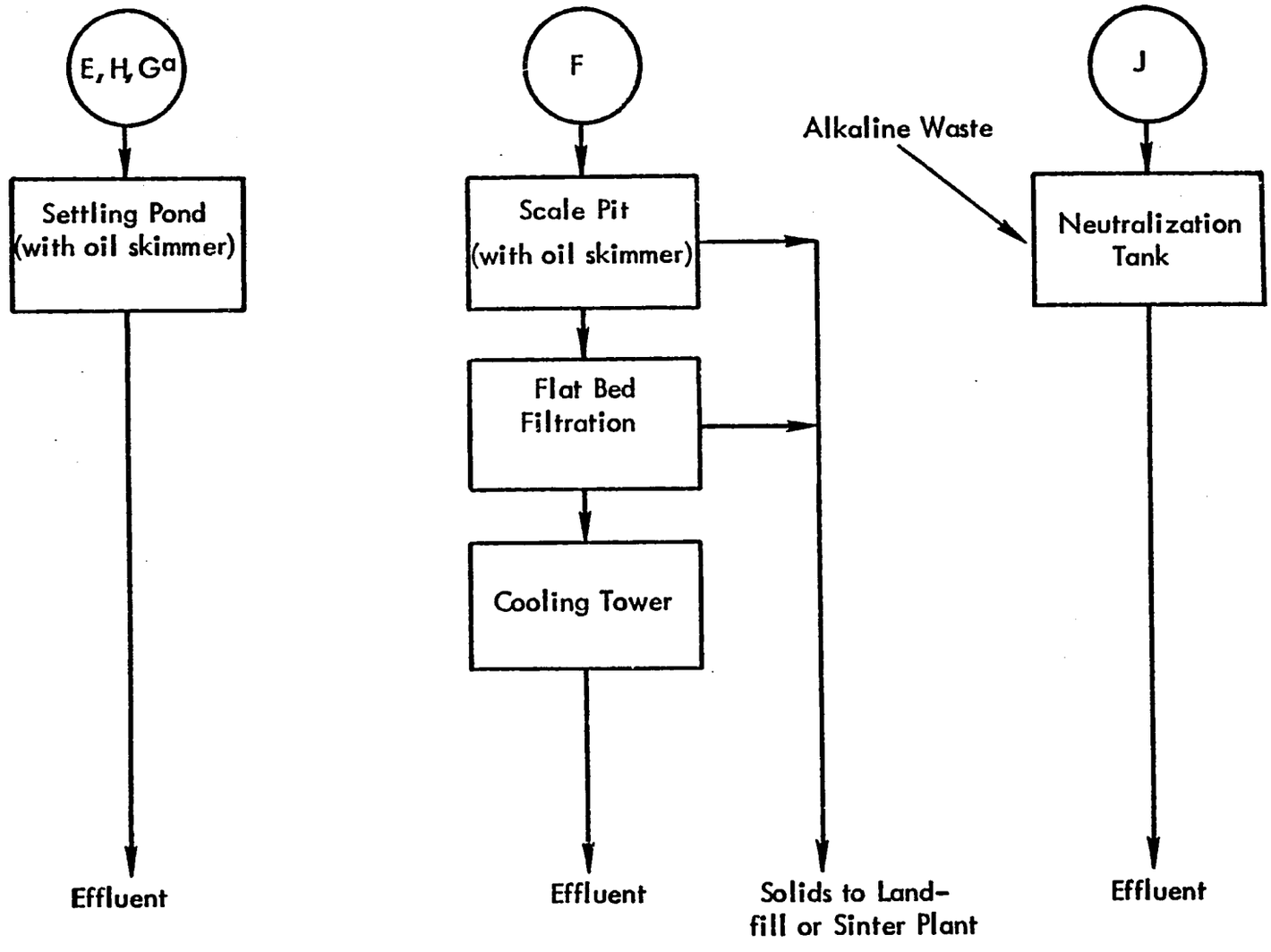
[a] Letters refer to air discharge sources as identified on Table 4-21.

FIGURE 14
TERTIARY AIR POLLUTION TREATMENT SYSTEM: IRON AND STEEL



[a] Letters refer to wastewater discharge sources as identified on Table 4-22 .

FIGURE 4-15
PRIMARY WASTEWATER TREATMENT SYSTEM: IRON AND STEEL



[a] Letters refer to wastewater discharge sources as identified on Table 4-22

FIGURE 4-15 (Cont.)

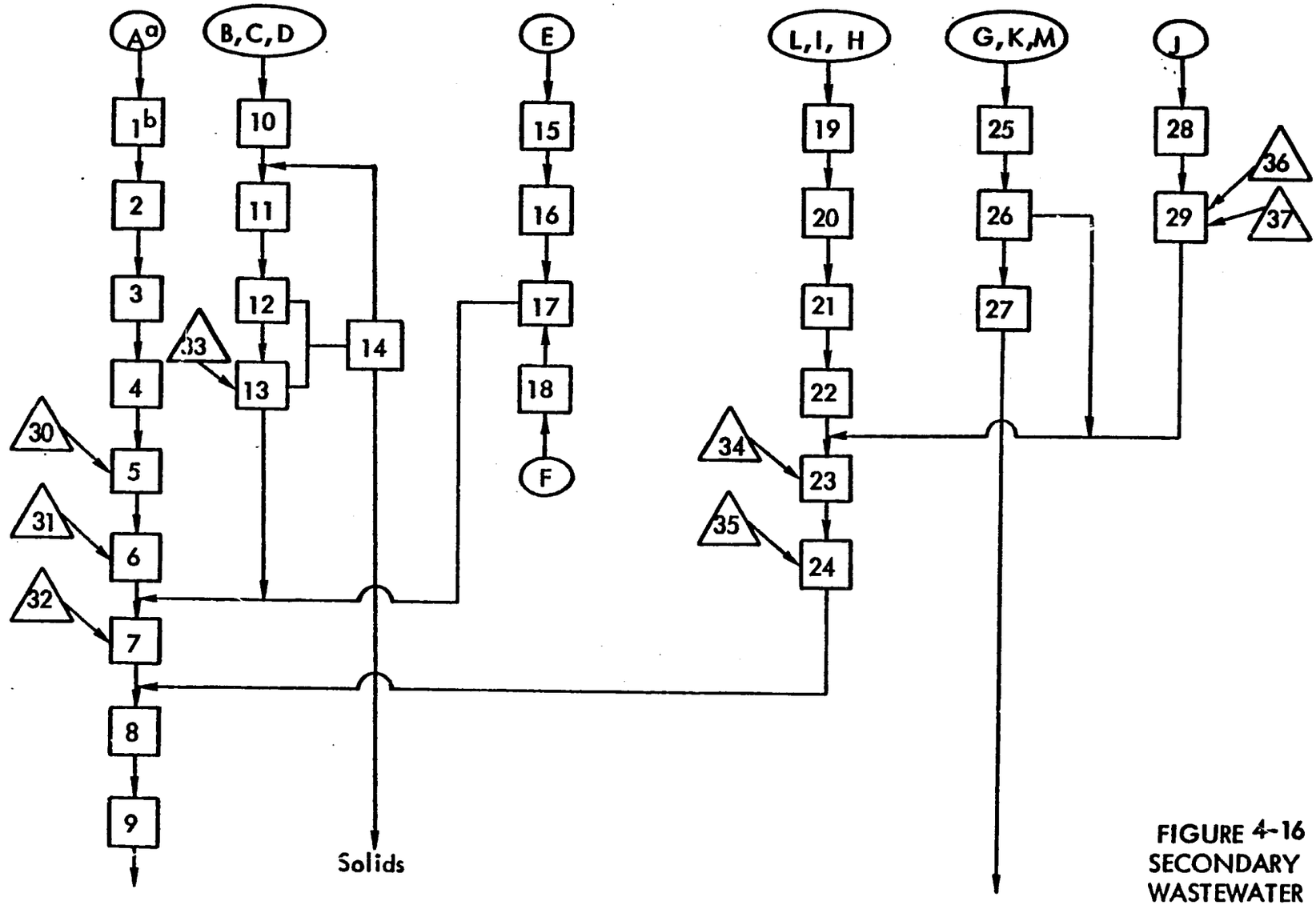


FIGURE 4-16
SECONDARY
WASTEWATER
TREATMENT SYSTEM:
IRON AND STEEL

(continued on next page)

Treatment Methods		Additives
1. Cooling tower	16. Coagulation tank	30. Potash or soda ash slurry
2. Equalization basin	17. Flat bed filter	31. Lime
3. Free ammonia still	18. Settling pond	32. Acid
4. Dephenolizer	19. Equalization basin	33. Polyelectrolyte
5. Desulfurization unit	20. Settling pond	34. Air
6. Fixed ammonia still	21. Clarifier or chemical treatment tank	35. Air
7. Neutralization tank	22. Neutralization tank	36. Alkaline waste
8. Final settling pond	23. Aeration	37. $Na_2S_2O_5$
9. Final cooling tower	24. Extended aeration	
10. Cooling tower	25. Scale pit	
11. Settling pond	26. Clarifier	
12. Thickener	27. Vacuum filter	
13. Thickener	28. Acid waste holding tank	
14. Vacuum filter	29. Neutralization tank	
15. Settling pond		

[a] Letters refer to wastewater discharge sources as identified on Table 4-22
[b] Numbers refer to treatment methods and additives as shown above.

FIGURE 4-16 (cont.)
LEGEND

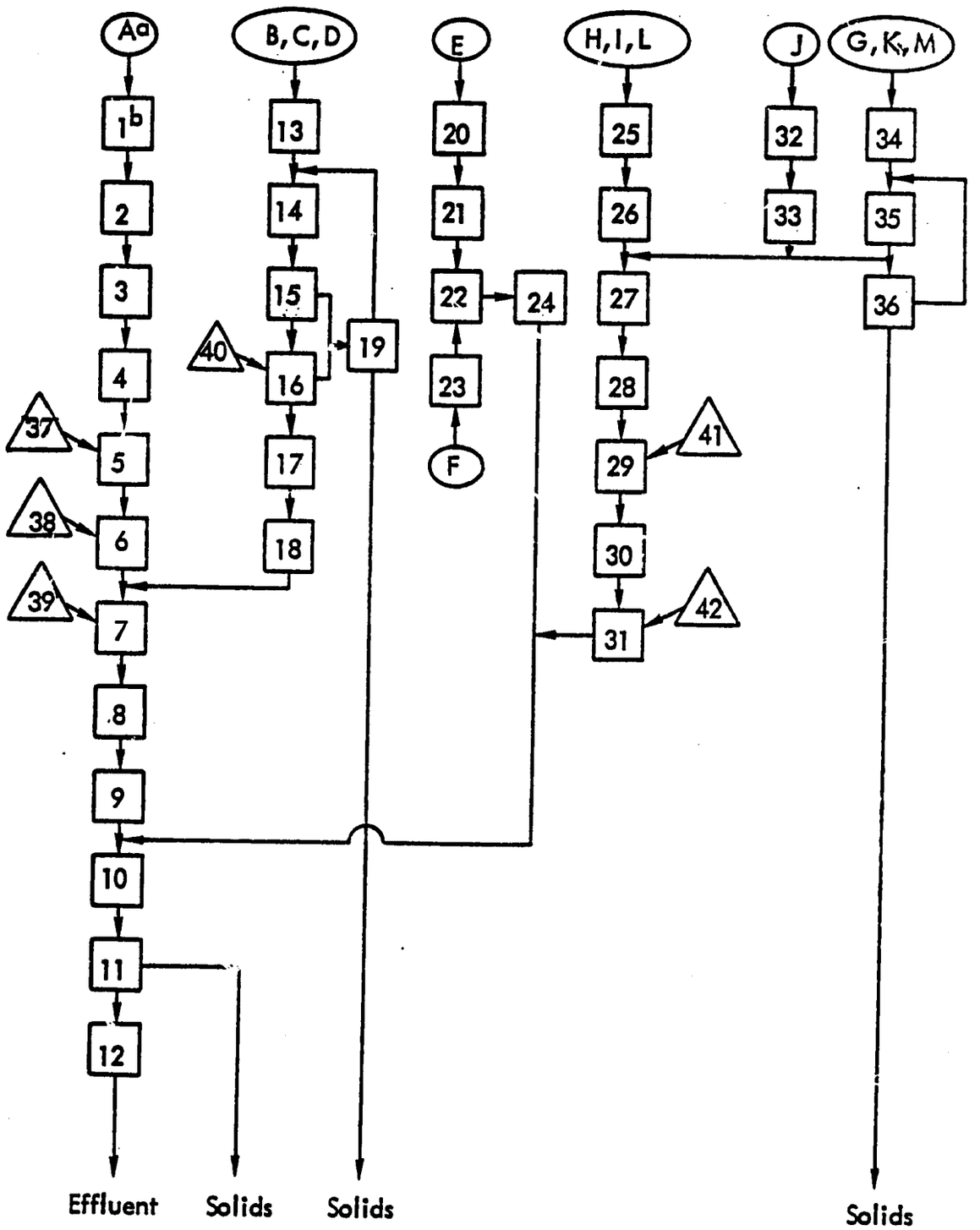


FIGURE 4-17
TERTIARY WASTEWATER
TREATMENT SYSTEM:
IRON AND STEEL

(continued next page)

Treatment Methods		Additives
1. Cooling tower	21. Coagulation tank	37. Potash or soda ash slurry
2. Equalization basin	22. Flat bed filter	38. Lime
3. Free ammonia still	23. Settling ponds	39. Acid
4. Dephenolizer	24. Cast spray system	40. Polyelectrolyte
5. Desulfurization unit	25. Equalization basin	41. Air
6. Fixed ammonia still	26. Settling pond	42. Air
7. Neutralization tank	27. Clarifier	
8. Settling pond	28. Neutralization plant	
9. Aeration basin	29. Aeration basin	
10. Carbon adsorption	30. Secondary clarifier	
11. Filtration	31. Extended aeration	
12. Final cooling towers	32. Acid recovery tank	
13. Cooling tower	33. Neutralization tank	
14. Settling pond	34. Scale pit	
15. Thickener	35. Clarifier	
16. Thickener	36. Vacuum filter	
17. Activated alumina treatment		
18. Alkaline chlorination tank		
19. Vacuum filter		
20. Settling pond		

[a] Letters refer to wastewater discharge sources as identified on Table 4-22.
[b] Numbers refer to treatment methods and additives as shown above.

FIGURE 4-17
LEGEND

TABLE 4-23
AIR POLLUTION CONTROL EQUIPMENT:
IRON AND STEEL

Control System		
Primary	Secondary	Tertiary
Cyclone Wet cyclone	Cyclone Wet cyclone Baghouse filter Wet scrubber	Cyclone Water scrubber Acid scrubber Oil scrubber Wet scrubber Venturi scrubber Electrostatic precipitator Flare up

TABLE 4-24
WATER POLLUTION CONTROL EQUIPMENT:
IRON AND STEEL

Control System		
Primary	Secondary	Tertiary
Cooling tower	Cooling tower	Cooling tower
Settling pond	Settling pond	Settling pond
Neutralization tank	Neutralization tank	Neutralization tank
Flatbed filtration system	Clarifier	Primary clarifier
Vacuum filter	Fixed ammonia still	Secondary clarifier
Scale pit	Desulfurization tank	Fixed ammonia still
Dephenolizer	Flatbed filtration system	Desulfurization tank
Thickener	Vacuum filter	Flatbed filtration system
	Scale pit	Vacuum filter
	Dephenolizer	Scale pit
	Thickener	Dephenolizer
	Acid waste holding tank	Thickener
	Aeration basin	Acid waste holding tank
	Extended aeration	Aeration system
	Equalization tank	Extended aeration
	Coagulation tank	Equalization tank
		Coagulation tank
		Activated carbon adsorption
		Final filtration unit
		Activated alumina treatment system
		Alkaline chlorination tank

TABLE 4-25
AIR POLLUTANT REMOVAL EFFICIENCIES OF THE SELECTED TREATMENT SYSTEMS: INTEGRATED IRON AND STEEL INDUSTRY

Pollutant	Removal Efficiency (%)		
	Primary	Secondary	Tertiary
Particulates	70 - 90	80 - 85	99
CO	30	70 - 80	85 - 99
NH_3	30	50 - 80	95 - 99
SO_x	30 - 50	75 - 85	90 - 99
Fe_2O_3	--	75 - 85	90 - 99
Manganese	10 - 30	70 - 85	90 - 99

Source: 12,105,96,83.

TABLE 4-26
WATER POLLUTANT REMOVAL EFFICIENCIES OF THE SELECTED TREATMENT SYSTEMS: INTEGRATED IRON AND STEEL INDUSTRY

Pollutant	Removal Efficiency (%)		
	Primary	Secondary	Tertiary
Lead	15	95	99.5
Manganese	20	95	99
Zinc	30	75	90
Ammonia	45	80	98
Cyanide	45	80	98
Sulphide	80	95	99
BOD_5	70	90	95
Suspended solids	80	95	99
Oil and grease	85	95	99-99.8
Fluoride	--	75	90

Source: 87,105,53,96,109,112.

KAISER STEEL PLANT AT FONTANA, CALIFORNIA

The Fontana, California, plant of Kaiser Steel Corporation is an outstanding example of what is possible in industrial pollution control. It has won several awards for its achievements in air and water pollution abatement. The firm's management is proud of the operation, and has requested that the plant be identified. They have welcomed inspection by visitors from all over the world.

Description

Fontana is located in the populous South Coast air basin of water-short southern California, about 97 km from the Pacific coast. The Fontana plant is an integrated facility with an annual ingot capacity of 3.0 million kkg. Integrated steel mills produce finished steel products from basic raw materials: power, coal, iron ore, limestone, air, and water. Since all of the basic steel-making and pollution-generating processes occur at a single site, an integrated mill is ideal for studying pollution problems and control for the entire steel industry. Table 4-27 presents general information concerning the Fontana plant, its operation, sources of raw materials, and products.

Steel plants are typically located close to large water sources, especially integrated mills which usually require from 135,000 to 175,000 liters of water per kkg of steel produced. But since the Fontana plant is in an arid region, it was designed to recirculate its process water. The plant uses only 3,780 liters per kkg of steel produced, approximately 2.5 percent of the industry average. Recirculation to compensate for a limited water supply has greatly reduced many water pollution problems and permitted others to be solved at minimum cost. Many steel plants with ample water supplies are now retrofitting recirculation systems to solve water pollution problems at much higher costs than if the systems had been initially installed.

Fontana is within a large metropolitan area with heavy air pollutant concentrations. Because air emission standards in this region (see Table 4-28) are very restrictive, Kaiser has had to institute advanced control measures, primarily for particulates. Nevertheless, the plant has been accused of primary responsibility for many of the area's air pollution problems, sometimes unjustly. For example, certain plant diseases were originally attributed to the mill. Through an extensive research program, Kaiser was able to show that the diseases were caused by ozone (a constituent in the area's photochemical smog) and not the plant's emissions. As a result of rigorous government regulations, public pressure, and a desire not to add to the existing, serious environmental problems, the Fontana plant has become a leader in the field of air and water pollution control techniques.

The Kaiser Fontana plant is of particular interest because: (1) it is both low-polluting and economically profitable, (2) reuse and recycling methods are emphasized over end-of-pipe treatment (environmentally and economically superior) in the design of new facilities, and (3) the technology and its effects on pollution emissions have been operationally proven by many years of industrial application, and are not just an experimental possibility.

TABLE 4-27

THE KAISER STEEL FONTANA PLANT:
GENERAL INFORMATION

Year operations started	1942.
Location	San Bernardino Valley, about 72 kilometers east of Los Angeles.
Area of plant site	729 hectares.
Number of employees	8,700.
Annual payroll	$80,000,000.
Ingot capacity	2,800,000 net metric tons.
Source of iron ore	Company-owned Eagle Mountain Mine located 262 kilometers southeast of Fontana Plant.
Principal sources of coal	Company-owned Sunnyside Mines in Carbon County, Utah, approximately 1300 kilometers from Fontana Plant, and Company-owned coal mines of considerable reserves in Raton and York Canyon, New Mexico
Sources of medium volatile coal	Purchased from mines in Colorado.
Sources of low-volatile coal	Purchased from mines in Oklahoma and Arkansas (12-1/2 to 17-1/2 percent of coal mix is low-volatile coal).
Present sources of limestone	Company-owned Cushenbury limestone quarry located near Victorville, California, 124 kilometers northeast of plant, and purchases from outside quarry, near Las Vegas, Nevada.
Source of power	Purchased from Southern California Edison Company.
Sources of water	In part from water company serving the area and in part from two company-owned wells located on the Fontana Plant property.
Rail transportation	Santa Fe and Southern Pacific.
Saleable products	Structural shapes, sheared plates, universal mill plates, hot rolled sheet, hot rolled strip, reinforcing bars, bar size shapes, merchant bar, cold rolled strip, cold rolled sheet, electrolytic tin plate, chrome plate, black plate, continuous-weld pipe, galvanized sheet, electric-weld line pipe, semi-finished slabs, blooms and billets, basic and

TABLE 4-27 (Cont.)

Saleable products (cont.)	foundry pig iron, ingot molds and stools, coal chemicals, specialty sketch plates and sheets, and alloy and other special sheets.

Source: 36.

TABLE 4-28

AIR POLLUTION EMISSION STANDARDS:
STEEL MANUFACTURING

Source	Pollutant	Air Discharge Standard
Stack	Smoke/color	Not to equal or exceed shade No. 1 Ringelmann Chart for more than 3 minutes in any one hour; or obscure an observer's view greater than shade No. 1 above.
	Nuisance	No discharge of materials causing any health or safety nuisance.
Transport, handling, construction, storage	Fugitive dust	Not to be visible in air beyond property line of plant source.
		Not to exceed 100 μg/cu m above the difference between upwind and downwind dust, except when instant and average wind speeds exceed 40 km/hr and 24 km/hr, respectively.
Stack	Particulates	Range Vol. discharged (m^3/min) — $\mu gm/m^3$ 25 or less — 450 70,000 or more — 23
	Carbon monoxide	Maximum of 2,000 μl/l averaged over a minimum of 15 minutes.
Stack, from steam generating equipment	Oxides of nitrogen	Gas fuel - 125 μl/l. NO_x Liquid and solid fuel - 225 μl/l NO_x
	Combustion contaminants	Not to exceed both 5 kg/hr and 23 mg/cu m
Stack, from fuel burning equipment	Oxides of nitrogen	Fuel — Heat input (kg-cal) — NO_x (μl/l) Gas — 140-450 — 300 450-540 — 225 540 or more — 125 Liquid and solid — 140-450 — 400 450-540 — 325 540 or more — 225

Source: 65.

Air Pollution Control

Air pollutants include particulates, ammonia, carbon monoxide, sulfur oxides, and hydrocarbons. Particulate control had first priority because it is technologically more tractable than control of the gaseous pollutants and because initial government regulations required it. Kaiser chose dry methods for particulate control because of the need for water conservation, the water pollution control problems after the particulates are transferred to water, and the high efficiencies and reliabilities of dry methods such as baghouses and electrostatic precipitators.

Kaiser's experience in choosing a particulate control method for the sinter plant illustrates the selection process for a given facility. Every known air pollution control device was either discussed, prototyped, or pilot-size units designed and installed during the selection process. The basic devices tested were: a reverse-air-jet cleaned baghouse, a reverse-air-flow cleaned baghouse, a four-section plate-type electrostatic precipitator with and without a high-efficiency cyclone in series, a cone-type wet scrubber, a weir-type venturi scrubber, a nozzle-type venturi scrubber, and an orifice washer.

The reverse-air-jet cleaned baghouse suffered considerable bag damage from abrasion by the reverse-air-jet assembly. The reverse-air-flow cleaned baghouse performed well and, of all the devices tested, required the least maintenance. Bag life was satisfactory, with Teflon and glass bags giving the longest life of those tested. The electrostatic precipitator, even after considerable experimentation, did only a marginal job due to the insulating effect of lime particle deposits on the charging and grounding electrodes. This required excessive maintenance which made it impossible to operate the precipitator at the recommended power input. Decreasing the power input to maintain a stable operation reduced removal efficiency to only about 65 percent. The cone-type wet scrubber produced many problems; the most important was plugging of the throat caused by the sloughing off of the wet-dry interface buildup. This scrubber and the other three wet scrubbing devices tested presented water and scaling difficulties. The high-energy venturi scrubbers consumed excessive amounts of power. The baghouse system required approximately one-sixth as much energy as the scrubbers. Kaiser chose the reverse-air-flow cleaned baghouse design with woven glass facric filters. It achieves better than 99 percent removal efficiency and the installation cost was $2.6 million.

Similar treatment processes were undertaken for other production areas. The coal handling plant also adopted a baghouse approach to particulate control. Blast furnace control uses mechanical dust collectors and orifice wasters. The open hearth furnaces use eight electrostatic precipitators with a net 98-99 percent reduction in particulates. The basic oxygen furnace uses three electrostatic precipitators (3 million liters per minute capacity each) which achieve better than 99 percent removal efficiency.

Although the noted dry methods are generally superior for particulate removal, they have three difficulties: (1) relatively higher costs for larger-sized installations, (2) large space requirements, (3) corrosion, (4) sensitivity to the type of material handled, (5) inability to remove gaseous pollutants such as SO_x, fluorides, and NO_x,

and (6) high maintenance cost of electrostatic precipitators and baghouses. Because of these disadvantages, existing stringent governmental (local, state, and federal) control standards on gaseous pollutants (particularly SO_x), and the anticipation of stricter standards (for example, NO_x control may be required), Kaiser is considering wet methods where applicable.

Kaiser considers scrubbers the only proven method of removing SO_x from steel mill stack gases. A venturi scrubber system with a water pressure drop of 60 inches can achieve good particulate removal and approximately a 95 percent SO_x removal efficiency. The best units available can achieve an 82-84 pressure drop and 98-99 percent SO_x removal, but this small increase in efficiency would greatly increase control cost. Low sulfur coal would also reduce SO_x emissions. Although not yet proven feasible for steel mill emissions, there is an alternative SO_x removal method--the citrate process (used in power plants). In this method contact with H_2S produces elemental sulfur. It is being considered as a possible alternative for future application.

The sources of fluorides are iron ores and spars. Fluoride removal is difficult, but the problem is mainly associated with open hearth furnaces. As Kaiser converts to basic oxygen furnaces, the problem will be greatly reduced. Also, by restricting the fluorides in the raw materials employed, they have been able to control fluoride air pollution. Extensive tests of surrounding areas indicate there is no significant fluoride contamination.

Nitrogen oxides are not yet subject to stringent control requirements. There are several theoretically possible end-of-pipe control methods for NO_x removal. However, no economically and technically long-proven method is currently available. If stringent control requirements are imposed, the Kaiser plant anticipates using process changes, such as controlling combustion time and temperature, to minimize emissions.

In addition to end-of-pipe control equipment, Kaiser has adopted several process modifications to reduce air pollutant emissions. For example, it was discovered that a mechanically driven cutting torch produced a small fraction of the air pollutants produced by one hand-held. Hand torch cutting is therefore being eliminated. This mechanization also allowed one man to control two separate cutting operations. In addition, for certain cutting jobs, shears were substituted for torches.

Water Pollution Control

Water pollutants include suspended solids, total dissolved solids, oils, acids, and dissolved chemicals. The water system at the Fontana plant emphasizes recirculation and reuse. Of the 3,780 liters of water required per ton of manufactured steel, only about 20 percent is discharged (from the wastewater treatment plant and the acid disposal plant) to the non-reclaimable wastewater line. The remainder is used in other plant operations such as slag and coke quenching, sinter cooling, cooling tower evaporation, and so forth. The non-reclaimable wastewater goes to the treatment plant of a local municipality; after treatment it is discharged to the Pacific Ocean. Recirculation is accomplished by dividing water uses according to required water quality and using the

blowdown from higher order uses for make-up water to supply processes with lower quality requirements. Figure 4-18 is a flow diagram of the plant's water system. Table 4-29 lists the water pollution discharge limits for the Kaiser Fontana plant.

Water Supply and Pretreatment. The plant requires about 10.6 billion liters of water annually, with two-thirds coming from a local water company and the rest from on-site wells. As received, this water is stored in the 17 million liter main reservoir until passing either to the water treatment plant or directly to the open 4.5 million liter industrial reservoir.

The water treatment plant uses a cold lime treatment (with sodium aluminate as the coagulating agent) for softening and clarification. Five 50-foot-diameter contact basins are used for this. Continuous sludge recirculation improves solids reduction. The water then passes to the carbonation basin for chlorination and pH control (by bubbling combustion gases, largely CO_2, through the water). Eight rapid sand filters provide the final treatment. Water from the plant flows into both the industrial and domestic supply lines.

Domestic Water Supply. The domestic reservoir is covered and has a 1.9 million liter capacity. From here the water is pumped to a tower which supplies the plant's domestic system, power plant boiler makeup and cooling system, and the fire protection system. Zeolite softening is added for the boiler water. Effluent from the power plant is used in cooling towers. Wastewater from domestic uses passes to a sewage plant with conventional primary and secondary treatment facilities (a small amount of industrial waste is also treated here). Treatment plant effluent has been reclaimed for rolling-mill cooling since 1943 with no known problems.

Industrial Water Supply. A corrosion inhibitor is added to the industrial reservoir to protect the plant's pipelines. From here the water feeds a complex set of industrial systems organized in series and parallel. The general idea is that water passes through a number of systems in series, with the blowdown of one system becoming the supply for the following system. This creates a hierarchy of water uses, from those with the highest quality requirements to those with the lowest. This hierarchy together with substantial recycling are responsible for the plant's low water requirements and high degree of water pollution control.

Highest Quality Uses. These are the motor-room and reheating-furnace cooling systems which are generally closed or internal systems. Each such system is supplied from a cooling tower and storage tank to maintain constant temperature and pressure, and provide an emergency supply in case of power failure. (Each also has stand-by steam or gasoline driven pumps for prolonged power failures.) If make-up to these systems were limited to the amounts lost from cooling tower evaporation, solids concentration would increase to the point of causing serious scale buildup in coolers and pipelines. However, make-up water requirements for the next level of use quality are large enough to keep solids concentrations within manageable limits. Chemicals are also added to control algae and slime development.

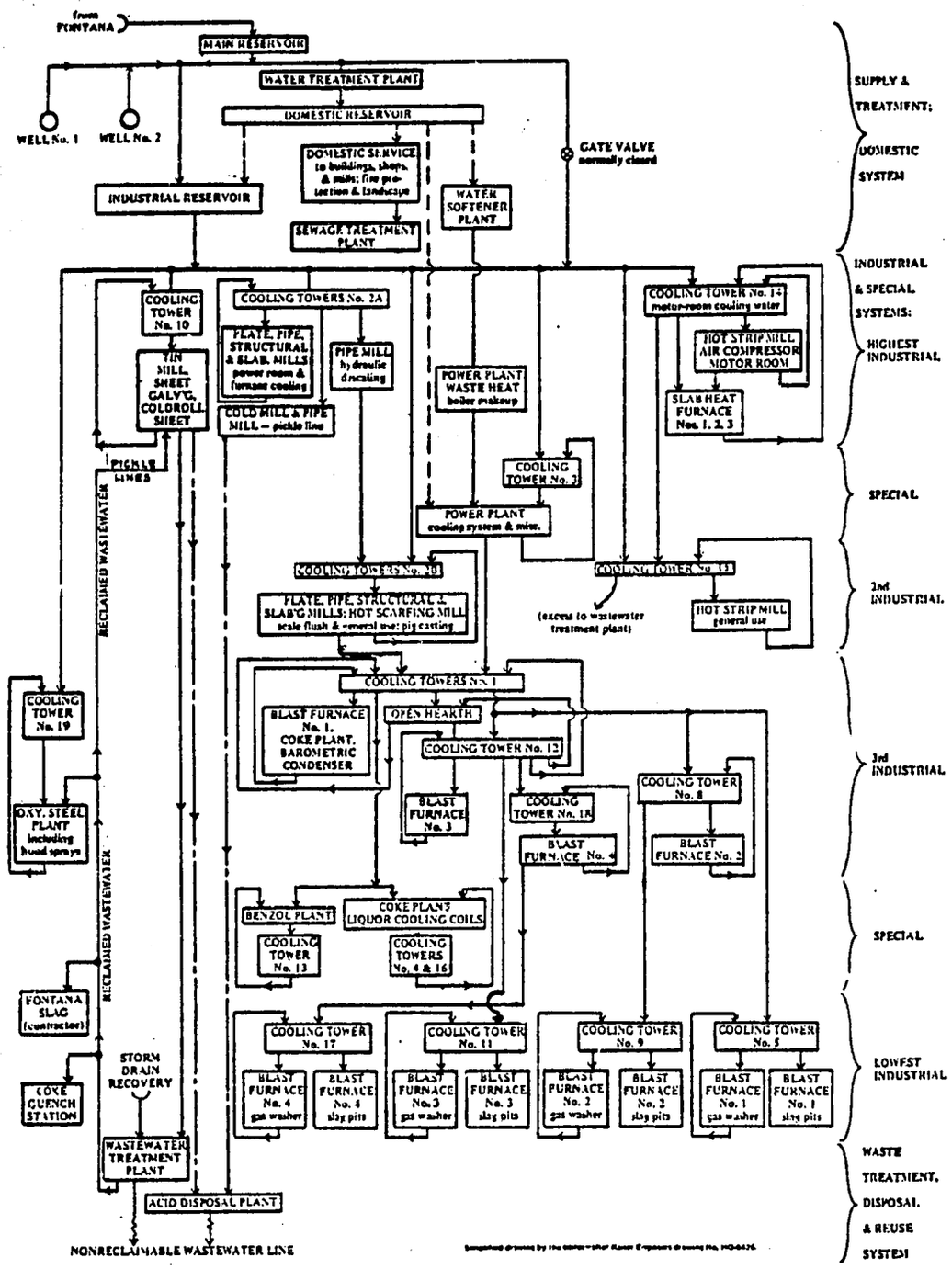


FIGURE 4-18
KAISER STEEL MILL:
WATER AND WASTEWATER SYSTEMS

TABLE 4-29

NPDES WASTE DISCHARGE REQUIREMENTS
KAISER STEEL PLANT, FONTANA, CALIFORNIA, U.S.A.

Plant/Process Source	Discharge		Effluent Limitations	
	Type	Source	Pollutant	Max. Concentrations
Steel manufacturing Plant area	Storm water Run-off	Plant Drainage System - West	Chloride Electrical conductivity Oil and grease Oil and grease	70 mg/l 600 micromhos/cm 15 mg/l None visible
Steel manufacturing Plant area	Storm water Run-off	Plant Drainage System-Control	Electrical conductivity Oil and grease Oil and grease	500 micromhos/cm 15 mg/l None visible
Steel manufacturing Ferric chloride plant	Pickling acid waste	Pickle lines to impervious ponds	Concentrated waste Hcl Nuisance	No co-mingling with state waters; 18-inch min. free board in ponds None.
Steel manufacturing Waste chrome storage	Chrome plating wastes	Plating lines to impervious ponds	Chrome waste Nuisance	The co-mingling with with state waters 18-inch min. freeboard in ponds None
Steel manufacturing Metal products division: Plate fabricating	Pressure test water Sanitary Wash water	Pressure test area Septic tank Sub-surface disposal	Electrical conductivity Boron Chloride Electrical conductivity	1650 micromhos/cm 0.5 mg/l 70 mg/l 900 micromhos/cm

TABLE 4-29 (Cont.)

STATE WASTE DISCHARGE REQUIREMENTS:
KAISER STEEL PLANT, FONTANA, CALIFORNIA, U. S. A.

Plant/Process Source	Discharge		Effluent Limitations	
	Type	Source	Pollutant	Max. Concentrations
Steel manufacturing	Cooling and quenching wastewaters	Pond disposal	Hexavalent chromium	0.10 mg/l
			Cadmium	0.02 mg/l
			Selenium	0.02 mg/l
			Phenols	1.0 mg/l
			Odor	None
			Unsightliness	None
			The following are the maximum increases in water concentration over the raw water supply:	
			Boron	0.5 mg/l
			Sodium	150 mg/l
			Sulfate	60 mg/l
			Chloride	150 mg/l
			Total hardness (as ($CaCO_3$)	70 mg/l
			Fluoride	2.0 mg/l

Source: 66.

Second Quality Uses. Rolling mill uses are at this level; the water is used for bearing cooling, roll cooling, and some scale flushing. (Most scale flushing is done by recirculating water at each mill). Water in these systems gains heat, oil, and grease, and some mill scale. Storage towers provide pressure control and reserve capacity. Effluent from the rolling mill passes to scale pits to settle out heavy scale particles. It then passes to clarifiers where fine scale and other solids are settled out and the oil is skimmed off. Sludge underflow is pumped from the clarifiers to sludge beds; after being dried as much as possible, the sludge is removed to a land disposal site. Solid waste recycle of these and other solids is actively being pilot researched at the time of this writing. Clarifier effluent passes to the cooling towers for heat exchange and then is recycled back to the mills. The water is satisfactory for all uses except high-pressure descaling, where it is necessary to provide additional cleaning with fine-meshed automatic strainers.

Third Quality Uses. These are as cooling water for the open-hearth and basic-oxygen steel-making furnaces, part of the coke plant, and the iron-making blast furnaces. Water in these systems picks up heat and dirt (mainly iron and graphite). The systems are equipped with cooling towers and, with one exception, clarifiers (to remove iron and carbon particles). The clarifiers were added to eliminate fouling problems. Sludge from these clarifiers is handled as previously mentioned. All the towers (with the one exception) are also intertied with two elevated towers operating in parallel. It is difficult to balance these separate systems but necessary that they back each other up to minimize the chance of complete water loss and the consequent failure in equipment and production. Emergency steam-driven pumps are installed at each cooling tower to maintain water flow in case of power failure.

Lowest Quality Uses. The lowest level cooling system is the blast furnace gas washer system. The large volume of gas produced by a blast furnace must be cleaned before being used as fuel in the blast furnace stoves, coke ovens, and powerhouse boilers. This is done by orifice scrubbers and gas washers with water supplied by the tower systems. Large quantities of dust are removed and then separated from the water with large clarifiers. After being cleaned the water is pumped through a cooling tower and then returned to the gas washers at the blast furnaces.

Dissolved solids build up quite rapidly in these systems. This is controlled by using the water to spray-cool the molten slag which runs into open pits every time the blast furnace is cast (approximately every five hours). The water application is closely controlled to prevent any excess or free water from developing. In this way all the soluble salts that were in the water combine with the blast-furnace slag.

Sludge from the gas washer system is pumped to sludge beds, then removed periodically and hauled to a landfill site. The beds are lined.

Special Water Systems. Other cooling towers serve special functions. A cooling system condenses spent steam after it has passed through the large turbines which drive the air blowers supplying the large amount of air required by the blast furnaces. A 167,800 liter per minute tower system serves the boiler house. No clarifier is required since only heat is removed.

The three tower systems (combined capacity of 70,100 liters per minute) serving the coke plant are used in processing the gas produced by the coking oven. One tower system services the final coolers, the second is part of the light oil production unit, and the third provides water for spraying the ammonia cooling coils.

Waste Treatment and Reuse. Several facilities are used to treat and partially recover wastewaters from various operations. Sewage treatment has already been discussed. There are two other major areas: waste acid and wastewater treatment.

Waste acid (called pickle liquor) from the several steel pickling operations in the plant is transferred to the acid disposal plant. It is first stored in two large receiving tanks; these serve to mix the waste pickle liquor (thereby equalizing the concentration of the plant feed) and to accommodate flow rate variations. From the receiving tanks, the waste pickle liquor is pumped to an "In Pipe" neutralization system where it is mixed with alkaline wastewater and anhydrous ammonia. An automatic pH monitoring and control system regulates the ammonia feed to keep the effluent at approximately pH 7.5. The discharge from the acid treatment plant is discharged to the non-reclaimable wastewater line. Slaked lime was originally used as the neutralizing agent, but it caused calcium sulfate scaling problems in the non-reclaimable line. Since periodic scale removal would have been too expensive, anhydrous ammonia was substituted. This enabled the sulfate to be discharged as a soluble salt, thus eliminating the scaling problem.

An iron hydroxide sludge precipitated in neutralizing the pickle liquor was originally removed by clarifiers and disposed of in a settling lagoon. The high level of soluble sulfate salts in the lagoon indicated it was possible to contaminate the underground water supply. A considerable research effort was made to develop a satisfactory method of dewatering the iron hydroxide sludge. No such method was found, however, and it was decided to discharge the iron hydroxide water solution into the non-reclaimable wastewater line.

This was not satisfactory, however, for two reasons: the receiving municipal treatment facility levied a charge on the waste, and the ammonium salts were eventually discharged to the ocean, thus polluting the marine environment. Alternative techniques were therefore investigated.

Kaiser next changed from sulfuric acid to hydrochloric acid in most pickling operations; this reduced the waste acid load by about 20 percent. Since hydrochloric acid also lends itself to recovery better than sulfuric acid, evaluation was made of methods to regenerate the acid or use the waste pickle liquor, the main objective being to reduce suspended solids and ammonium salts discharged to the non-reclaimable wastewater line. The method chosen involved mixing the acid waste with metal chips, and pumping the mixture to five Hypalon-lined evaporation ponds. Evaporation increases the ferrous chloride ($FeCl_2$) concentration from an initial 19 to 20 percent to 35 percent. The concentration is not allowed to increase beyond 35 percent since above that level a yellow precipitate forms that harms the efficiency of the recovery operation. A contractor purchases this waste liquor and through chlorination converts it for use as a

coagulant in sewage treatment plants, thus turning an environmental hazard into an environmental benefit. The recovery operation reduces the cost of neutralization and reduces the plant's suspended solids discharge 75 to 80 percent. The ammonia discharge is also considerably reduced.

Facilities at the wastewater treatment plant include an elevated surge tank, a clarifier, two mixing tanks, and two large oil separating tanks equipped with both sink and float dragout equipment. The separating tanks remove a major portion of the oil and grease from the wastewater. Final separation is done in the clarifier, with the rather milky overflow returned to the mill for reuse. Any excess over requirements is discharged to the non-reclaimable line. As a milky suspension, the overflow is suitable only for terminal uses, such as rinse water on the pickling lines, slag quenching, and hood sprays. A continuing research program is attempting to improve the quality of this water so that it can be reused in higher-level systems and so increase the number of cycles and reduce the amount which has to be discharged from the plant.

Water Residues.

Steel production processes and most pollution control measures both generate residues as a by-product. Waste oils and grease from the oil and grease wastewater plant are transferred to the coal beds, and the mixture is burned for its fuel value. Particulates from the baghouses are appropriately recycled, depending on their composition (iron ore, coal, etc.).Kaiser sells its fly ash to a local company for use in producing building products. Iron salts are recovered from waste pickle liquor by a contractor. Slag is sold to a local company for use as a building aggregate. Sludges are bed dried, then removed for land disposal. Scrap metal is baled at the plant and then recycled.

FOOD CANNING

INDUSTRY OVERVIEW

Preserving food (by drying, canning, freezing, etc.) frees the consumption of perishables from the seasonal pattern of the catch or harvest and permits their stockpiling for future use. Canning is the principal method of preserving food. The industry has a strong impact on nutrition, uses an easily accessible and relatively labor-intensive technology, and generates significant quantities of pollutants.

Food canning generates mainly water pollutants, some odor problems, and cooking and drying operations generate small quantities of air pollutants. The amount and character of the air pollutants depend on the combustion fuel used and operating conditions. Abatement measures may be advisable in sensitive areas and where low-polluting fuels are not available. However, the air pollution problem is relatively small.

Two broad categories of food canning are considered: (1) fruit, vegetable, and specialty (as in Table 4-30), and (2) seafood (catfish, blue crab, shrimp, and tuna). The two categories differ significantly in production process, type and quantity of pollutants generated, and applicable control techniques.

Production Process

Fruit, Vegetables, and Specialties. The general processing steps (Figure 4-19) include: receiving and washing, preparation, processing, and packaging. Washing, used for both cleaning and cooling, occurs at several points in the process. Washing and rinsing may use one-half or more of total process water. Detergents are sometimes added to the wash water to aid in cleaning.

Preparation operations include sorting; stemming, snipping, and trimming; and peeling and coring. Many types of fruit and vegetables are sized to facilitate subsequent operations (such as pitting, peeling, and filling) and to meet final product requirements. Sorting methods include hand sorting, density graders, flotation, and screening. Many fruits and vegetables must be peeled before processing. This also removes any remaining dirt and pesticide residues. Peeling may be done mechanically (by cutting or abrasion), thermally (loosening the peel by applying steam, hot water, hot oil flame, or heated air), or chemically (usually with caustic soda to soften the peel enough to permit removal by high pressure water spray). Table 4-31 lists the principal peeling methods.

Processing includes such operations as slicing, deaerating, blanching, canning, and sauce or molasses production. Slicing is sometimes done in conjunction with pitting or coring and sometimes separately. The product may be halved, cut into segments or flat rings, or diced. Methods used to puree and juice include hydraulic presses, pulpers, and vibrating screens. Deaeration uses a vacuum to remove oxygen and other gases present

TABLE 4-30
SPECIFIC PRODUCTS IN THE FRUIT, VEGETABLE, AND SPECIALTY CANNING SUBCATEGORIES

Subcategory		
Fruit	Vegetable	Specialty
Apricots	Asparagus	
Caneberries	Beets	Baby food
Cherries	Broccoli	Chips
Cranberries	Brussels sprouts	Ethnic foods
Dried fruit	Carrots	Jams and jellies
Grape juice	Cauliflower	Mayonnaise and dressings
Olives	Corn	Mixed fruits and vegetables
Peaches	Dry beans	
Pears	Lima beans	Soups
Pickles	Mushrooms	Tomato-starch-cheese specialties
Pineapples	Onions	
Plums	Peas	
Raisins	Pimentos	
Strawberries	Sauerkraut	
Tomatoes	Snap beans	
	Spinach	
	Squash	
	Sweet potatoes	
	White potatoes	

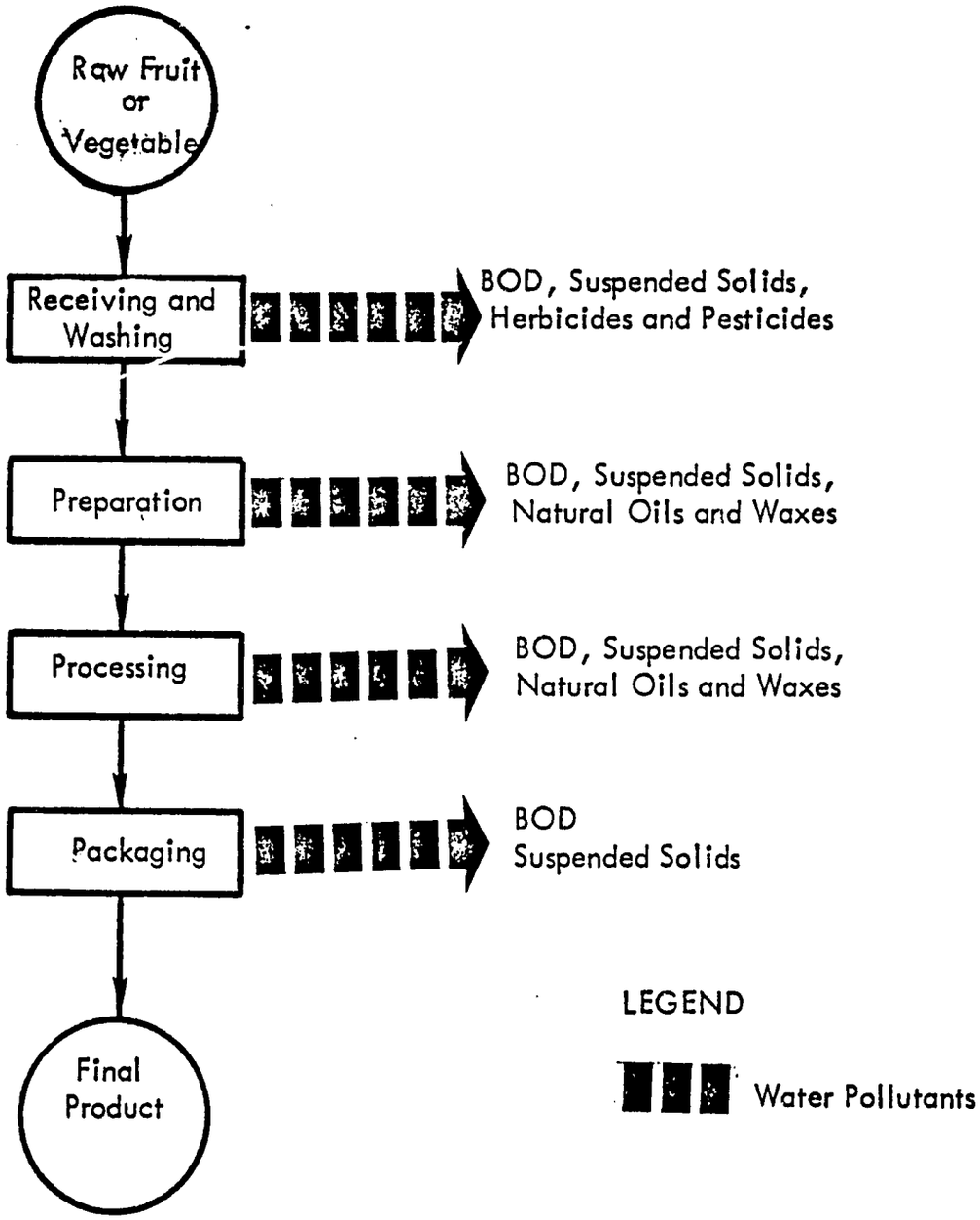


FIGURE 4-19
FRUIT, VEGETABLE, AND SPECIALTY CANNING

TABLE 4-31

PEELING METHODS

Method	Action	Used For	Effectiveness and Suitability
Hot water	Loosens peel by disintegrating underlying tissue	Tomatoes, peaches, beets, sweet and white potatoes	Excellent
Live steam	Same as above	Same as above	Good, but often not uniform
Hot oil	Same as above	Pimientos	Fair, may leave an oil residue
Freezing	Same as above	Peaches and other fruits	Poor
Ultrasonics	Same as above	Tomatoes, ripe fruits	Little known, but promising
Steam pressure	Develops pressure beneath peel	Sweet and white potatoes, other root crops, apples	Good, but requires close control
Flame	Disintegrates peel	Pimientos, onions, potatoes, and other root crops	Limited usefulness, wastes product
Lye	Same as above	Peaches, pears, grapefruit segmenis, sweet and white potatoes, carrots, tomatoes, apricots, others	Good, but waste may be high
Abrasion	Wears away peel by rotating product against an abrasive surface	Potatoes, beets	Good, but wasteful
Knives	Special designs by manually or mechanically operated blade	Apples, pears, root crops	Good, but limited capacity and is wasteful

Source: 95.

in freshly processed fruit and vegetable juices. Deaeration improves color and flavor, and reduces foaming during filling and separation of suspended solids.

Vegetables may be blanched to remove air or solubles, fixate pigment, inactivate enzymes, protect flavor, leach out undesirable flavors or components, shrink tissue, increase temperature, or destroy microorganisms. The several ways to blanch fall into two categories: hot water blanching and steam blanching.

In the canning process, cans are washed before being filled. Depending on the product, the fruit or vegetable is put into the can by hand or semi- or fully-automatic machines. The cans are then exhausted to achieve a vacuum and preserve product quality. Finally, the containers are sealed (usually mechanically). The can or jar contains a sterilized product which will stay unspoiled indefinitely. Labeling and final packaging complete the canning process.

Seafood. Figure 4-20 is a general process schematic of the seafood canning industry. Specifics of the process depend on the type of seafood being processed. By-product processing, for example, is generally restricted to tuna processing.

Receiving the raw product and transferring it to the processing area may be done by water flume, conveyor, or container. Although fluming is usually the cheapest and most efficient method, many plants are replacing it with one of the other methods because it is highly polluting.

Preprocessing (preparing the fish or other seafood for subsequent processing steps) involves a variety of steps, including washing dredged crabs, thawing frozen fish, and de-icing shrimp. Seafood is frequently frozen on fishing boats to preserve the catch until the ship returns to port. The catch must then be thawed before processing. In the traditional flow-through system, the catch is put in a large container and water passed through to thaw it. This requires large volumes of water and results in significant pollution. New methods used by some canners to reduce the water flow include heating and recycling the entering water.

After preprocessing, the catch is butchered and eviscerated. The resulting wastes are usually screened from the waste stream and used for by-product production. The butchered fish then are usually precooked to prepare them for picking and cleaning. Precooking facilitates removing the skin, bones, shells, and other unwanted parts. In tuna processing, the steam condensate (stick water) from precooking is usually collected and transferred to a solubles plant for by-product recovery.

Picking and cleaning, the final preparation for canning, separates the edible from the inedible parts of the product. Wastes from this are usually used in by-product processing. The edible portions may be separated into those fit for human and those fit for animal consumption, with the latter (usually mixed with other food elements) canned as pet food.

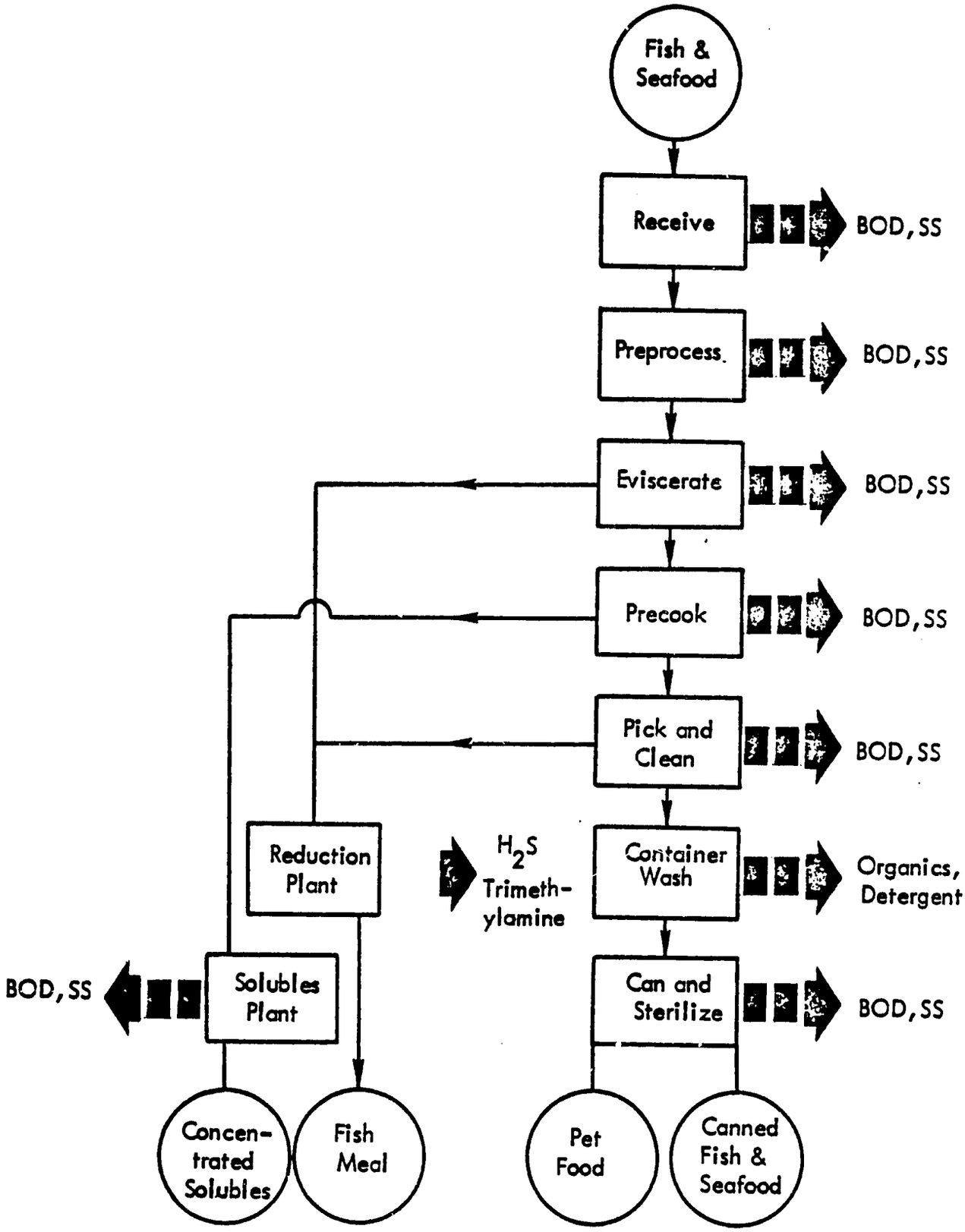


FIGURE 4-20
SEAFOOD CANNING

The canning process steps are similar to those for fruit and vegetables. The cans are washed and packed, sealed under a vacuum, washed, and retorted (pressure cooked to kill microorganisms which would lead to spoilage). The final step is labeling.

Pollution Control

Fruit, Vegetables, and Specialties. Figure 4-19 shows the major pollutants, basically BOD and SS, generated by each step in the production process. Table 4-32 presents average wastewater characteristics. Flow rates and pollutant generation rates vary by product and process. Since wastes are compatible with municipal wastes (they can be treated by the same methods and do not interfere with the operation of a conventional municipal treatment plant), food canners usually treat only solids (screening, perhaps supplemented with air flotation) prior to discharging to the municipal system. The sewage treatment system usually charges a fee to recover its cost of treating the received wastes. The advantages of municipal treatment are: (1) the sewage treatment system's greater expertise, and (2) its economies of scale. A variety of methods are available, however, for plants providing their own waste treatment.

Suspended solids removal methods are primarily mechanical. Suspended solids can be removed by screening (filtering), catch basins, sedimentation, and air flotation. Stationary screens separate solids from transporting fluids; rotating screens are also used to remove suspended solids present in low concentrations. Grease and oil are removed with catch basins, settling tanks, or flotation units. A top skimmer removes floating scum and a bottom scraper removes settled sludge. If lime or another coagulant is added, most suspended solids accumulate as sediment.

Chemical treatment such as flocculation can increase suspended solids removal. Other chemical treatments which may be used are: (1) pH adjustment, since wastewaters are often acidic, and (2) chlorination, for odor, algal growth control, and disinfection.

Biological treatment processes for BOD removal are attractive alternatives where a high proportion of the biodegradable material is in soluble form. Feasible treatment systems include trickling filters, anaerobic processes, aerated lagoons, and activated sludge. Trickling filters perform better in warm than in cold weather. Their BOD removal efficiency is inversely proportional to the BOD surface loading rate. Trickling filters have the disadvantages of greater first-cost construction and fly attraction. Anaerobic processes are able to handle shock loads, are easy to operate, and have a comparatively low initial cost. Odors are a problem, however. Aerated lagoons employ mechanical aeration to maintain the oxygen level needed by the digesting bacteria. They require less land than facultative lagoons, but more than activated sludge systems, and have greater energy requirements than anaerobic lagoons. Activated sludge treatment can also be used.

Sand filters can effectively remove suspended solids; the effluent is filtered through sand to an underdrain system. In pressure filters, the effluent can be pumped through

TABLE 4-32

AVERAGE WASTEWATER PARAMETERS: FRUIT, VEGETABLE, AND SPECIALTY CANNING

Industry Subcategory	Parameter (per kkg of final product)		
	Flow Rate (10^3 liters)	BOD_5 (kg)	SS (kg)
Fruit	11	12	2
Vegetable	23	13	7
Specialty	15	15	14

Source: 95.

under high or low pressure. High pressure systems require daily cleaning. Low pressure systems may operate for 60 days without cleaning, but require a larger area to achieve comparable removal efficiency. Clogging is the major problem encountered with sand filters. Sand filters are highly efficient in removing bacteria, color, and suspended solids.

Disposal of the treated effluent can be achieved in lagoons with high percolation and evaporation rates, or by using the treated effluent for irrigation. In lagoon systems, the inflow of treated effluent equals losses due to evaporation and percolation through the soil. The evaporation ponds and spreading basins may fail over time if the permeability of the soils beneath them decreases due to clogging or swelling of clays. This could be remedied by allowing the pond or basin to dry for short periods. Also, the effluent may enter an aquifer and increase salinity. Odor may be a problem.

Spray irrigation allows farm crops or other plants to use residual nutrients in the treated effluent. It works best when large areas of flat land near the canning plant are available at low cost. It is a relatively low-cost system which can maintain crop yield on the irrigated land, and causes few odor problems if properly employed.

Several reuse and process modification options can also reduce pollutant generation. Washwater can be recirculated. Treatment for removal of certain wastes, such as fertilizers and agricultural chemicals may be necessary before reuse. Washwater can also be used as a coolant where needed, as in canning. Some food wastes (peelings, etc.) can be used for other products (cider, molasses, feed, etc.). A recent trend in the fruit processing industry is towards dry methods such as dry peeling. These methods need some water, but the volume is considerably smaller than in conventional wet methods. The amount of food wastes that need dewatering and effluent BOD levels are lower in dry peeling systems than in wet, but equipment costs are higher. BOD effluent levels from dry peeling wastes are about one-quarter the level of wet wastes in potato peelers; similar results may be expected with other fruit and vegetables.

Seafood. Figure 4-20shows that the major pollutants generated by each step in the production process are BOD and SS, with some odor from the fish meal reduction plant. Table 4-33presents average wastewater characteristics for each subcategory. Odor (resulting mainly from hydrogen sulfide and trimethylamine) can be controlled by wet scrubbing, activated carbon adsorption, or incineration.

Wastewater treatment control options include mechanical, biological and physical-chemical methods. Mechanical control uses screens, centrifuges, gravity clarifiers, and sedimentation. Rotary or tangential screens can remove more than half the total solids, and some COD. Oxidation ponds and aerated lagoons can be used for biological treatment.

Physical-chemical control methods (e.g., coagulation, air flotation) require significantly less area than biological methods. Alum, polycoagulant disinfectants, activated carbon,

TABLE 4-33

AVERAGE WASTEWATER PARAMETERS: SEAFOOD CANNING

Wastewater Characteristic	Industry Subcategory			
	Catfish	Blue Crab	Shrimp	Tuna
Flowrate (10^3 liters/kkg)[a]	19	1.2	47	18
pH	6.4	7.6	6.7	6.7
Pollutants (kg/kkg[a])				
Suspended solids	8.46	0.79	37.60	12.06
BOD_5	7.90	5.25	51.70	16.20
COD	6.00	7.64	108.10	39.60
Grease and oil	4.88	0.26	12.22	6.48
Organic nitrogen	0.62	0.94	9.40	1.08
Ammonia - N	0.02	0.06	0.56	0.13

[a] Per kkg of final product.

Source: 94.

or other chemicals may be added in this treatment. Air flotation can remove suspended solids, grease, oil, and some dissolved organics in the form of a floating sludge that is skimmed, collected, and dewatered. Likely reductions are 95 percent of the BOD_5 and 99 percent of the suspended solids.

Sedimentation and gravity clarification can also use chemical additives to improve removal efficiencies. Adding 2.5 grams clay, 2.5 grams lime, and 100 milligrams ferric chlorine per liter of wastewater produces the optimum precipitation of fats and grease, and reduces BOD_5 75 percent. Two hours of sedimentation without coagulation aids can remove from wastewater 32-70 percent of the suspended solids, 25-40 percent of the BOD, and 50-66 percent of the organic matter.

A variety of reuse and process modification options are used. For example, dissolved proteins in the effluent can be recovered as a high-grade flour (by removing the oil), as a concentrated protein (by hydrolysis with an enzyme process), or can be precipitated with sodium hexametaphosphate. Reuse, recycling, and other process modifications have reduced seafood cannery water use. The USEPA has encouraged this as a means of reducing pollutant discharges. Perhaps the most visible impact has been the elimination of water flumes and the substitution of mechanical conveyors to transport the received seafood.

Prevention (Recycling/Reuse). Since organic waste is common to all food processing operations, its productive reuse is an attractive approach to preventive control. The experience of a potato processing operation illustrates some of the possibilities. The plant originally provided only primary treatment before discharging its wastewater to a river whose seasonal low flows prevented the use of conventional biological treatment methods. The daily wastewater discharge contained 1,135 kg ammonia, 269 kg phosphorus, 3,405 kg suspended solids, and 18,614 kg BOD. In order to meet strict discharge standards, the plant decided to eliminate all discharges to receiving waters.

The plant's control system now combines primary treatment with spray irrigation. Nutrients in the wastewater are sprayed on land to produce high protein forage; this is combined with additional potato processing solid wastes to feed 26,000 yearling steers. Waste heat in the effluent spray permits a 10 to 11 month growing season, and the annual crop yield is almost double that of normal crop lands in the area. A government study indicates that virtually all BOD, nutrients, and suspended solids have been eliminated from both the river and groundwater.[75]

Cost of Pollution Controls

This section considers only water pollution control, since air pollution is not a serious problem. Tables 4-34 and 4-35 list the control equipment chosen to meet three control levels for the various canning subcategories being considered. Figures 4-21 through 4-32 are schematics of the treatment systems. Table 4-36 summarizes for each subcategory the approximate pollutant removal efficiencies attainable with the indicated treatment systems.

Table 4-44 and Figures 4-54 through 4-68 demonstrate water pollution control cost as a function of plant capacity, and are found at the end of the chapter.

TABLE 4-34

WATER POLLUTION CONTROL EQUIPMENT:
FRUIT, VEGETABLE, AND SPECIALTY CANNING

Control System		
Primary	Secondary	Tertiary
Screening Air flotation basin	Screening Equalization tank Aeration basin Clarifier Aerobic digester Vacuum filter Sludge holding tank	Screening Equalization tank Aeration basin Clarifier Aerobic digester Chlorination basin Mixed media filter Vacuum filter Sludge holding tank

TABLE 4-35
WATER POLLUTION CONTROL EQUIPMENT
SEAFOOD CANNING

Product	Control System		
	Primary	Secondary	Tertiary
Catfish	Raw waste sump Screening	Raw waste sump Screening Aerated lagoon Oxidation pond	Raw waste sump Screening Aerated lagoon Oxidation pond Aerobic digester Sludge holding tank Activated carbon adsorption
Blue Crab	Raw waste sump Screening	Screening Equalization basin Extended aeration Clarifier	Screening Equalization basin Extended aeration Clarifier Chlorination Activated carbon adsorption
Shrimp	Raw waste sump Screening	Screening Holding tank Pressure retention tank Flotation tank Equalization tank Aeration tank Clarifier Floated solid holding tank Centrifuge Sludge holding tank	Screening Holding tank Pressure retention tank Flotation tank Equalization tank Aeration tank Clarifier Floated solid holding tank Centrifuge Sludge holding tank Extended aeration Chlorination Activated carbon adsorption
Tuna	Raw waste sump Screening	Screening Equalization tank Flotation tank Aeration basin Clarifier Sludge holding tank	Screening Equalization tank Flotation tank Aeration tank Clarifier Sludge holding tank Aerobic digestion Chlorination (contact basin) Activated carbon adsorption

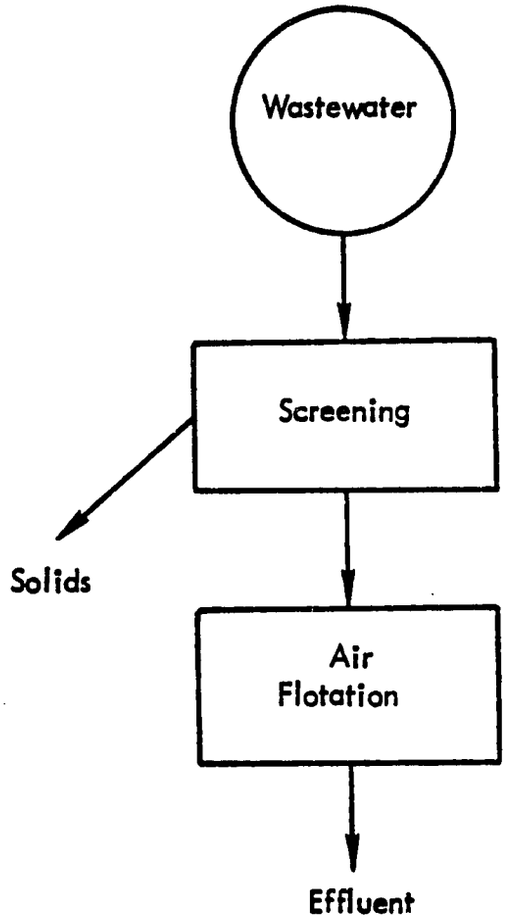


FIGURE 4-21
PRIMARY WASTEWATER
TREATMENT SYSTEM:
FRUIT AND VEGETABLE
CANNING

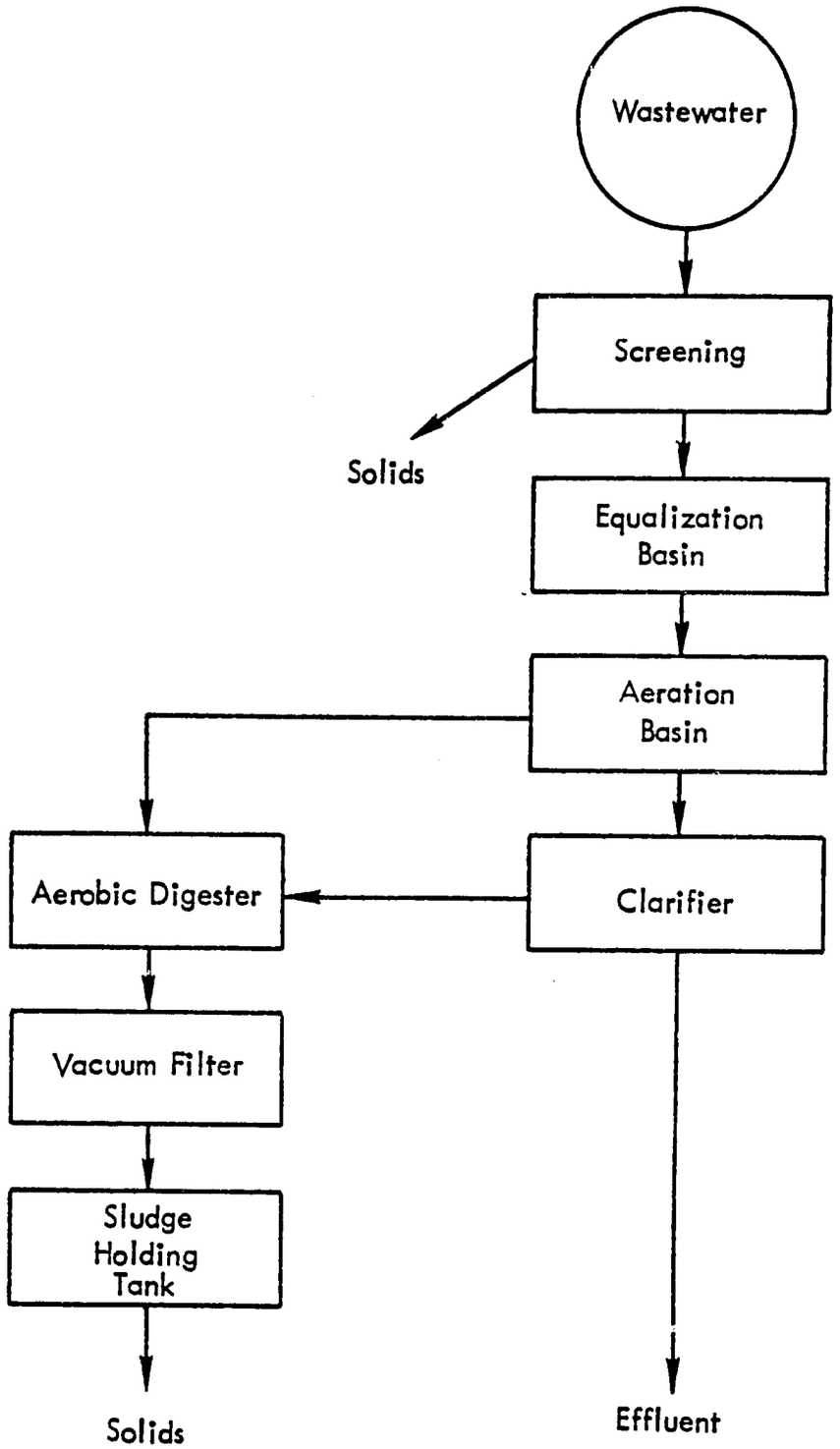


FIGURE 4-22
SECONDARY WASTEWATER TREATMENT SYSTEM: FRUIT AND VEGETABLE CANNING

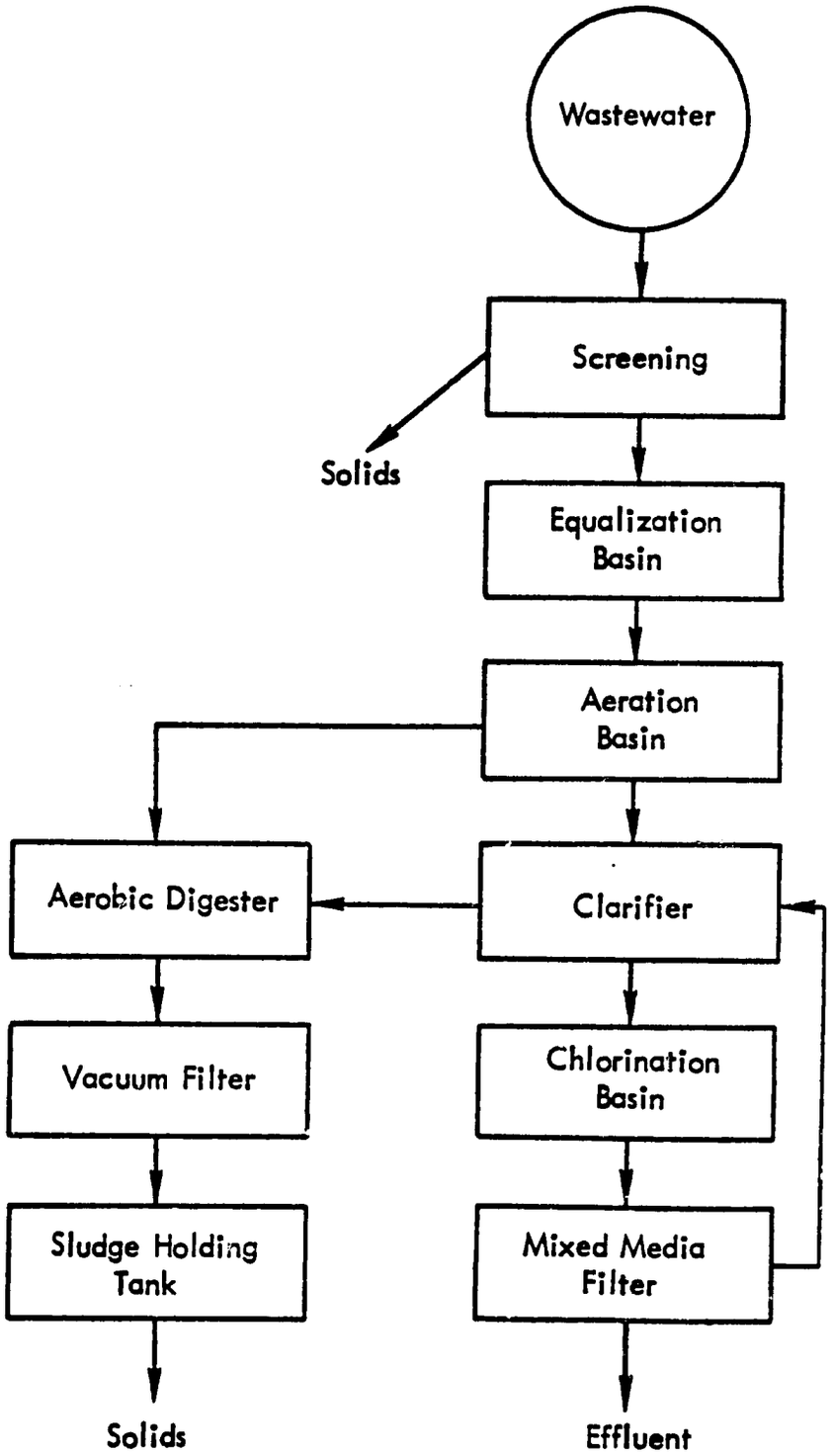


FIGURE 4-23
TERTIARY WASTEWATER TREATMENT SYSTEM: FRUIT AND VEGETABLE CANNING

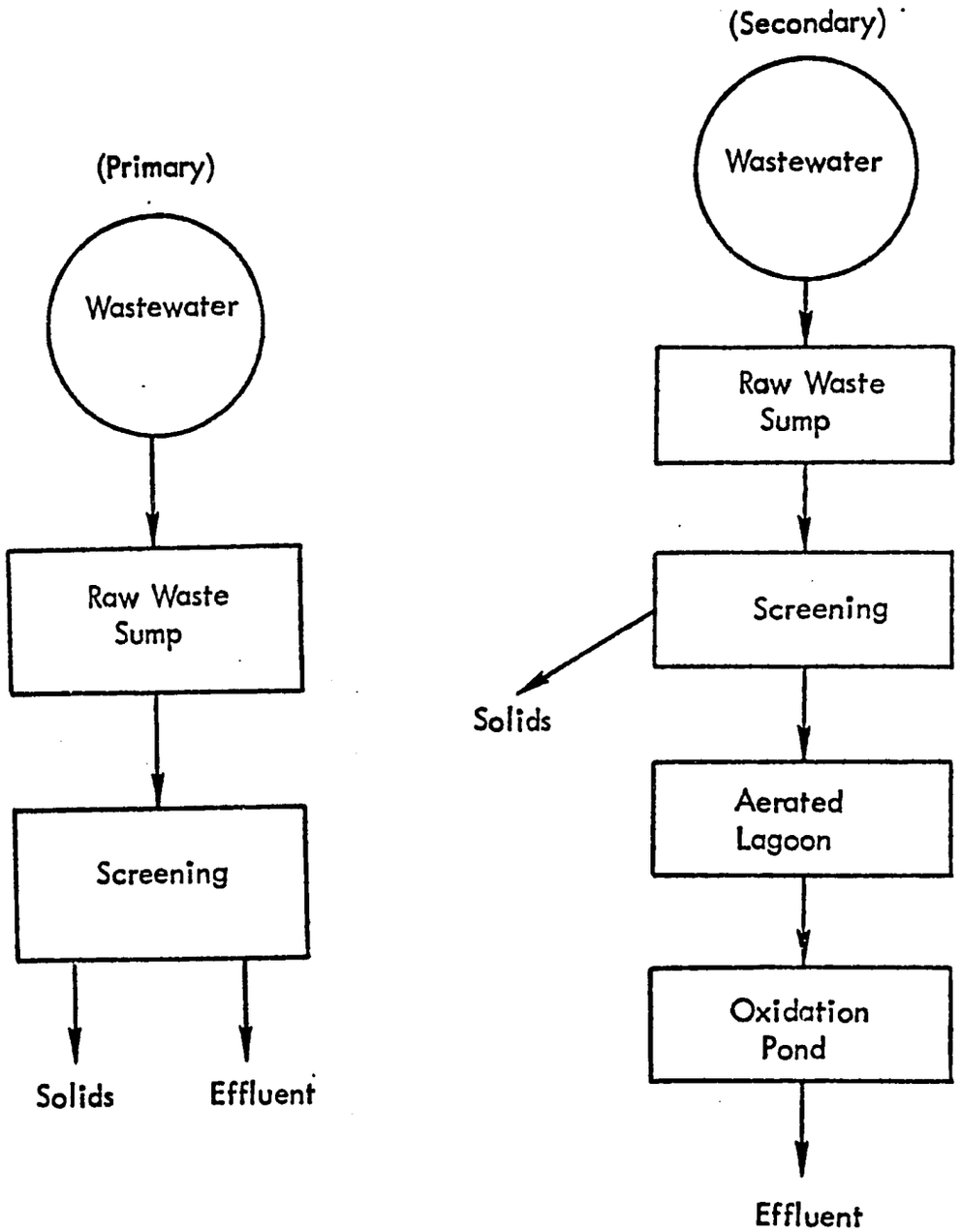


FIGURE 4-24
PRIMARY AND
SECONDARY
TREATMENT SYSTEMS:
CAT FISH CANNING

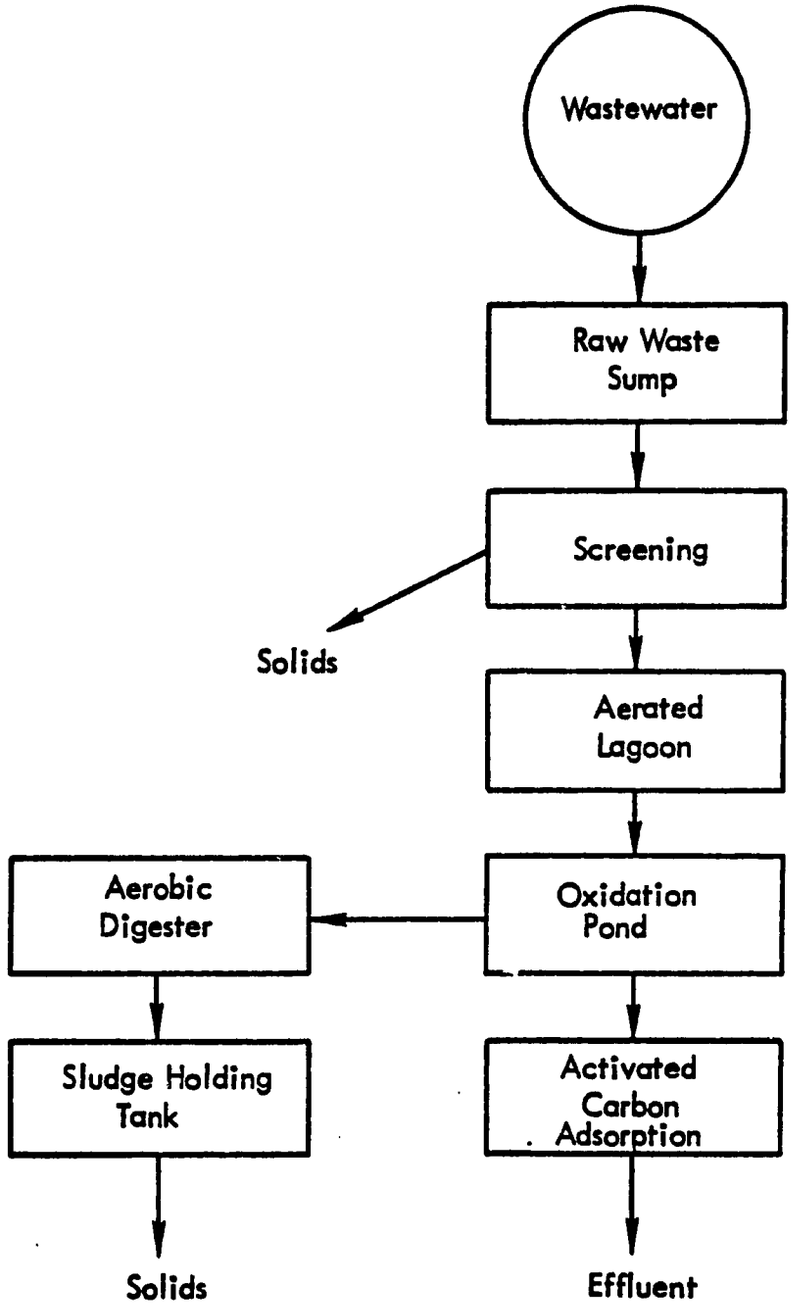


FIGURE 4-25
TERTIARY WASTEWATER TREATMENT SYSTEM: CAT FISH CANNING

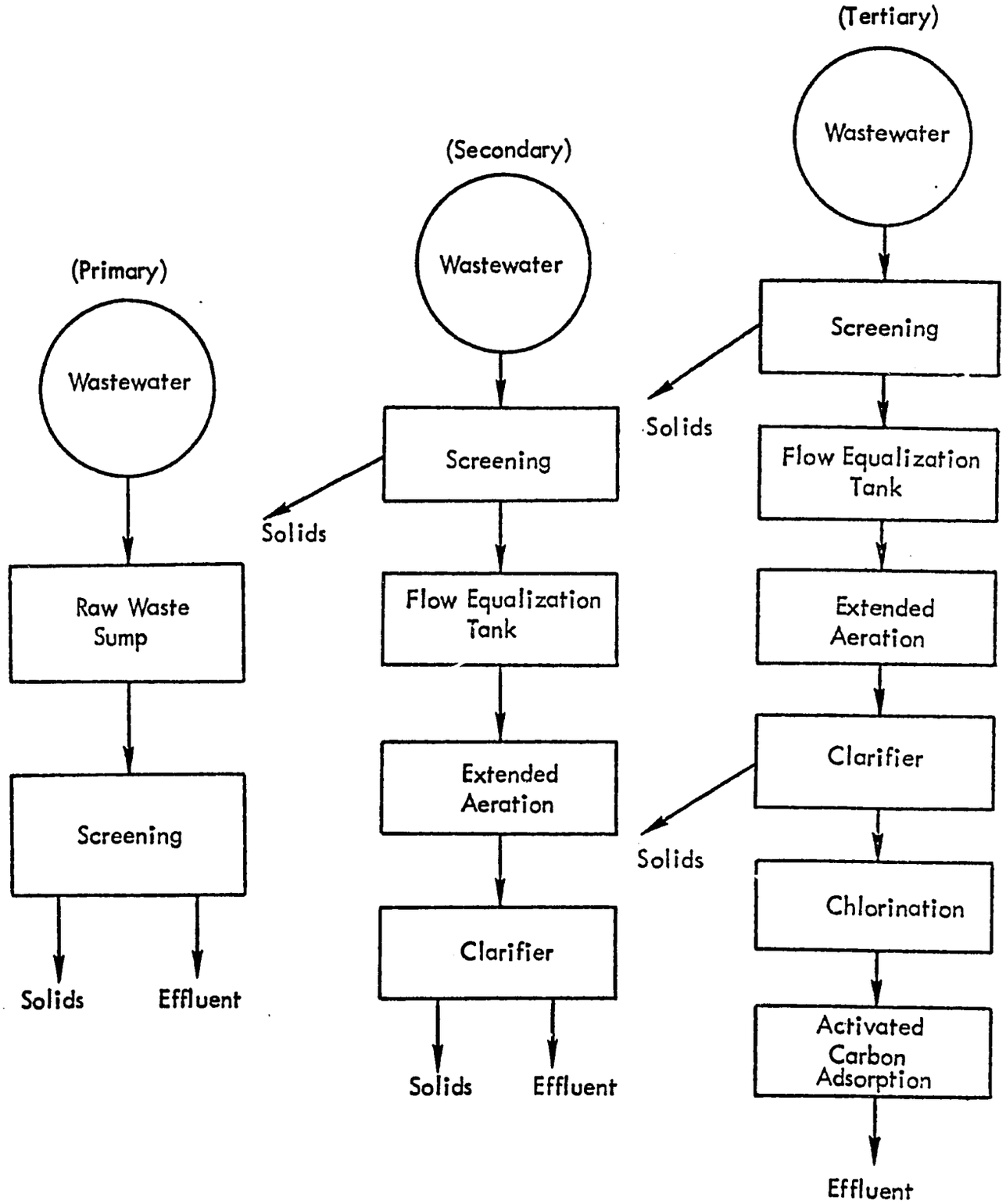


FIGURE 4-26
PRIMARY, SECONDARY, AND TERTIARY WASTEWATER TREATMENT SYSTEMS: BLUE CRAB CANNING

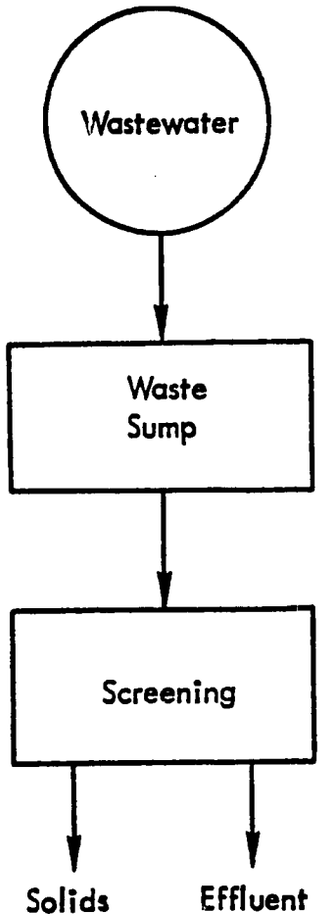


FIGURE 4-27
PRIMARY WASTEWATER
TREATMENT SYSTEM:
SHRIMP AND TUNA CANNING

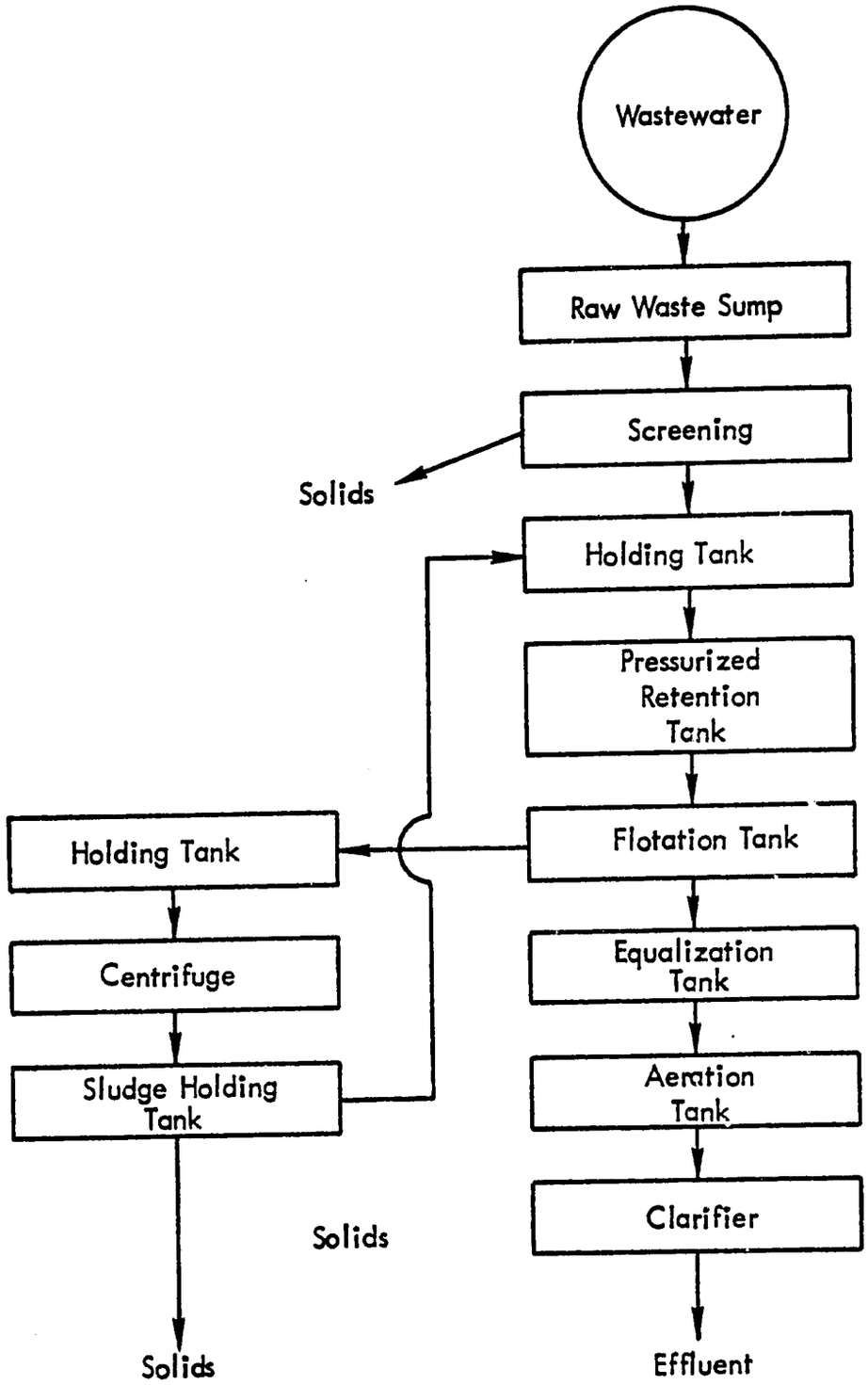


FIGURE 4-28
SECONDARY WASTEWATER TREATMENT SYSTEM: SHRIMP CANNING

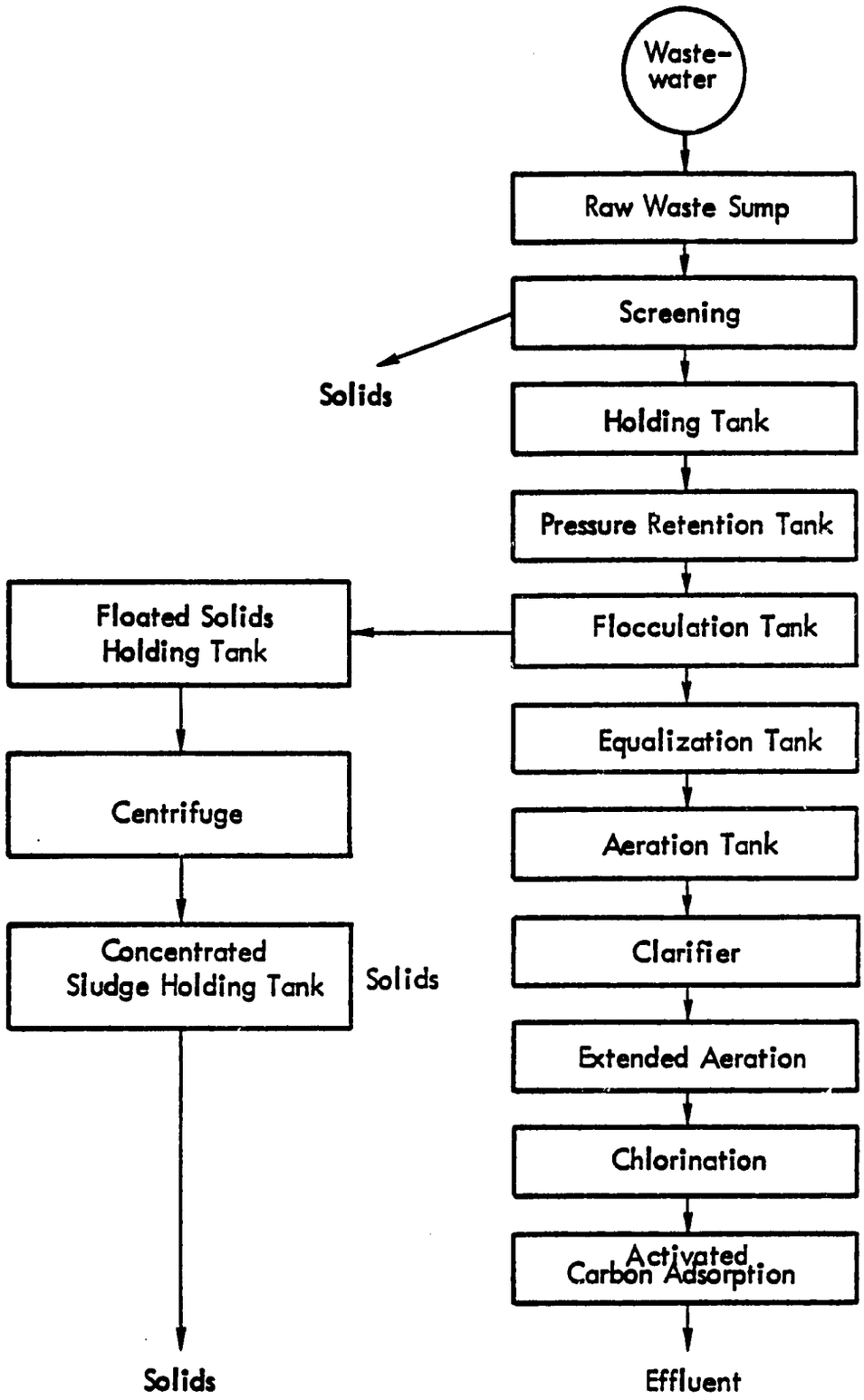


FIGURE 4-29
TERTIARY WASTEWATER
TREATMENT SYSTEM:
SHRIMP CANNING

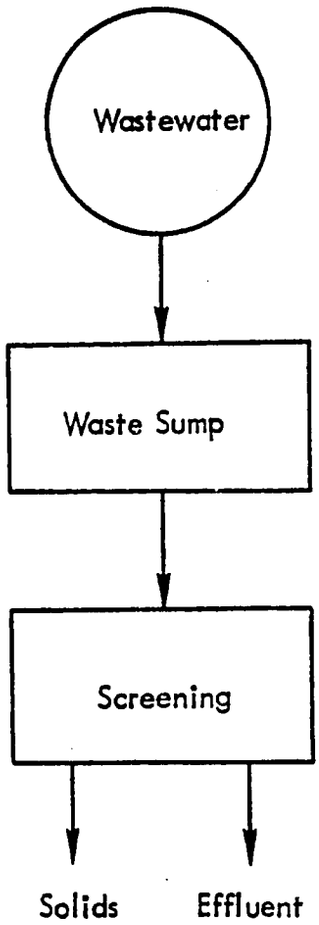


FIGURE 4-30
PRIMARY WASTEWATER
TREATMENT SYSTEM:
TUNA CANNING

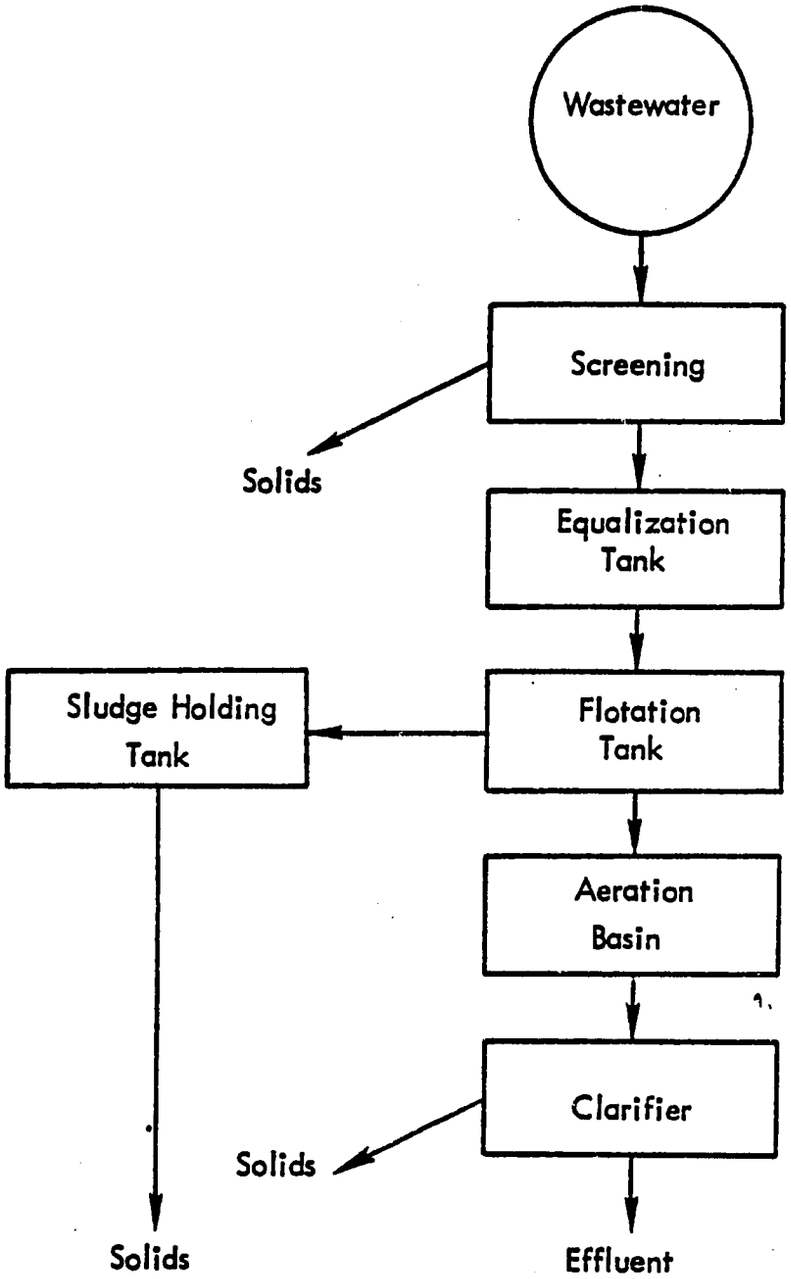


FIGURE 4-31
SECONDARY WASTEWATER
TREATMENT SYSTEM:
TUNA CANNING

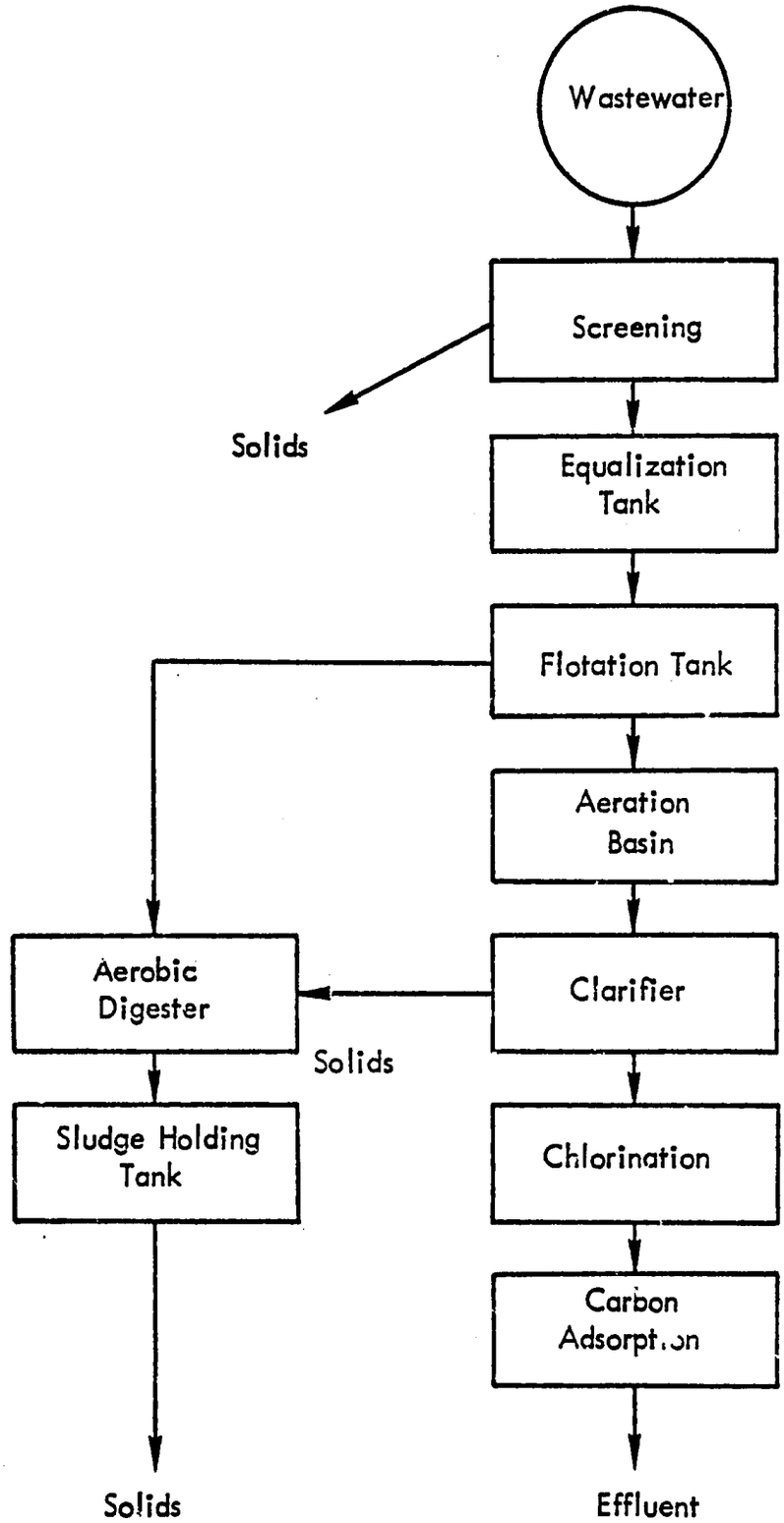


FIGURE 4-32
TERTIARY WASTEWATER
TREATMENT SYSTEM:
TUNA CANNING

TABLE 4-36
WATER POLLUTANT REMOVAL EFFICIENCIES OF THE SELECTED TREATMENT SYSTEMS: FOOD CANNING

Subcategory	Pollutant	Removal Efficiency (%)		
		Primary	Secondary	Tertiary
Fruits	BOD_5	20-30	60-90	85-98
	COD	15-30	70-75	90-95
	Total suspended solids	40-65	70-95	95-99
	Total nitrogen	5-10	65-85	90-98
Vegetables	BOD_5	25	60-85	90-95
	COD	20	60-80	85-95
	Total suspended solids	40-55	75-90	90-99
	Total nitrogen	10	65-80	90-99
Specialties	BOD_5	20-30	60-75	90-98
	COD	15-25	70-80	90-95
	TSS	40-55	70-90	90-98
	Total nitrogen	10	65-75	95-98
Catfish	BOD_5	20	88	95
	Suspended solids	70	87	97
	Grease and oil	75	90	98
	Total nitrogen	20	85	90
Blue crab	BOD_5	25	85	97
	Suspended solids	70	86	94
	Grease and oil	88	95	99
	Total nitrogen	20	55	78
Shrimp	BOD_5	24	90	98
	Suspended solids	75	88	96
	Grease & oil	90	95	99
	Total nitrogen	15	65	85
Tuna fish	BOD_5	20	80	94
	Suspended solids	70	85	96
	Grease and oil	75	94	99
	Total nitrogen	15	40	75

Source: 95, 94, 53, 109, 112.

CANNERY A (VEGETABLES)

Description

This large profitable cannery is an older plant which processes primarily tomatoes and smaller quantities of spinach, pork and beans, potatoes, and other vegetables. The plant is located in what is now a mixed residential/commercial area of a major metropolitan area in the United States. There is little commercial agriculture in the immediate vicinity, but major producing farms are within a 500-mile radius. Raw produce is trucked in an average of 100-150 miles. The tomatoes are mechanically picked which, in comparison to manual harvesting, increases dirt, debris, and damage to the fruit. The firm which owns and operates Cannery A is a large diversified company with several other canning plants throughout the United States.

Air Pollution Control

Air pollution is not a major problem in this fruit and vegetable cannery. Odor generated at older installations (such as this one) in the cooking and evaporation stages does not usually impact the surrounding areas. Newer plants use condensers and are therefore odor-free. Cannery A minimizes air pollutants generated during steam production by using natural gas or low sulfur fuel. See Table 4-37 for air pollution emission standards.

Water Pollution Control

Cannery A uses flumes for receiving, washing, and in-plant transport, and an alkali-lye peeling process. Peel residues are landfilled rather than reclaimed because of government agency concern with pesticide residuals. Some work is in progress, however, on recycling peel residue for animal feed or other products. Water pollution control consists of rotary screening the wastewater and recycling the process water. To recycle process water cannery A uses a counter-current approach: new water enters at the cleanest process (final wash) and is recycled through three other systems, each with a slightly lower quality requirement than the previous one.

Some "wet waste" (e.g., waste pieces, broken fruit) is used as animal feed. Much is still landfilled because (1) the waste is not dried before marketing, thus limiting demand, and (2) certain wastes (such as those which may be contaminated) are rejected for health reasons. The waste is not dried because of costs and potential air pollution problems.

Wastewater from the cannery is considered "compatible" with the domestic wastes entering the local municipal waste treatment plant. See Table 4-38 for discharge limits. Cannery A is therefore permitted to discharge to the municipal system without pretreatment and is charged a rate equal to the treatment plant's cost of handling the waste. The charges are based on: flow rate ($40 per million liters of wastewater), suspended solids ($44 per kkg of SS), and BOD ($26 per kkg of BOD_5). This is a satisfactory way of handling compatible wastes because of the municipal treatment plant's expertise in waste treatment, and economies of scale (lower cost per unit with increased flows) in

TABLE 4-37

AIR POLLUTION EMISSION STANDARDS:
FOOD PROCESSING PLANTS

Source	Pollutant	Air Discharge Standard
Stack	Smoke/color	a) Not to exceed shade No. 1 Ringelmann chart for more than 3 minutes in any one hour; or b) Obscure an observers view greater than (a) above.
	Nuisance	No discharge of materials causing any health or safety nuisance.
Transport, handling, construction, storage	Fugitive dust	Not to be visible in air beyond property line of plant source. Not to exceed 100 μg/cu m above the difference between upwind and downwind dust, when instant and average wind speeds exceed 40 km/hr and 24 km/hr, respectively.
Stack	Particulates	Range (linear between values) Vol. discharged — Grams/cu ft 25 or less — 0.196 70,000 or more — 0.010
Stack	Lead, lead compounds	Range (linear) Kg/hr particulates — Kg/hr lead 100 or less — 0.450 500,000 or more — 13.60
	Carbon monoxide	Maximum of 2,000 mg/l averaged over a minimum of 15 minutes
Stack, from steam generating equipment	Oxides of nitrogen	Gas fuel - 125 mg/l NO_x Liquid and solid fuel - 225 mg/l NO_x
	Combustion contaminants	Not to exceed both 5 kg/hr and 23 mg/cu m
Stack, from fuel burning equipment	Oxides of nitrogen	Fuel — Heat input (kg/cal) — NO_x (mg/l) Gas: 140-450 — 300; 450-540 — 225; 540 or more — 125 Liquid and solid: 140-450 — 400; 450-540 — 325; 540 or more — 225

TABLE 4-38

NPDES WASTE DISCHARGE REQUIREMENTS:
CANNERY A

Plant/Process Source	Discharge		Effluent Limitations	
	Type	Source	Pollutant	Max. Concentrations
Vegetable canning	Process (wash, peel, etc.) wastewater	Vegetable canning process	BOD	210 mg/l average
			Suspended solids	260 mg/l average

treatment plant construction and operation. Levying a charge equal to the cost of treatment also gives the industrial plant an incentive to lower its waste discharges.

Another cannery owned by the same company has used land disposal for over three years. During the season it disposes over 11 million liters of wastewater daily to a 130 hectare plot. The site is landscaped, terraced, and planted in grass over which the wastewater is discharged by spray irrigation. The wastewater trickles across the terraced grass and soil in an overland flow technique. As the wastewater percolates through the dense sod to the soil surface, most of the suspended solids are left behind; as it continues to trickle downslope in a thin sheet, the dissolved pollutants are subjected to biological degradation. With time, an organic crust develops on the soil surface which increases the system's effectiveness. Runoff from the terraces (with most of the pollutant load removed) is collected and discharged to a local river. This treatment system cost about $1 million to build.

An alternative land treatment system appropriate for certain soil types allows the wastewater to percolate through the soil and enter the groundwater. The same biological processes act to purify the water as with the overland flow. Land treatment is an attractive alternative for cannery wastes where land is available and inexpensive. There is some evidence it may improve the quality of the soil, perhaps allowing marginal land to be reclaimed.

CANNERY B (TUNA)

Description

This large cannery produces canned tuna and other fish (such as anchovies), pet food, fish meal, and concentrated solubles. Of the raw product entering the cannery, 99.6 percent is converted into useful products; the remaining 0.4 percent is waste. The plant is located in a coastal area of the United States in an industrial section of a major urban area. The company which owns and operates the cannery operates several other tuna canneries and a fleet of fishing vessels; a majority of the ships delivering their catch to cannery B are company owned.

Nearly all the ship-generated wastes are dumped at sea; while docked, however, ships discharge some of these wastes to the plant's treatment system. This supersaturated brine solution presents a difficult treatment problem. The plant discharges directly to the ocean. It has its own outfall with a discharge point just beyond the rocks. No diffusers are used.

Air Pollution Control.

The fish meal reduction plant and the solubles plant are potential sources of air pollution problems (mainly odor). The use of closed evaporators has virtually eliminated odor from the solubles-plant. Air pollution at the reduction plant is handled by using (1) low-sulfur fuel (oil or natural gas) in the dryers, (2) a scrubber on emissions from the dryers, and (3) incineration through a recycling furnace. The impact of any residual odor from either plant is minimal since there are no nearby residential areas. Air emissions are in full compliance with the local air pollution control requirements. See Table 4-37 for air pollution emission standards.

Water Pollution Control

Treatment. The cannery has installed the equipment suggested by the USEPA as sufficient to meet the 1977 standards, essentially primary and secondary screening and dissolved air flotation (see Table 4-39). Figure 4-33 is a schematic of the system. The retention time in the air flotation tank depends on the flow rate, but averages between 30 and 60 minutes. It has two skimmers: one on the top for floatables and one on the bottom to remove settled solids. Two chemicals are currently used to encourage floc formation: alum ($AlSO_4$) and an anionic polymer. They are added at the rate of 40-60 ppm for alum and 0.2-0.6 ppm for the polymer. Solids removed from the air flotation cell and secondary screens are either recycled to the reduction plant or land disposed. An option being considered, however, is to centrifuge the sludge from the air flotation cell and recycle the solids to the reduction plant or to land disposal. Solids from the primary screening are currently recycled to the reduction plant.

Table 4-40 shows the treatment system's removal efficiencies for selected pollutants. They are lower than the USEPA predicted efficiencies. The cannery's current system can achieve the 1977 discharge standards for oil and grease but not for BOD or SS. Cannery B suggests that part of the problem is that much more soluble BOD is present than was previously suspected. Substantial testing and experimentation have gone into trying to increase removal efficiencies. Cannery B and others in the industry contend the standards are unachievable with the guideline methods and should be revised on the basis of accumulated performance data.

More stringent standards are scheduled for 1983. To meet these, Cannery B must connect to a central treatment facility currently being constructed. Its share of the costs for this treatment plant including necessary hookups would be about $750,000 initially and then substantial user fees for operation and maintenance thereafter. Cannery B contends: (1) this is an unnecessary waste of resources, (2) that the wastes being discharged to the ocean are non-toxic, natural wastes which augment the supply of food available for marine life, (3) although excessive concentrations of the wastes could be harfmful (e.g., by reducing the dissolved oxygen level), current control measures achieve adequate reduction, and (4) current fish tissue discharge levels may be beneficial to the ecology of the receiving waters. The tuna canneries in the area have commissioned a study of the impact of their effluents on receiving waters.

Process Modification and Recycling. Tuna canners must maintain high standards of cleanliness to protect the health of consumers and plant workers. Several government agencies monitor and regulate related practices. These regulations require generous use of water for washing and keeping the product, cans, processing equipment, and processing area clean. Environmental agencies, on the other hand, emphasize reducing water use to control pollution. Canners have therefore looked for ways to reduce water use (either by changing to a "drier" process or by reusing process water) without violating health regulations.

TABLE 4-39

NPDES WASTE DISCHARGE REQUIREMENTS:
CANNERY B

Plant/Process Source	Discharge		Effluent Limitations	
	Type	Source	Pollutant	Max. Concentrations
Fish canning	Washdown water	Fish preparation water discharge	BOD_5	12,520 lbs/day 30-day mean (kg/1,000 kg of material processed)
				Tuna 9.0
				Mackerel 9.0
				Anchovy 0.9
				Non-fish material 0.9
			Oil and Grease	1,140 kg/day 30-day mean
				Tuna 0.84
				Mackerel 0.84
				Anchovy 0.084
				Non-fish material 0.084
			Suspended solids	4,520 kg/day 30-day mean
				Tuna 3.3
				Mackerel 3.3
				Anchovy 0.33
				Non-fish material 0.33

TABLE 4-39 (Cont.)

NPDES WASTE DISCHARGE REQUIREMENTS:
CANNERY B

Plant/Process Source	Discharge		Effluent Limitations	
	Type	Source	Pollutant	Max. Concentrations
Fish canning	Retort cooling water, air scrubber dehumidifying water, refrigeration condenser water	Equipment wastewater	Suspended solids	75 mg/l
			Settleable solids	0.2 mg/l
			Oil and grease	15 mg/l
			BOD_5	30 mg/l
			Residual chlorine	0.5 mg/l
Fish canning	All wastes	All wastes	pH	6.5 to 9.0
			Temperature	100° F
			Sludge deposits	None
			Visible solids	None
			Color/turbidity	None
			Odor	None

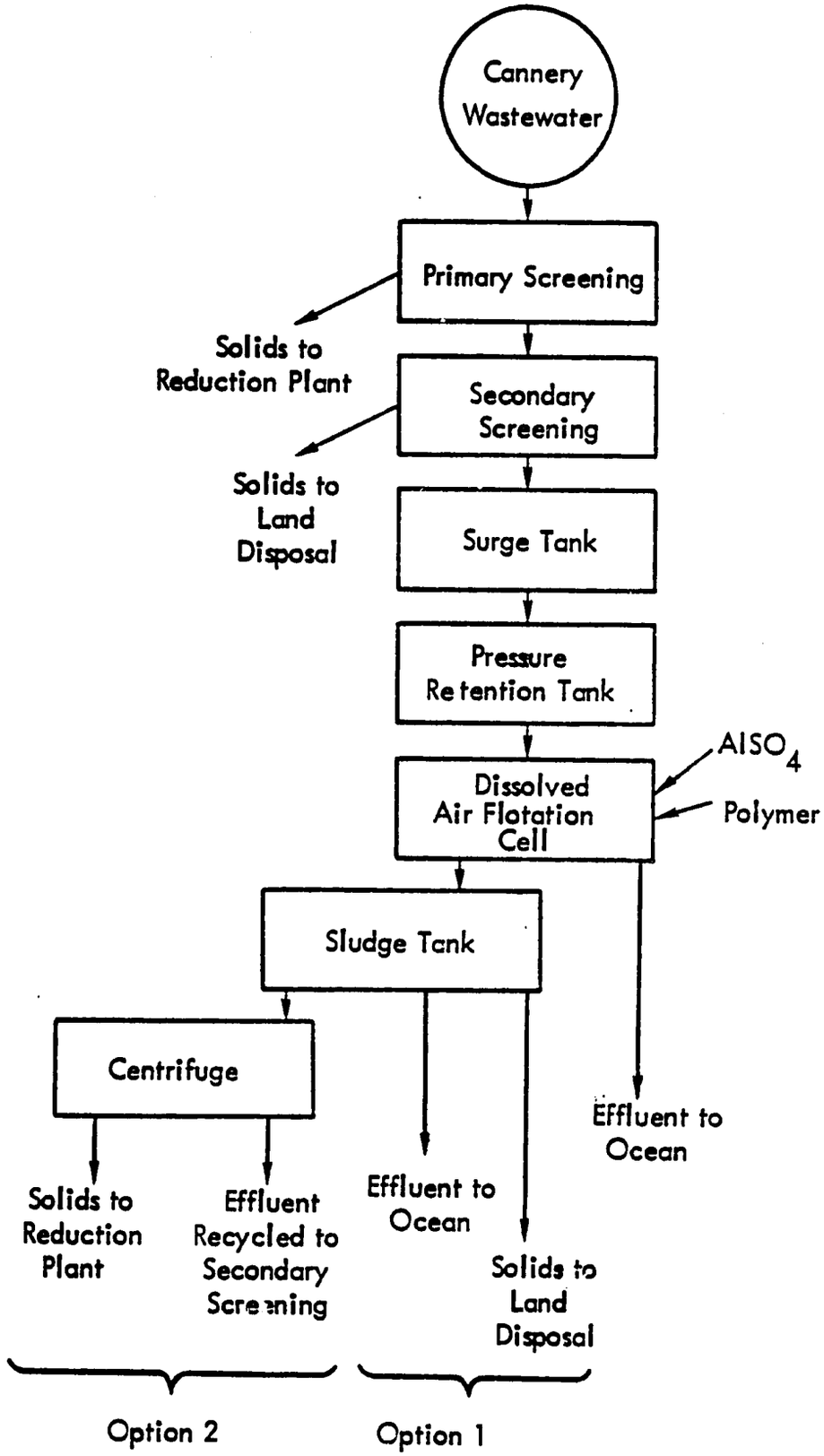


FIGURE 4-33
WASTEWATER TREATMENT SYSTEM:
TUNA CANNERY B

TABLE 4-40
WATER POLLUTANT REMOVAL EFFICIENCIES
FOR THE DISSOLVED AIR FLOTATION SYSTEM

Pollutant	Removal Efficiency (%)	
	Average	Range
BOD_5	45-55	25-65
SS	60-65	50-80
Oil and grease	85-90	70-95

Over the past few years, despite gradually increasing production, Cannery B has reduced water use from over 38 million liters per day to about 4 million, at an initial conversion cost of $5 million. The two principal changes were to: (1) replace receiving flumes with a mechanical conveyor, and (2) change from a flow-through to a recirculation defrosting system. Cannery B points out that although the mechanical conveyor has greatly reduced water use, it has increased (1) cost, (2) damage to the fish, and (3) operating problems (because more mechanical equipment is involved; a pump was the only mechanical equipment used with the flume system). Fish received in a frozen state used to be thawed by a flow-through system. In this simple method the fish are placed in large tanks and sea water is pumped through the tanks and discharged. Water for thawing is now recirculated through the tanks; to compensate for the cooling effect of the frozen fish, the water is heated during recycling.

LATIN AMERICAN PLANTS

IRON FOUNDRY

The iron foundry is in a residential suburb of a major South American city. It manufactures cast iron equipment under contract with various industries, including automobile manufacturing. Some of the products contain nickel, as specified by the contractor. The foundry produces 11 metric tons of cast iron per man-day, or 2,000 metric tons per man-year, and uses 40 metric tons of pig iron and 400 metric tons of anthracite coal (imported from Germany) per month.

The air pollutants generated by the manufacturing process include sulfur dioxide and particulates. A Venturi scrubber was installed to control these pollutants. Installation and purchase costs were $52,000; operating and maintenance costs, about $40 per month.

The principal water pollutants were the particulate and calcium sulfate solids generated by the Venturi scrubber's operations. A 15,000 liter settling tank is used to remove these solids. The water is recirculated, and the tank is periodically cleaned of sludge. The sludge is disposed to a landfill.

COFFEE ROASTING

The coffee roasting facilities are in a residential section of a suburb of a large South American metropolitan area. The plant produces ground coffee for retail sale.

The plant generated only air pollutants: particulates from the coffee roasting and from incineration of the coffee bean husks; and odors from the roasting process. In response to the pollution control ordinance, the plant manager installed an afterburner to control the odors, and two cyclones to trap particulates (one for the processing wastes and one for the afterburner emissions). The afterburner consumes ten liters of diesel oil per hour. The total capital cost of these control devices was around $20,000.

SPARK PLUG MANUFACTURING

The spark plug manufacturing plant had two pollution control problems: the wastewater contained chromate and cyanide from its chromium plating process, and the stacks above its cupola emitted an excessive amount of particulates.

To control water pollutants, wastewater is routed into large tanks and chemically treated. The addition of sodium bisulfite and sulfuric acid causes the chromium to precipitate out as CrO_3. The precipitate is filtered out, mechanically squeezed dry, and then landfilled. To eliminate the cyanide ion, sodium hypochlorite and sodium hydroxide are used to convert the cyanide ion to a carbonate and nitrogen gas in a separate tank. For both these processes mechanical mixers keep the liquids well mixed. After treatment the two solutions are mixed, pH adjusted using either hydrochloric acid or calcium hydroxide, and discharged into the nearby river.

The air pollutants are controlled by a cyclone. The gathered particulates are then landfilled.

The control costs are quite small. They contribute only 0.14 percent towards the product cost. This fraction compares favorably with an average profit rate before taxes of 20 to 25 percent.

CERAMICS MANUFACTURING

The ceramics manufacturing plant is in a suburb of a large metropolitan area. The plant's sole product is decorative ceramic tile.

Clay silt is the principal water pollutant discharged by the plant. To remove the silt from its wastewater, the plant pumps the water to a settling tank where the clay particles settle out. The clay sludge is then removed and pressed dry before being reused to form new clay tiles. Because of the clay's value, the benefit of reclaiming it has completely compensated for the recovery system's purchase, installation, and operating costs.

PULP AND PAPER MILLING

The case study pulp and paper mill is in a suburb of a major South American city. Eucalyptus saligna is the major fiber source developed and planted through the efforts of the mill; 50 percent of the timber used is grown on a company-owned plantation, and the mill produces 900 tons/day of finished paper. The mill was required to provide effective pollution controls before the government would allow it to expand its facilities.

Particulate air pollution is controlled with electrostatic precipitators, which are almost 99 percent efficient. SO_x and odors are controlled by closed cycle reclamation of the chemicals used to break down wood fibers.

The main water pollutants generated are dissolved sugars, bark, dyes, and other chemicals. Water supply treatment facilities consist of a mixing chamber, flocculation chamber, settling tank, and filtration tank. The industrial wastewater is retained in settling basins for 20 hours for primary sedimentation. Secondary treatment is provided by mechanical diffused air and activated sludge return, achieving a 90 to 95 percent total BOD reduction. A closed circuit wastewater recirculation system recovers almost all pulp and chemicals; the savings in recovered water, pulp, and chemicals pays for the cost of the wastewater treatment.

The mill formerly used 15,000 gallons (57 cu m) of water per ton of finished product; with recirculation and modern pollution controls it uses 5,000 to 6,000 gallons per ton (19-23 cu m/t). Water pollution controls cost about $1.37 per ton of product, excluding in-plant recirculation. As a result of the recirculation system, less water and smaller amounts of manufacturing chemicals are needed. The sludge from the settling basins is dredged and landfilled into the low-lying adjacent wetland areas, thus reclaiming land for plant expansion and preventing flooding.

WASTE COMPOSTING

A large South American city operates two large composting plants. The larger plant processes 40,000 cubic meters per month (about 15 percent of the city total) and covers 3.5 hectares. It is near a major highway, which provides easy access to the plant's customers who bring full farm produce trucks to market and load the purchased compost on their return to their fields.

The plant contains six independent process lines, each with its own conveyors, sorters, and composting cylinder. The composting process begins as solid waste with considerable garbage dumped into one of the storage bins. A conveyor belt carries the waste up to the inside sorting area. Sharp prongs bolted just above the conveyor puncture and tear open plastic bags and distribute the contained waste along the belt.

Once inside, non-organic materials are sorted out, both manually and mechanically. Magnets are used to remove ferrous metals; women workers sort out other materials: glass, plastics, cloth, nonferrous metals, and paper. The conveyor moves at only one meter per minute, permitting nearly all undesirable materials to be removed. Cloth and paper, though technically biodegradable, take longer to compost than the other organics. They are therefore sorted out and reclaimed for other uses.

After sorting, the remaining organic material is fed by conveyor into the fermenting cylinders. Each of these is a large rotating drum 3.5 meters in diameter and about 15 meters long. The cylinders rotate to promote oxidation of the material. The composting materials are monitored for temperature using three thermometers spaced equidistantly along each drum. The humidity of the cylinders is also monitored and water can be added or removed as necessary. All monitor readings are transmitted to a single control room where humidity and rotation speed are controlled for each of the six process lines. The use of six independent process lines permits controlled experiments to determine optimal fermenting conditions. Tests are made to find the best rotation speed, correct amount of moisture, and whether to add old compost or fertilizer as catalytic substances. Compost produced in cylinders under varying test conditions can be compared with that produced under constant conditions in the control cylinders.

After fermentation (60 hours average), the compost is removed and brought to an area where a gruvimetric separator removes small non-ferrous metals. These metals, along with the metals separated earlier, are baled and sold for recyling. The processed compost is stored outdoors in piles until sold. The piles are 1.5 m high, 2 meters wide, and of variable length. Since the materials are not yet completely oxidized, the piles are turned with mechanical loaders once per week (as of the time of the visit). The compost was being sold at $1.75 per cubic meter. All of the 100,000 cubic meters of compost manufactured in 1974 were sold.

The turnkey cost of the composting plant was $3.56 million. In 1974, compost sales generated revenue of $175,000. An official who was interviewed thought the compost selling price was artificially low, and that it could be increased with no loss in sales

volume to provide a better return on the initial capital investment. He explained that applying the compost to agricultural land 30 days before applying fertilizer effectively improves fertilization up to 70 percent, and could economically justify a higher sales price since it would replace costly artificial fertilizer.

SUMMARY CASE STUDY OBSERVATIONS

The case studies indicate the following.

- Present technology can effectively control most air and water pollutants from industrial sources.

- There are economies of scale: control cost per unit of product varies inversely with size of operation.

- Control cost per unit of product also varies inversely with rate of operation. If operating time is reduced 50 percent, for example, capital cost will remain the same, operating and maintenance cost will decline slightly, and pollution control cost per unit of product will increase significantly.

- Pollution control costs are generally a small percentage of total production cost; for large, on-line power facilities, for example, they are estimated at less than 4 percent for tertiary (highest level) treatment, and correspondingly less for lower control levels and cleaner fuel types.

- Costs based on the equations would be overstated for (1) new plants which do not require retrofitting, (2) older plants with existing control facilities, and (3) all plants which can take advantage of more efficient control methods including process modification, raw materials substitution, and recovery and reuse of commercially valuable waste residues (either in the production process or for outside sale or use).

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COST CURVES FOR CASE STUDY INDUSTRY TREATMENT SYSTEMS

The following equations and cost curves were discussed in the chapter introduction under INDUSTRY OVERVIEWS, Cost Analysis.

TABLE 4-41
COST OF POLLUTION CONTROL:
POWER GENERATION

Fuel	Control Level	Control Cost[a]	
		(¢/kwhr)	(% of product price)
Coal	Air pollution		
	Primary	0.041	1.37
	Secondary	0.068	2.27
	Water pollution		
	Primary	0.018	0.60
	Secondary	0.029	0.95
	Tertiary	0.037	1.22
Oil	Air pollution		
	Primary	0.027	0.91
	Secondary	0.047	1.58
	Water pollution		
	Primary	0.016	0.55
	Secondary	0.025	0.83
	Tertiary	0.031	1.04
Natural gas	Air pollution		
	Primary	0.007	0.23
	Secondary	0.022	0.75
	Water pollution		
	Primary	0.012	0.40
	Secondary	0.022	0.72
	Tertiary	0.027	0.97

[a] Assuming 500 Mw generating capacity, a 50 percent utilization rate, and a price of 3.0¢/kwhr.

TABLE 4-42
POLLUTION CONTROL COST
EQUATIONS: POWER GENERATION

Fuel	Treatment Level	Cost Equation[a]	
		Air Pollution Control	Water Pollution Control
Coal	Primary	$y = 6{,}897\ x^{0.78}$	$y = 22{,}486\ x^{0.46}$
	Secondary	$y = 16{,}994\ x^{0.72}$	$y = 23{,}160\ x^{0.53}$
	Tertiary	b	$y = 23{,}190\ x^{0.57}$
Oil	Primary	$y = 6{,}005\ x^{0.74}$	$y = 21{,}906\ x^{0.45}$
	Secondary	$y = 16{,}210\ x^{0.66}$	$y = 22{,}908\ x^{0.51}$
	Tertiary	b	$y = 25{,}332\ x^{0.53}$
Natural gas	Primary	$y = 2{,}995\ x^{0.63}$	$y = 14{,}901\ x^{0.46}$
	Secondary	$y = 4{,}093\ x^{0.77}$	$y = 22{,}641\ x^{0.49}$
	Tertiary	b	$y = 20{,}558\ x^{0.54}$

[a] x = plant capacity (Mw).
y = total annual cost ($).
[b] No tertiary system designed.

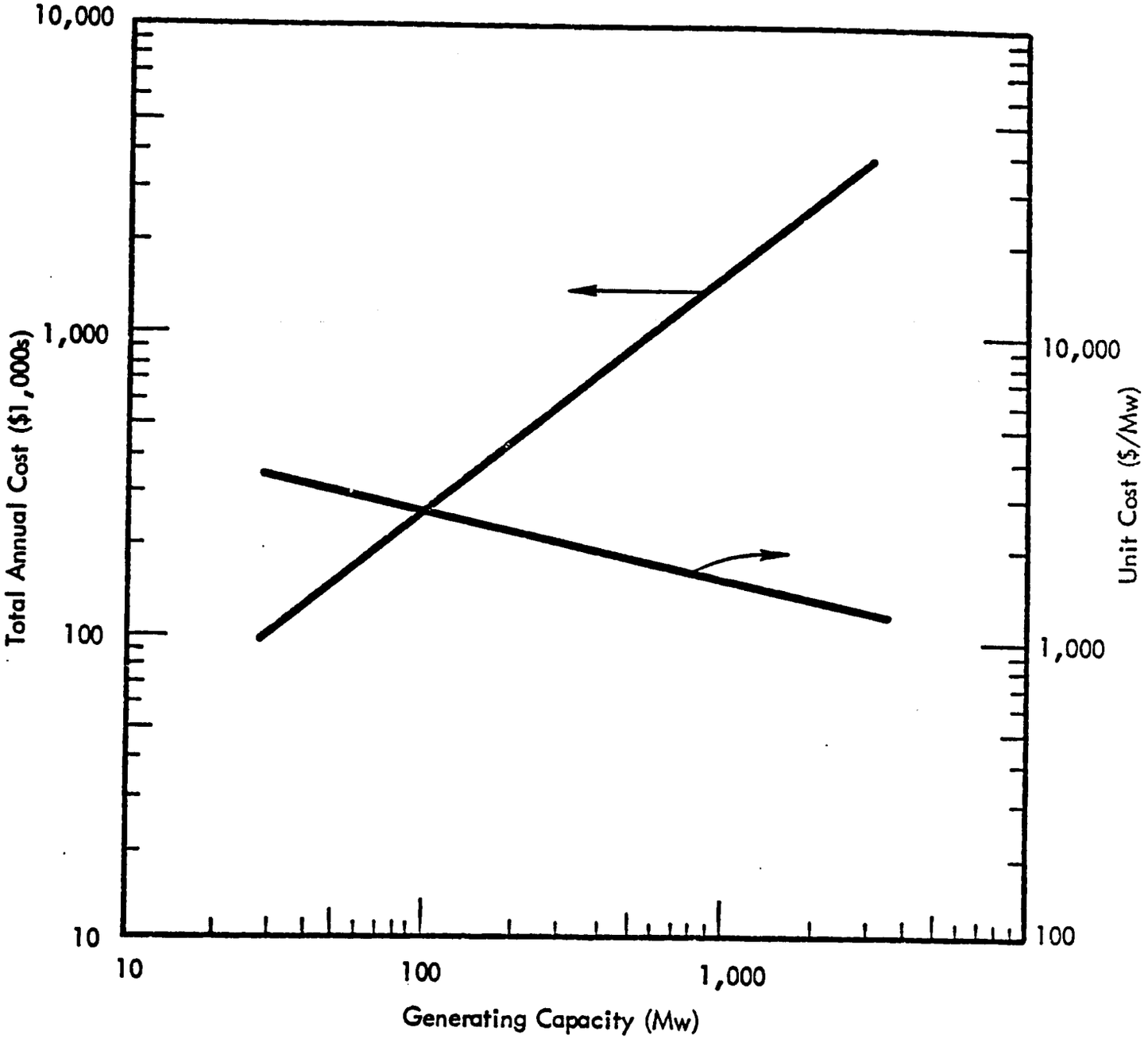


FIGURE 4-34
AIR POLLUTION CONTROL COST:
POWER GENERATION (COAL)
PRIMARY TREATMENT

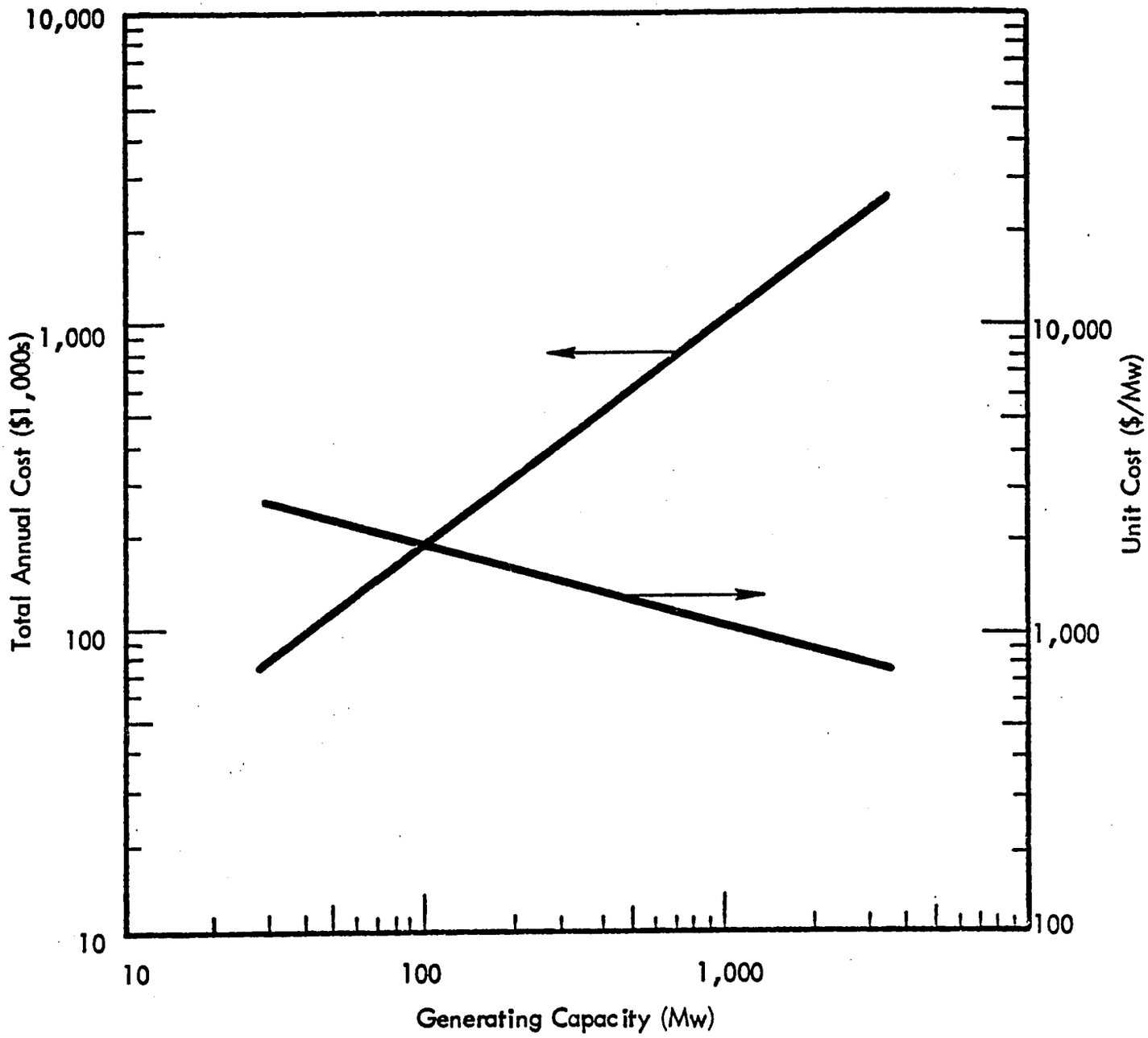


FIGURE 4-35

AIR POLLUTION CONTROL COST:
POWER GENERATION (OIL)
PRIMARY TREATMENT

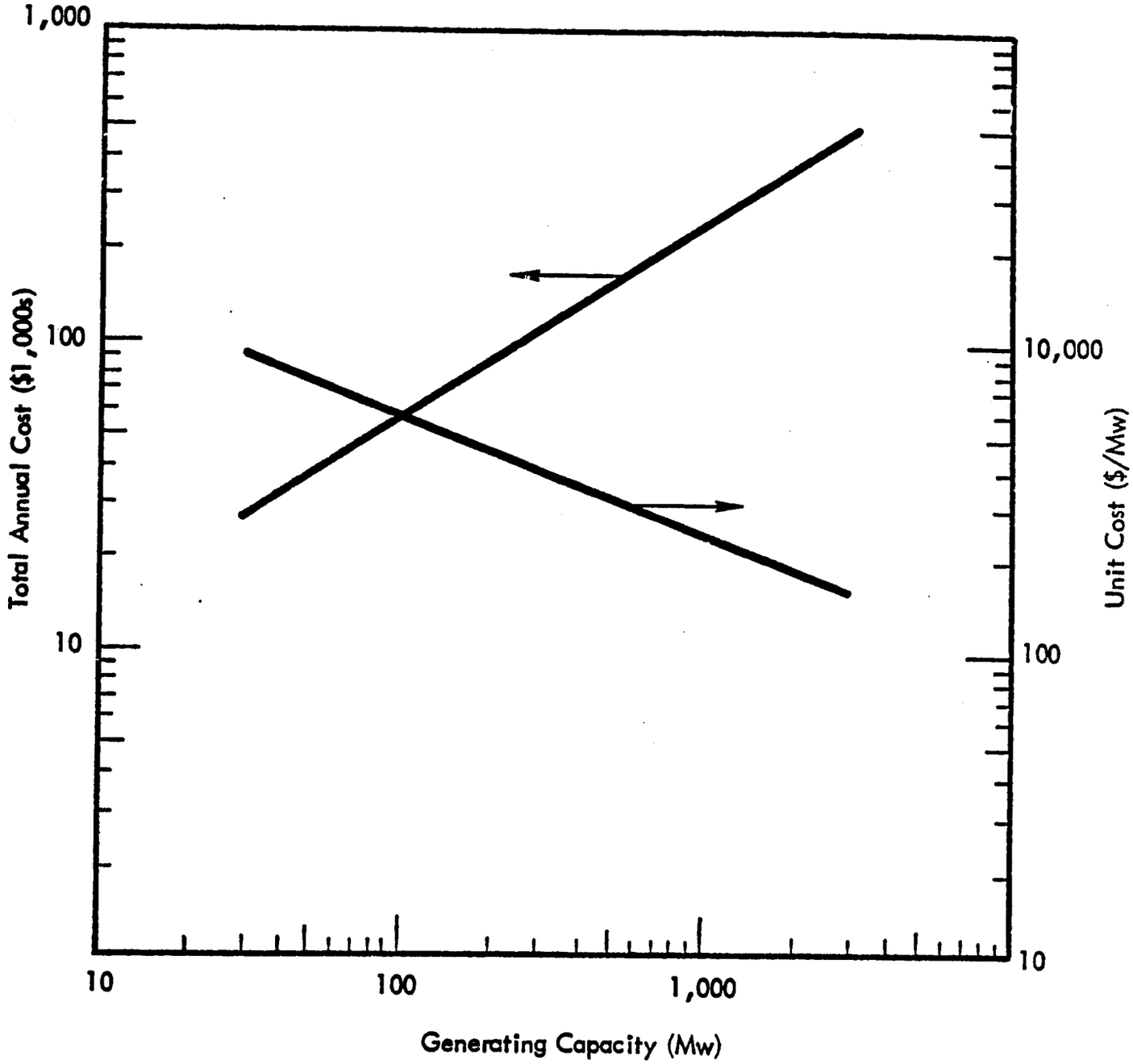


FIGURE 4-36
AIR POLLUTION CONTROL COST:
POWER GENERATION (NATURAL GAS)
PRIMARY TREATMENT

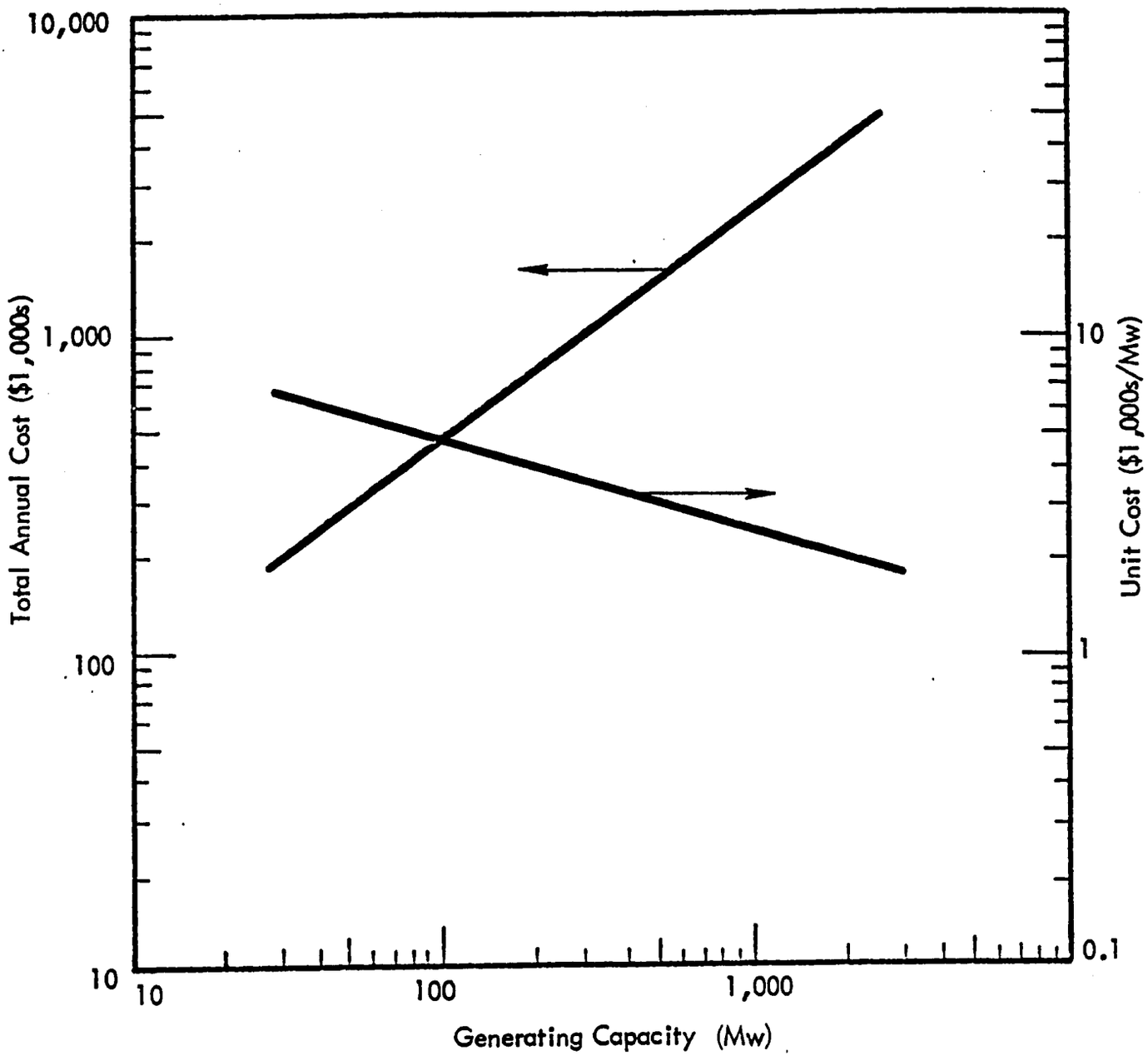


FIGURE 4-37
AIR POLLUTION CONTROL COST:
POWER GENERATION (COAL)
SECONDARY TREATMENT

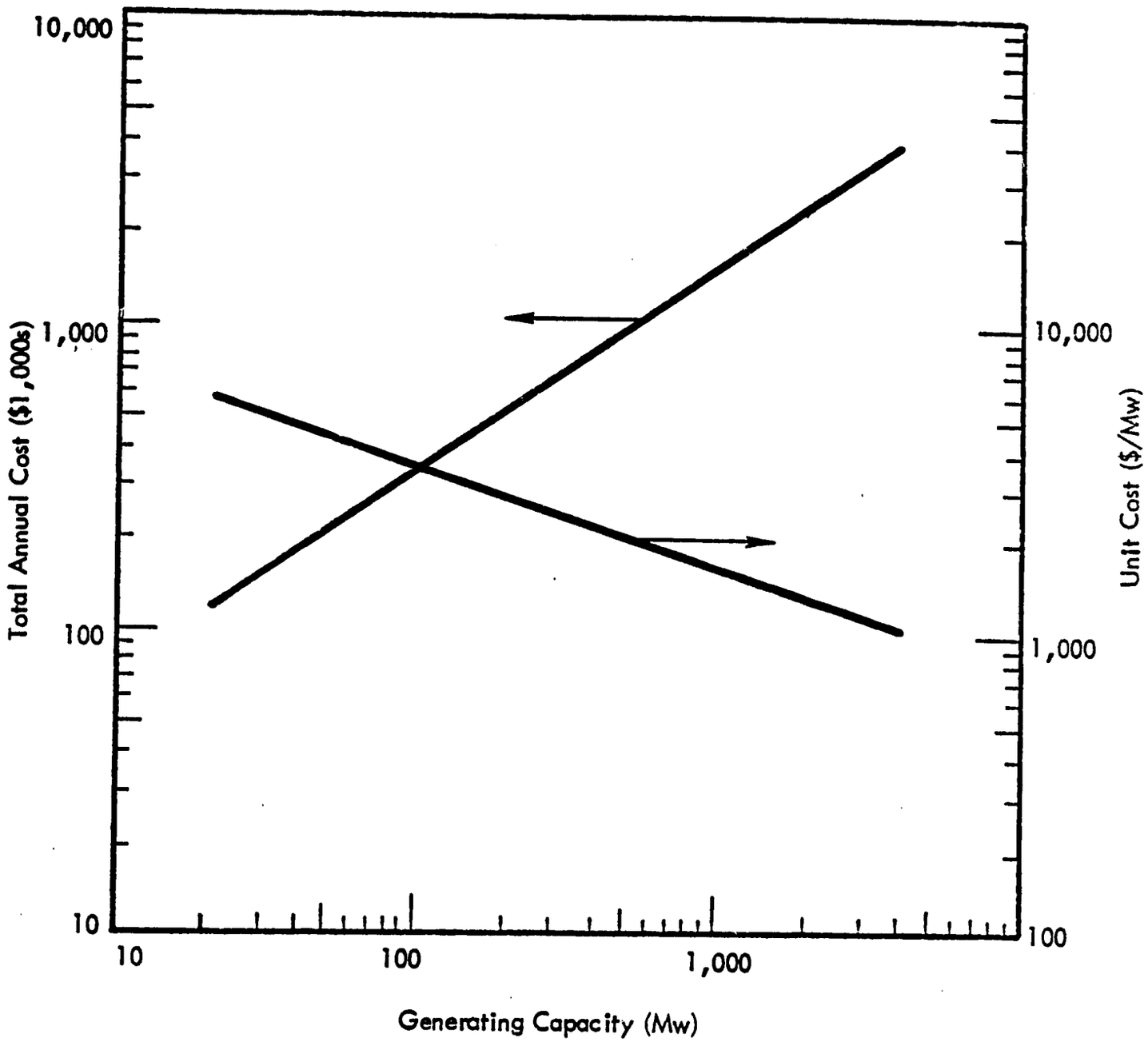


FIGURE 4-38

AIR POLLUTION CONTROL COST:
POWER GENERATION (OIL)
SECONDARY TREATMENT

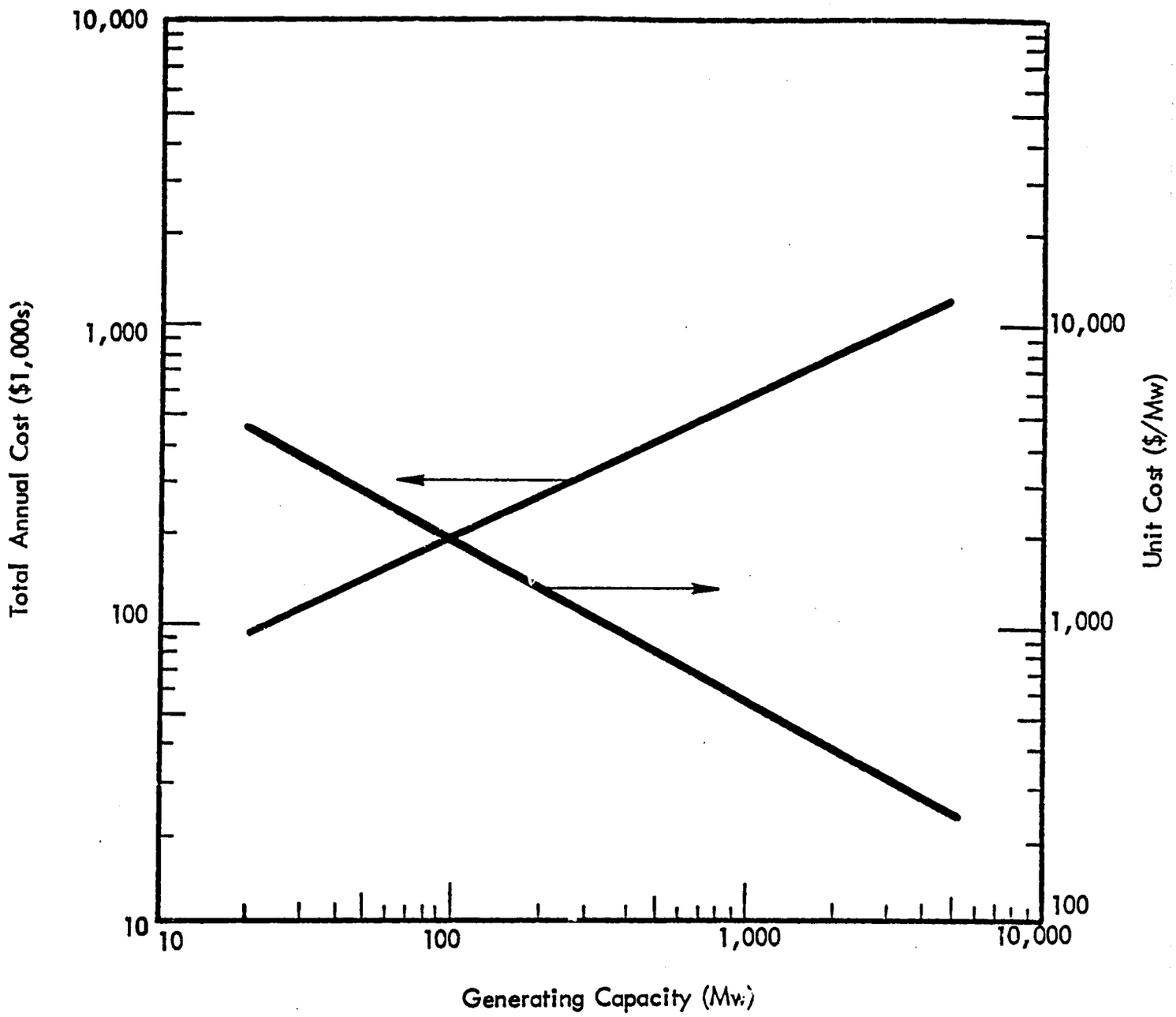


FIGURE 4-39
WATER POLLUTION CONTROL COST:
POWER GENERATION (COAL)
PRIMARY TREATMENT

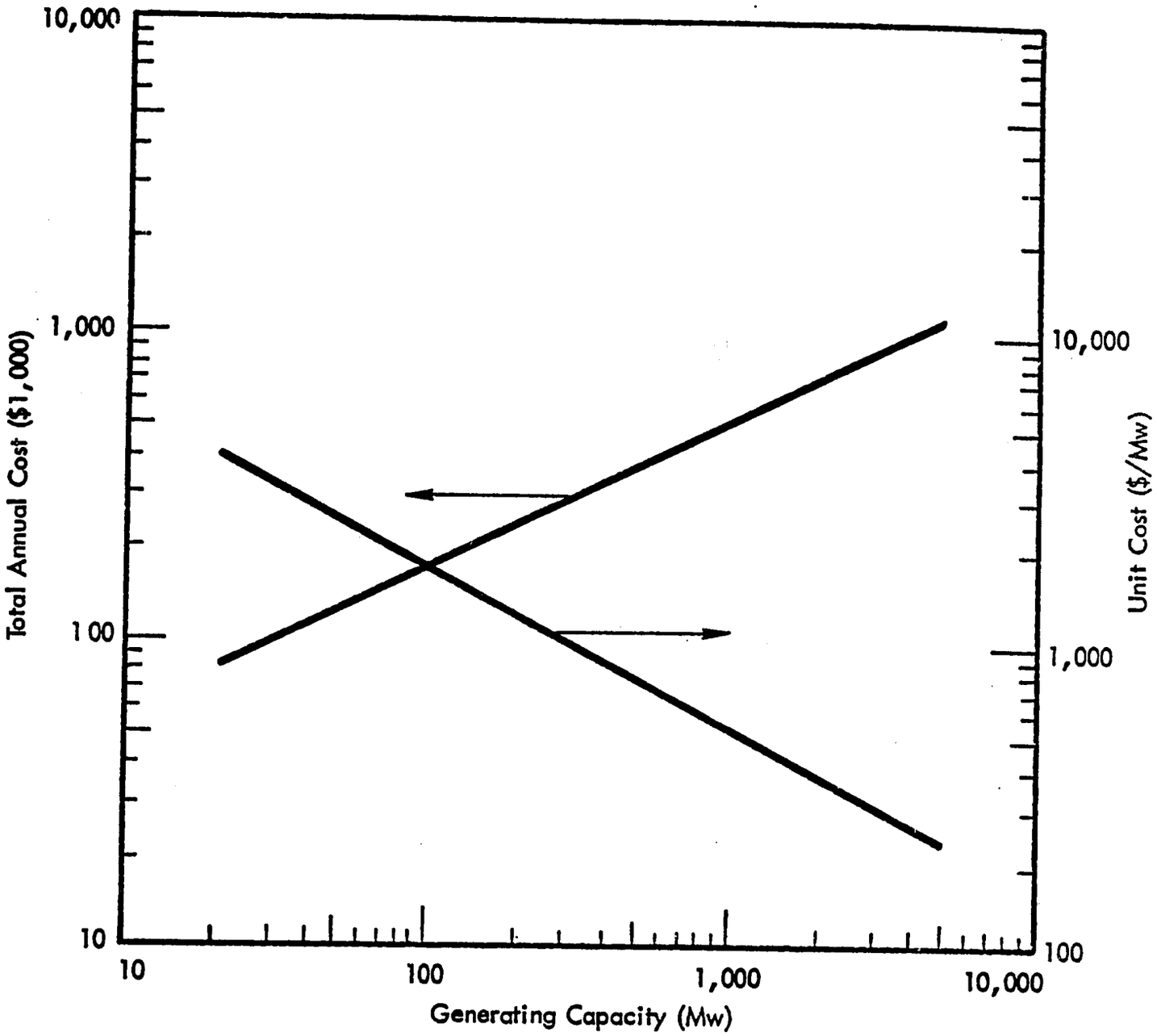


FIGURE 4-40
WATER POLLUTION CONTROL COST:
POWER GENERATION (OIL)
PRIMARY TREATMENT

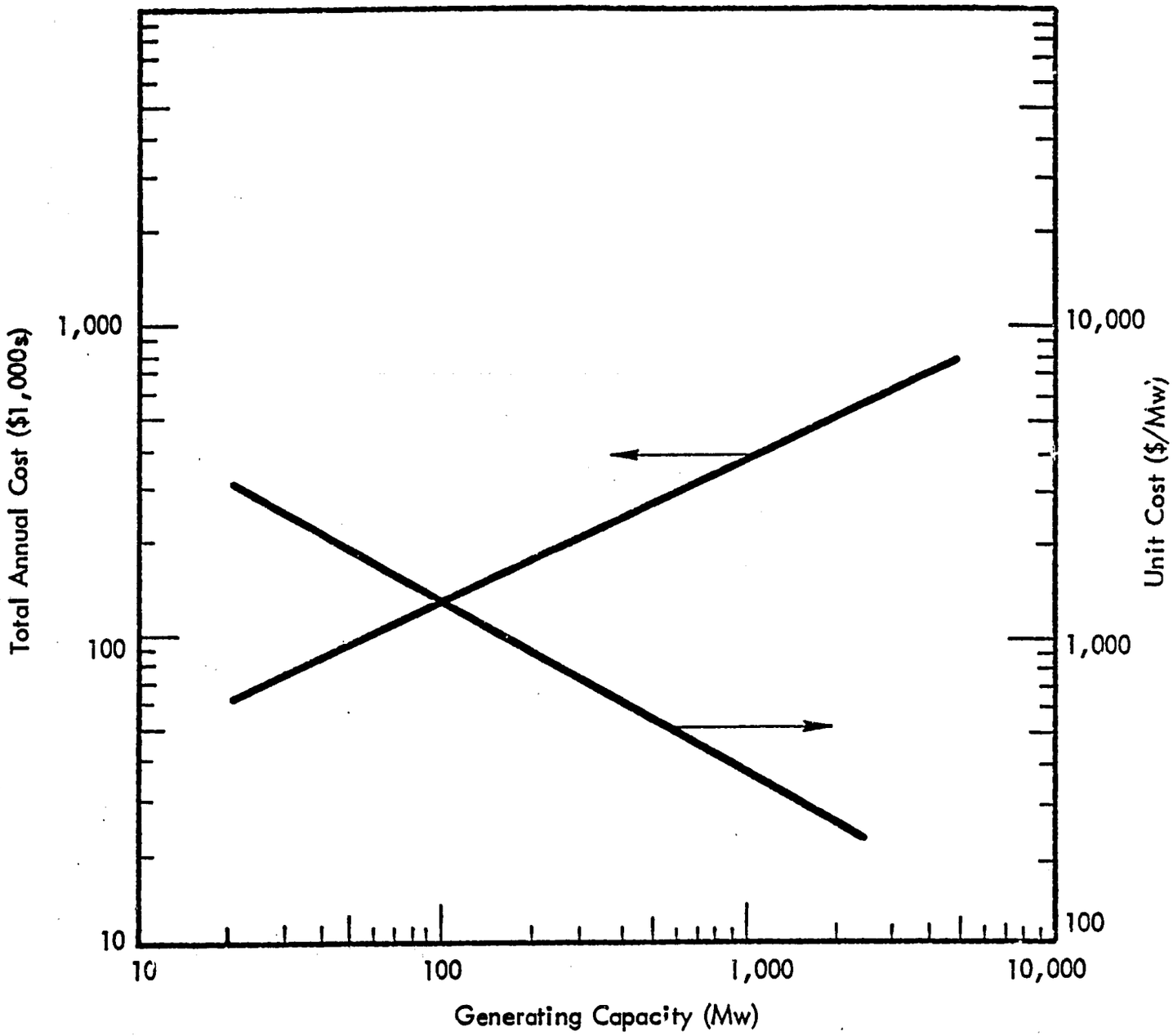


FIGURE 4-41
WATER POLLUTION CONTROL COST:
POWER GENERATION (NATURAL GAS)
PRIMARY TREATMENT

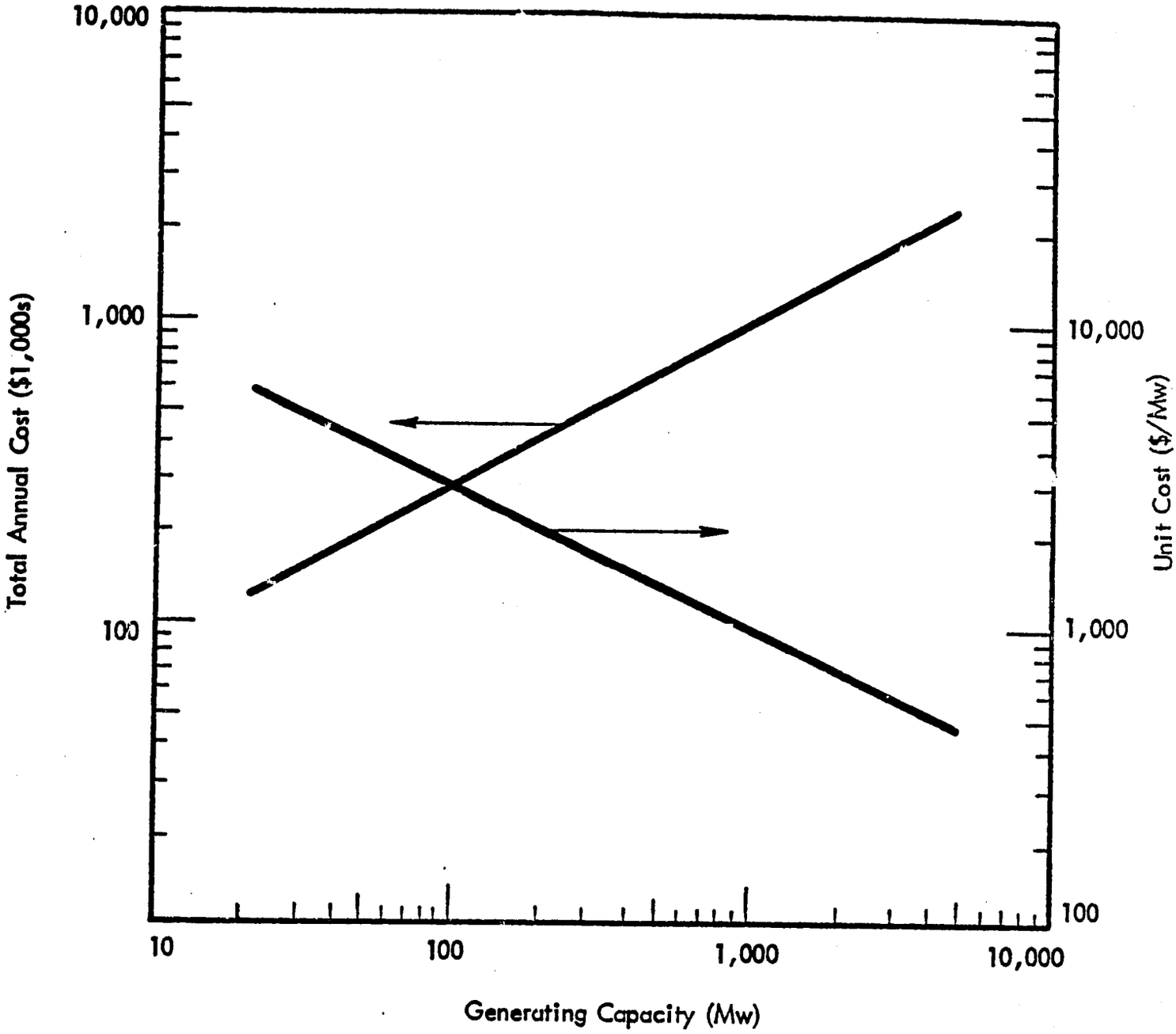


FIGURE 4-42
WATER POLLUTION CONTROL COST:
POWER GENERATION (COAL)
SECONDARY TREATMENT

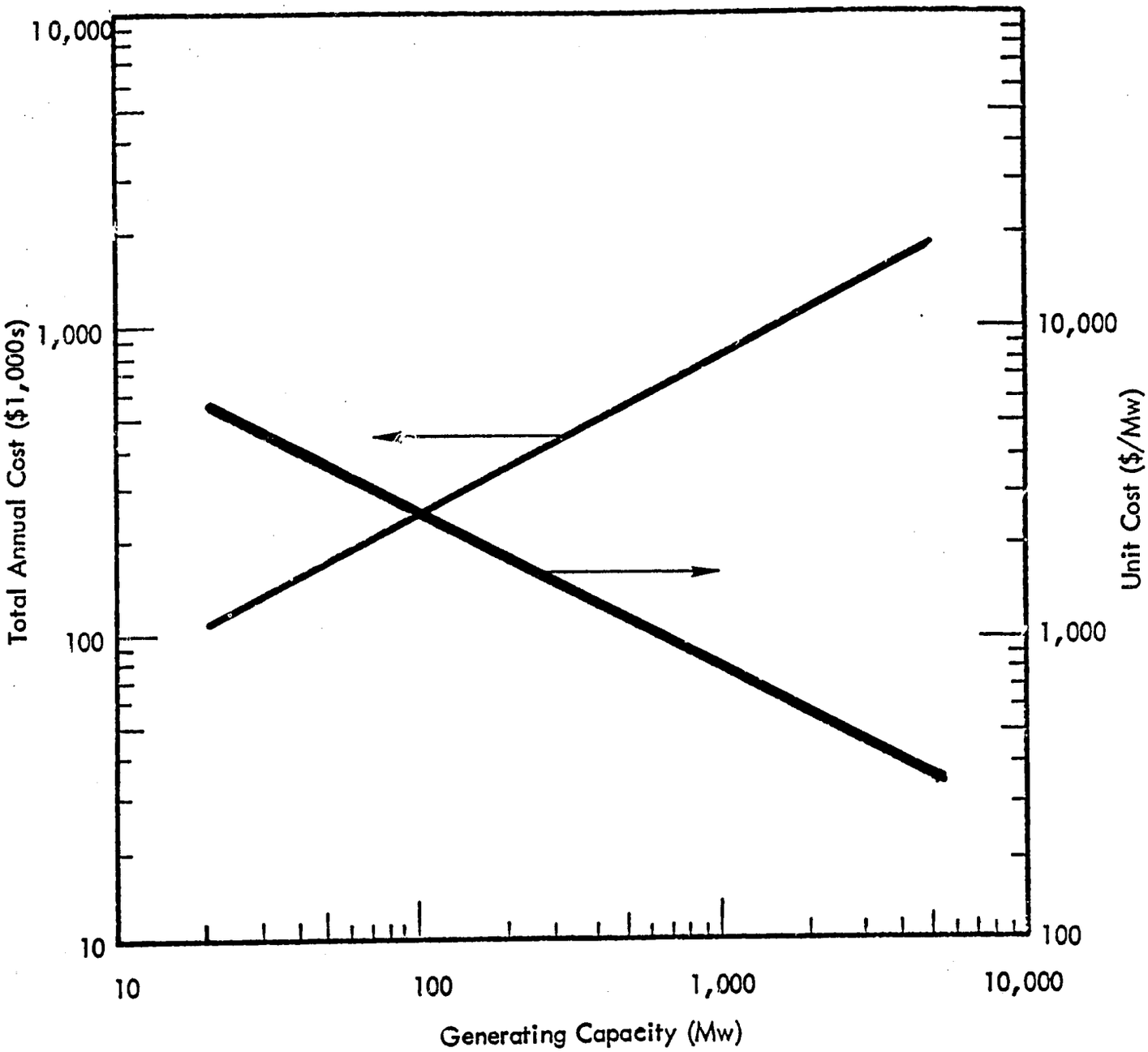


FIGURE 4-43
WATER POLLUTION CONTROL COST:
POWER GENERATION (OIL)
SECONDARY TREATMENT

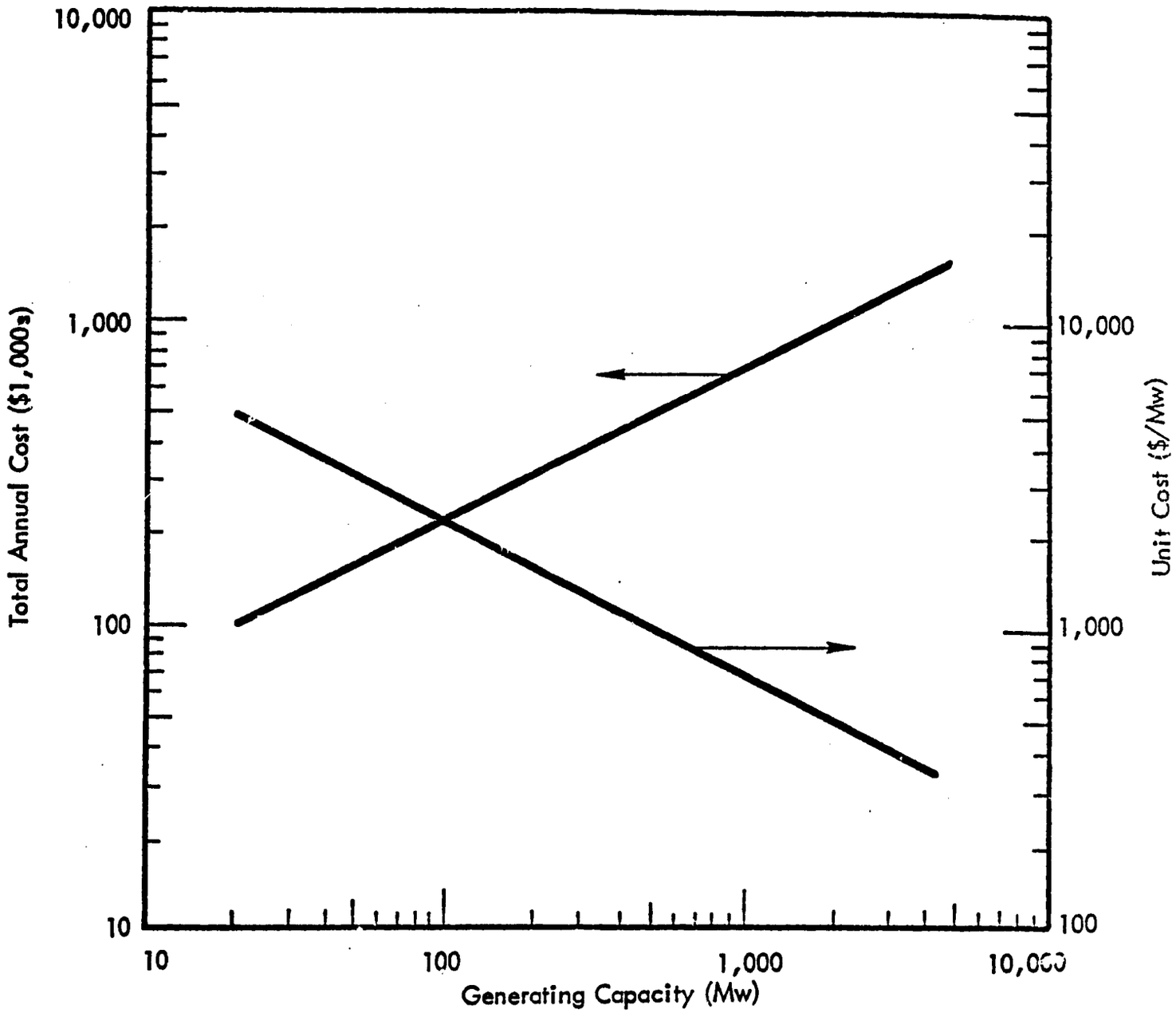


FIGURE 4-44

WATER POLLUTION CONTROL COST:
POWER GENERATION (NATURAL GAS)
SECONDARY TREATMENT

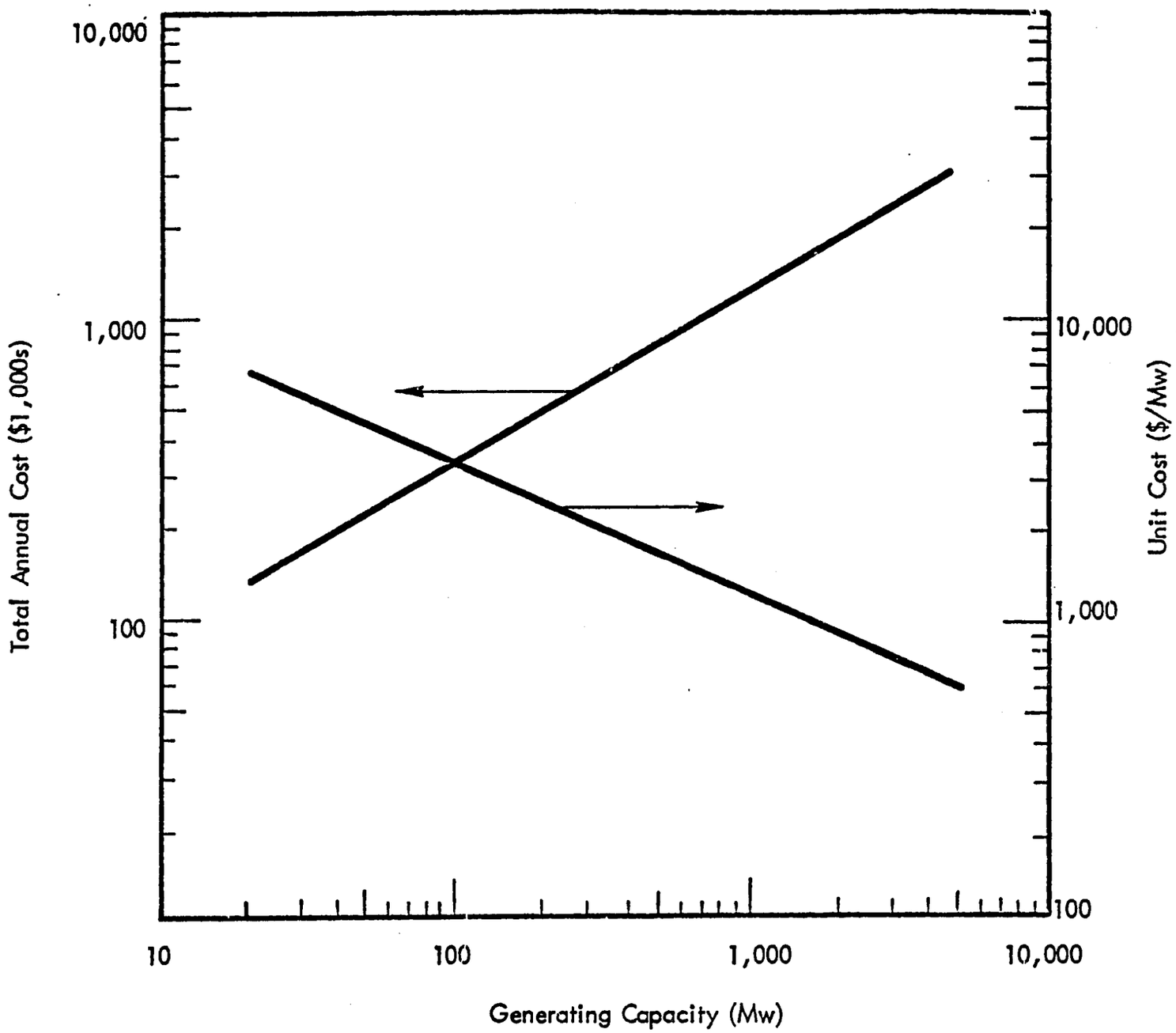


FIGURE 4-45
WATER POLLUTION CONTROL COST:
POWER GENERATION (COAL)
TERTIARY TREATMENT

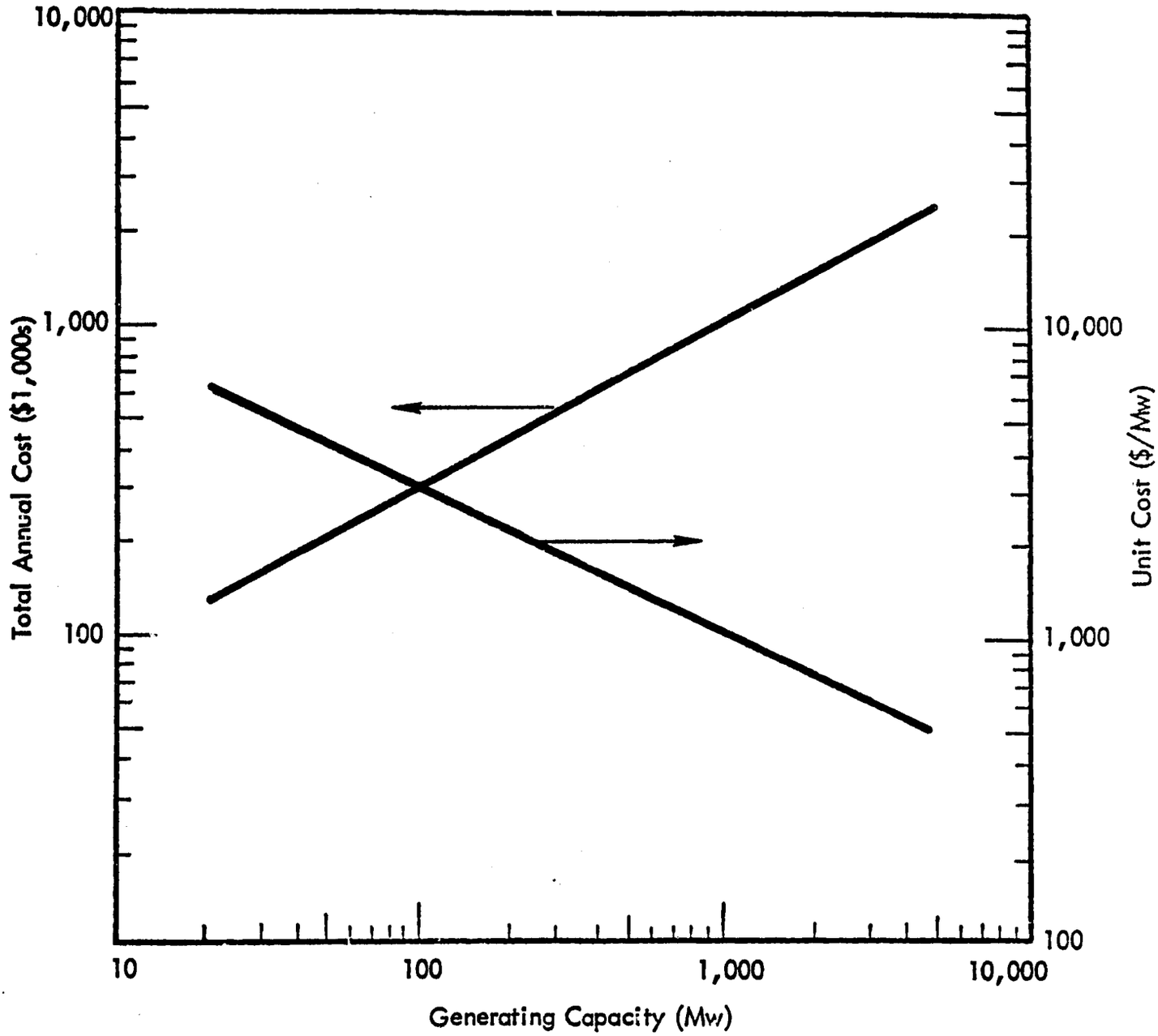


FIGURE 4-46
WATER POLLUTION CONTROL COST:
POWER GENERATION (OIL)
TERTIARY TREATMENT

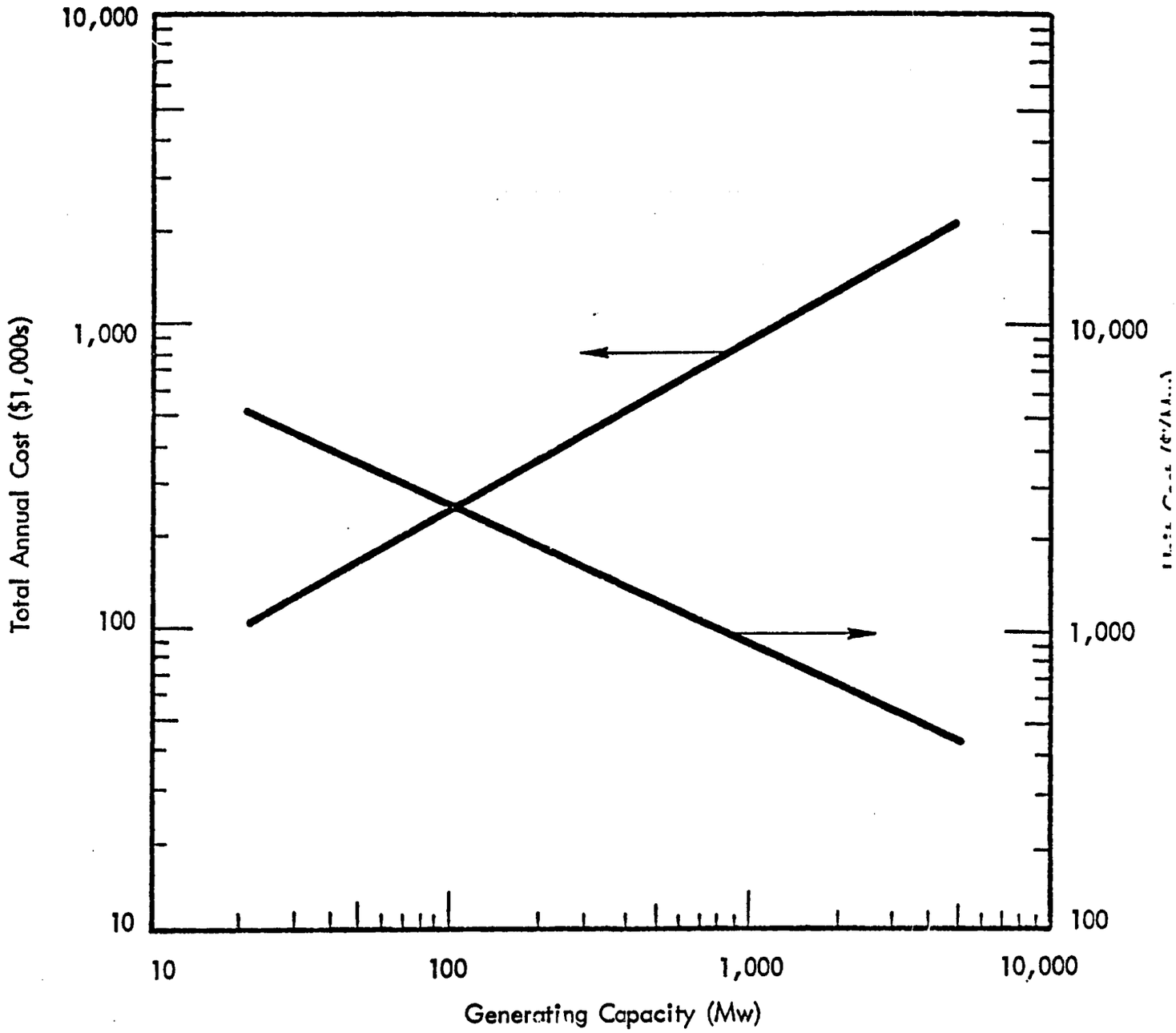


FIGURE 4-47
WATER POLLUTION CONTROL COST:
POWER GENERATION (NATURAL GAS)
TERTIARY TREATMENT

TABLE 4-43

POLLUTION CONTROL COST EQUATIONS: IRON AND STEEL

Treatment Level	Cost Equation[a]	
	Air Pollution Control	Water Pollution Control
Primary	$y = 1.07x^{0.87}$	$y = 11.05x^{0.84}$
Secondary	$y = 118x^{0.62}$	$y = 30.38x^{0.83}$
Tertiary	$y = 20x^{0.76}$	$y = 58.9x^{0.81}$

[a] x = plant capacity (kkg/year)

y = total annual cost ($)

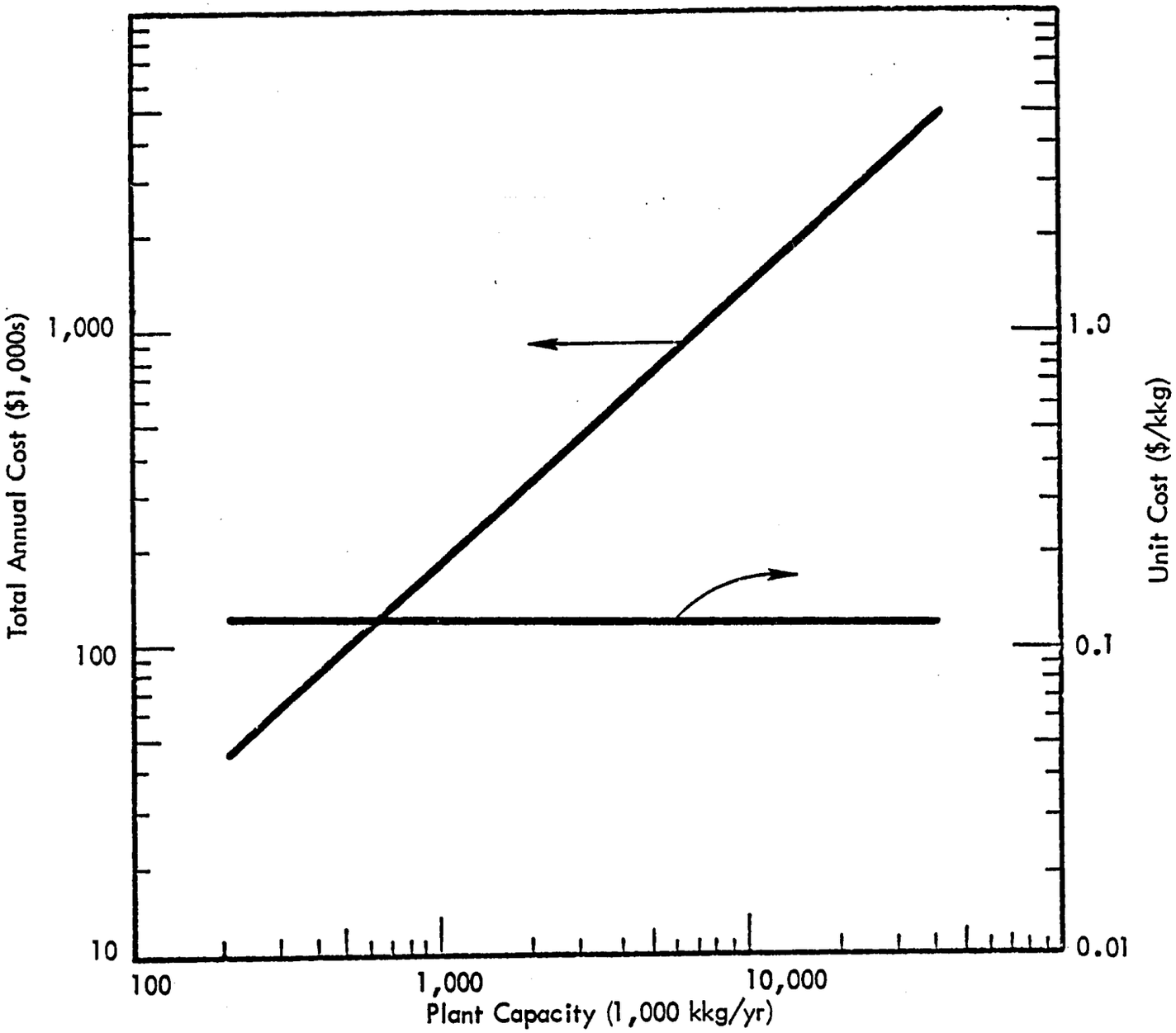


FIGURE 4-48

AIR POLLUTION CONTROL COST:
IRON AND STEEL
PRIMARY TREATMENT

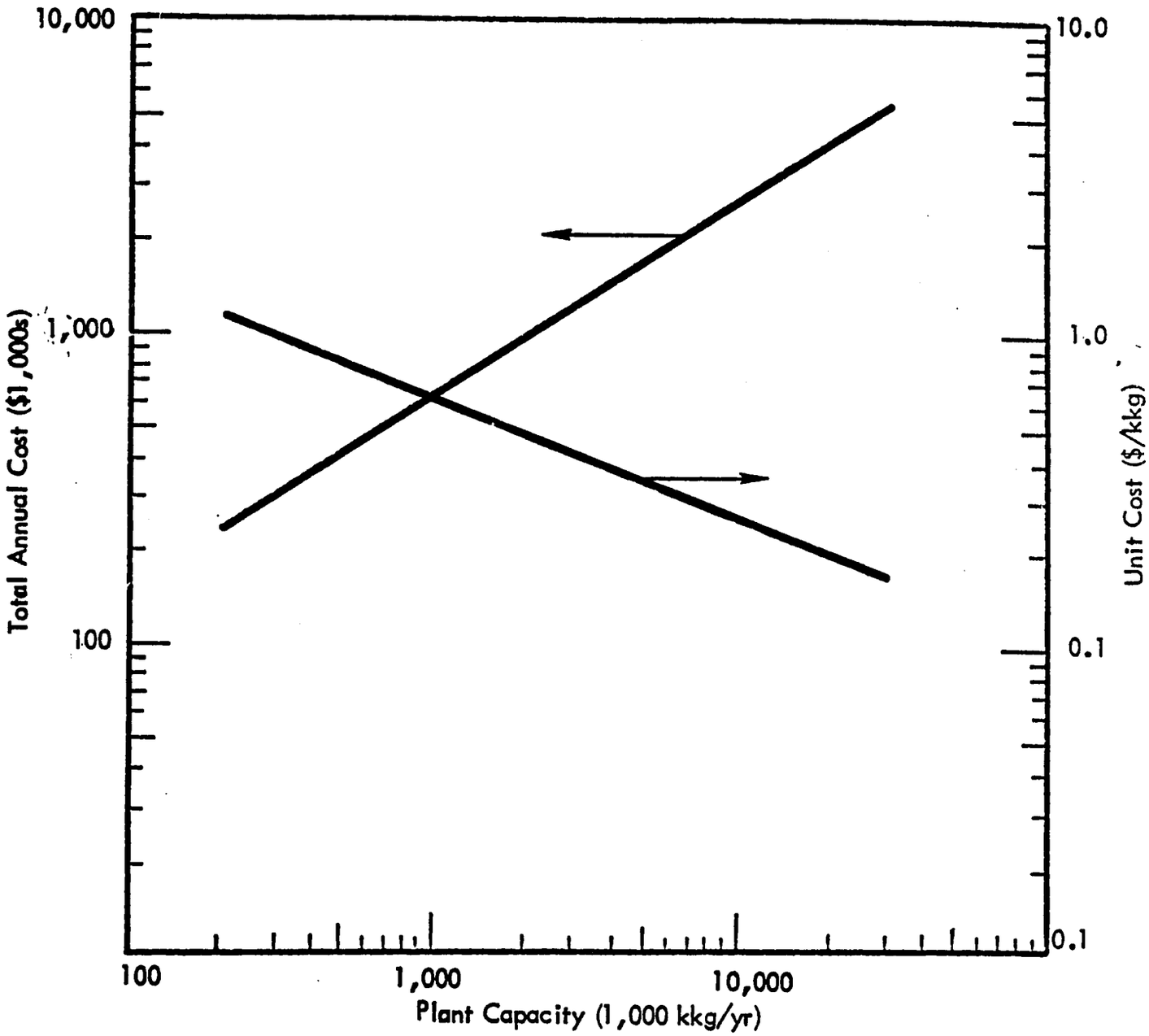


FIGURE 4-49

AIR POLLUTION CONTROL COST:
IRON AND STEEL
SECONDARY TREATMENT

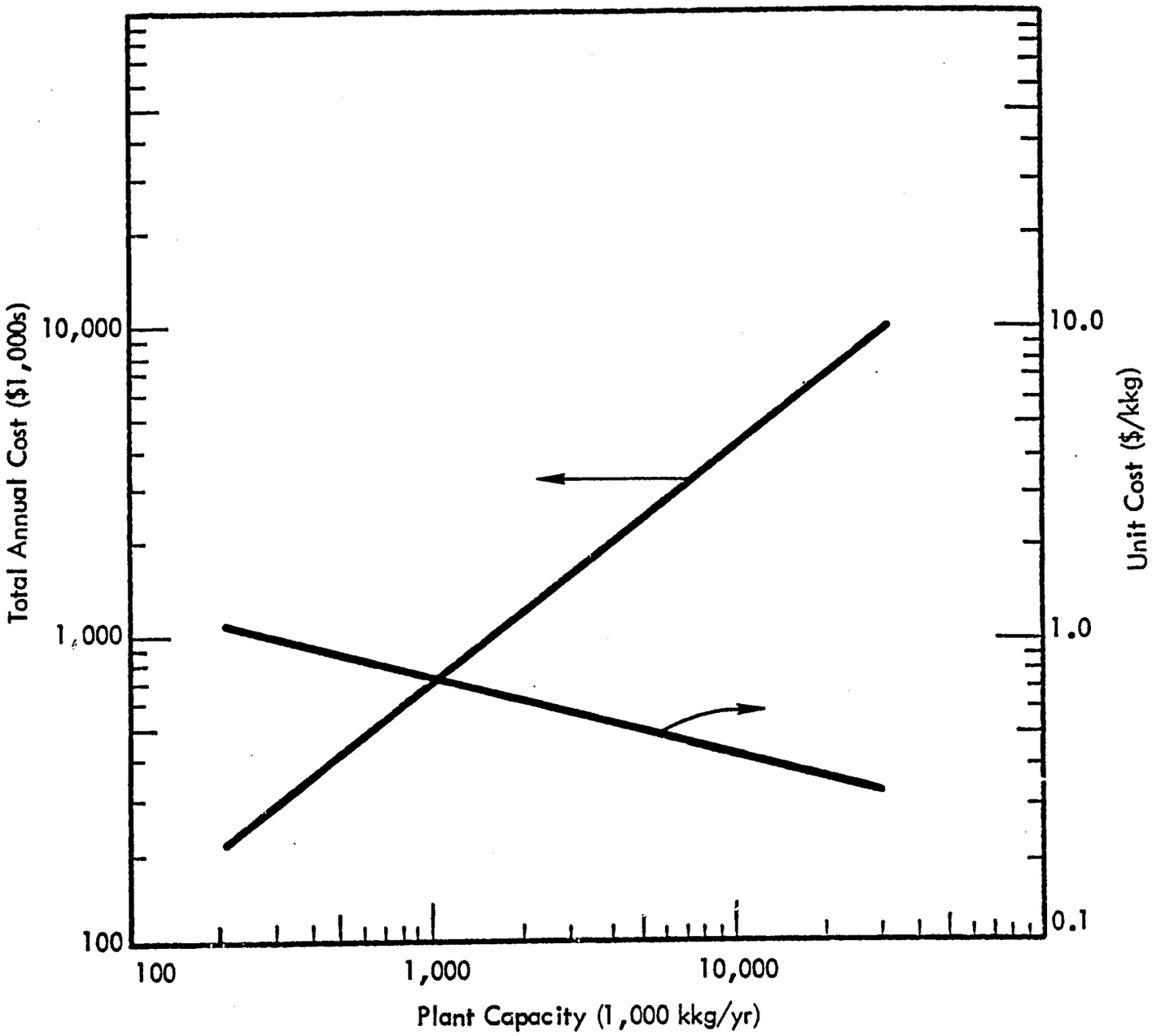


FIGURE 4-50
AIR POLLUTION CONTROL COST:
IRON AND STEEL
TERTIARY TREATMENT

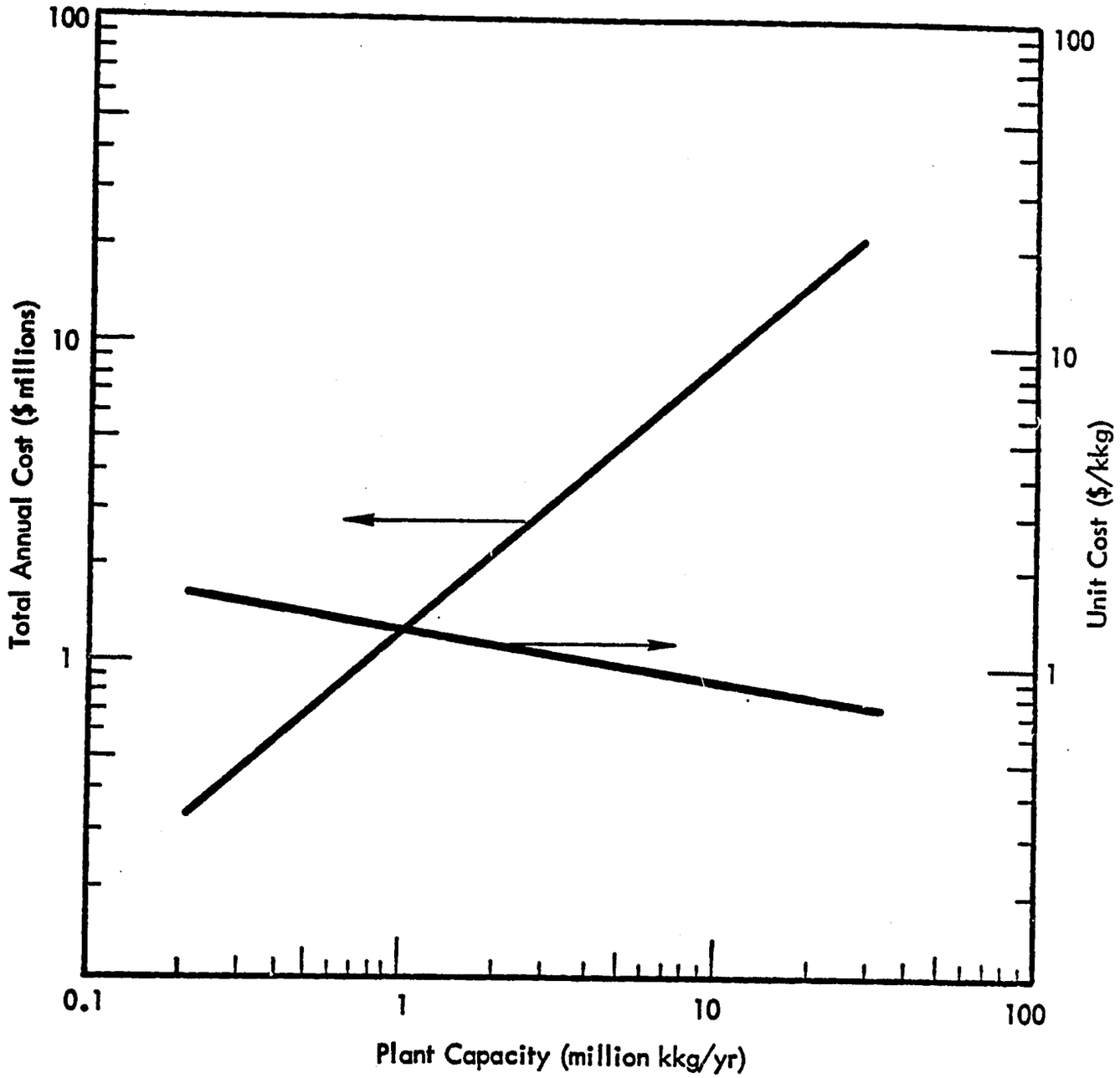


FIGURE 4-51
WATER POLLUTION CONTROL COST:
IRON AND STEEL
PRIMARY TREATMENT

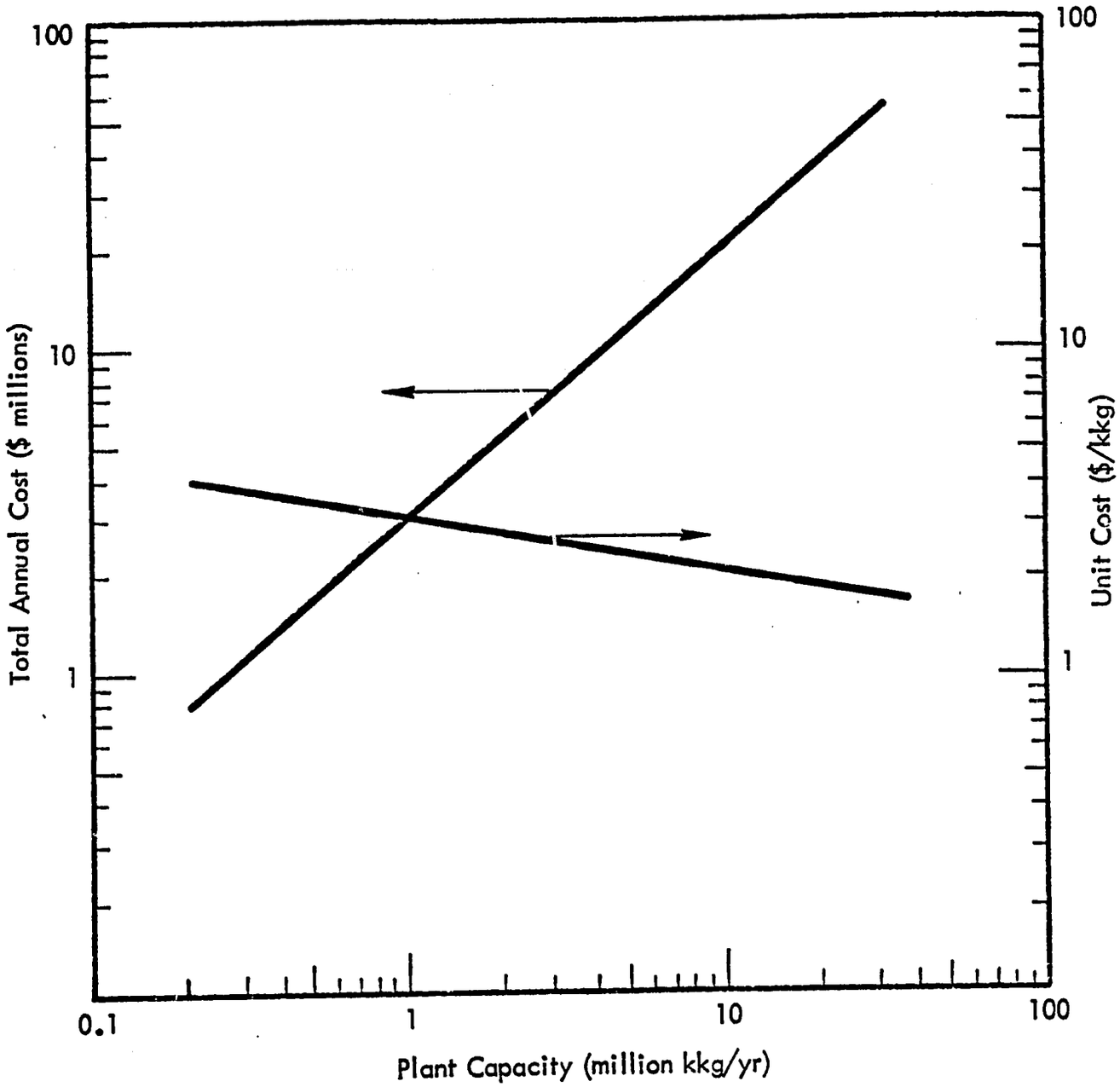


FIGURE 4-52
WATER POLLUTION CONTROL COST
IRON AND STEEL
SECONDARY TREATMENT

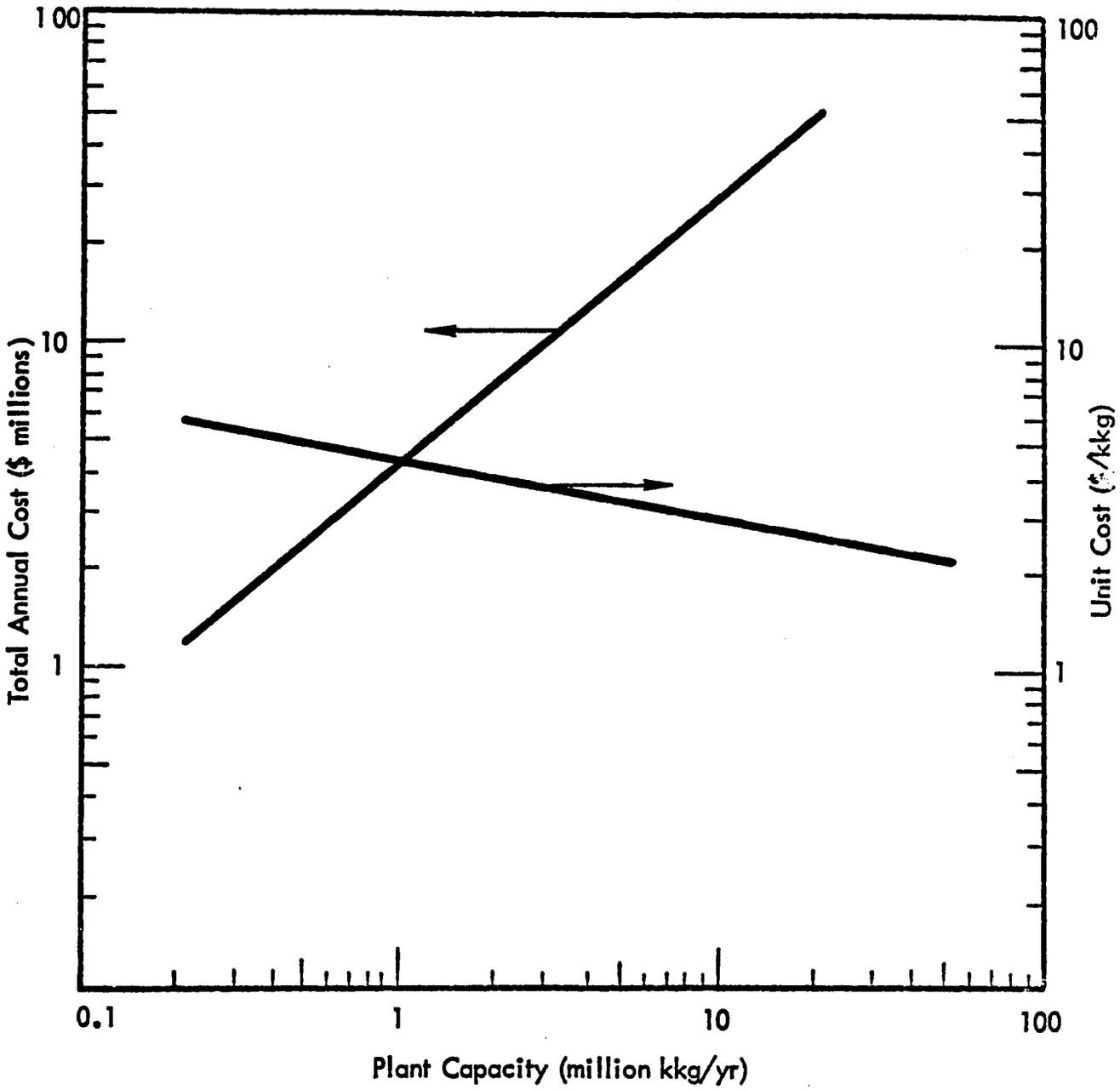
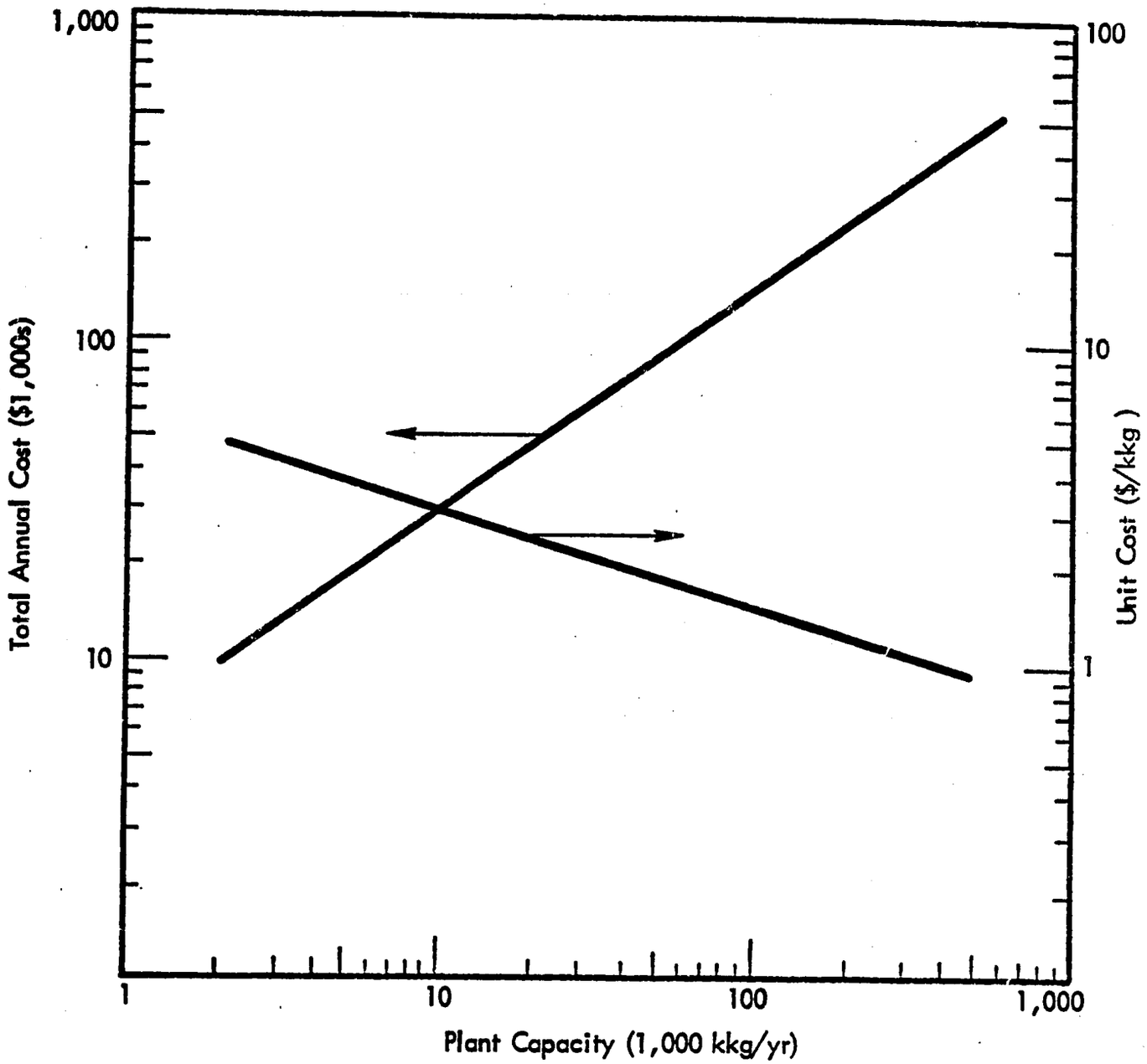


FIGURE 4-53
WATER POLLUTION CONTROL COST:
IRON AND STEEL
TERTIARY TREATMENT

TABLE 4-44
WATER POLLUTION CONTROL COST EQUATIONS:
FOOD CANNING

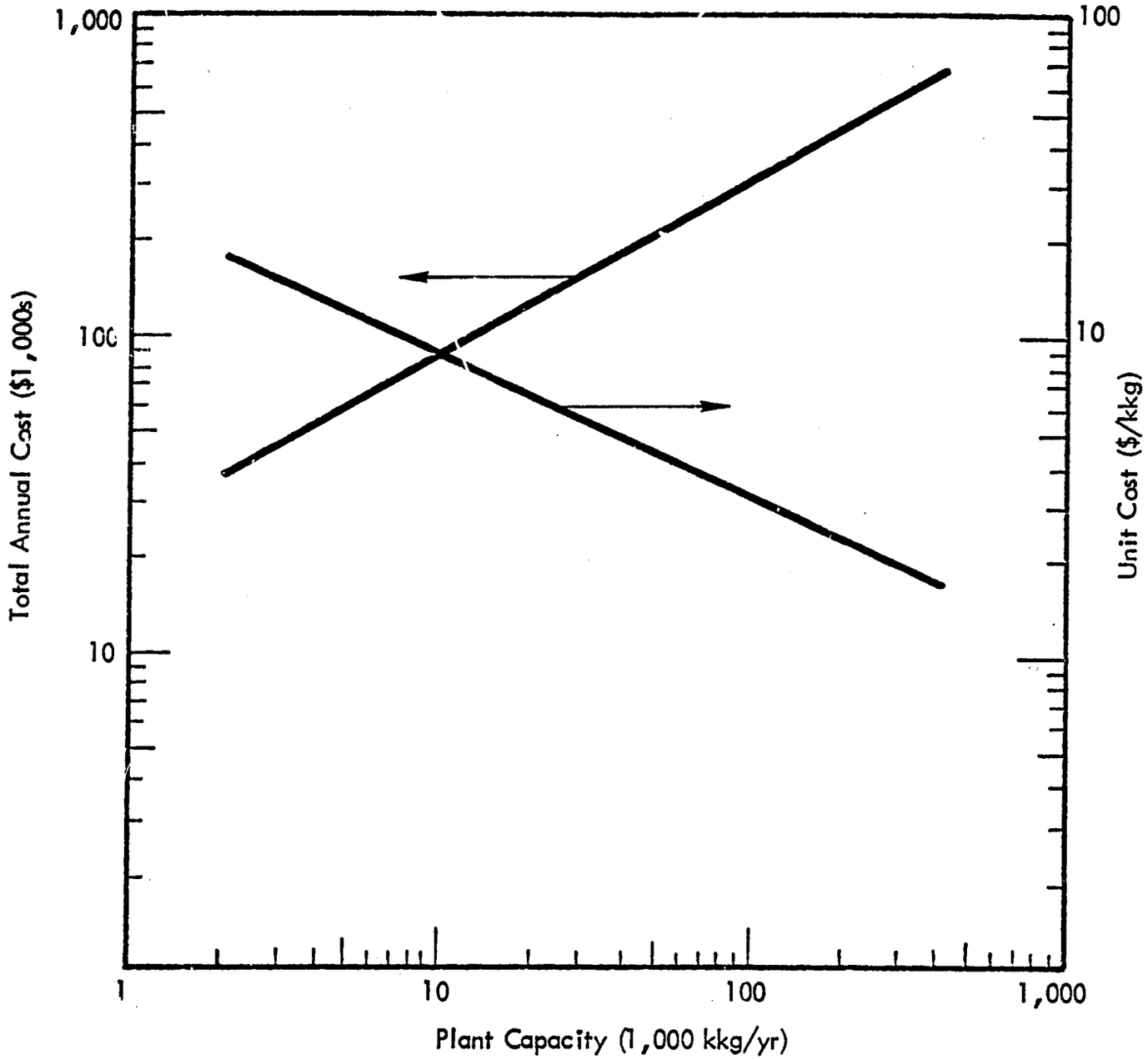
Subcategory	Treatment Level	Cost Equation[a]
Fruit	Primary	$y = 50\ x^{0.69}$
	Secondary	$y = 544\ x^{0.55}$
	Tertiary	$y = 1145\ x^{0.51}$
Vegetable[b]	Primary	$y = 146\ x^{0.69}$
	Secondary	$y = 1582\ x^{0.55}$
	Tertiary	$y = 3331\ x^{0.51}$
Specialty[b]	Primary	$y = 68\ x^{0.69}$
	Secondary	$y = 767\ x^{0.55}$
	Tertiary	$y = 1614\ x^{0.51}$
Catfish	Primary	$y = 1556\ x^{0.40}$
	Secondary	$y = 1817\ x^{0.49}$
	Tertiary	$y = 2139\ x^{0.52}$
Blue crab	Primary	$y = 1315\ x^{0.37}$
	Secondary	$y = 3064\ x^{0.37}$
	Tertiary	$y = 4188\ x^{0.38}$
Shrimp	Primary	$y = 497\ x^{0.70}$
	Secondary	$y = 3070\ x^{0.56}$
	Tertiary	$y = 4172\ x^{0.57}$
Tuna	Primary	$y = 658\ x^{0.50}$
	Secondary	$y = 465\ x^{0.63}$
	Tertiary	$y = 440\ x^{0.68}$

[a] x = plant capacity (kkg/year)
y = total annual cost ($)
[b] Based on estimated cost adjustment factors shown in Figures 4-54 through 4-56 .



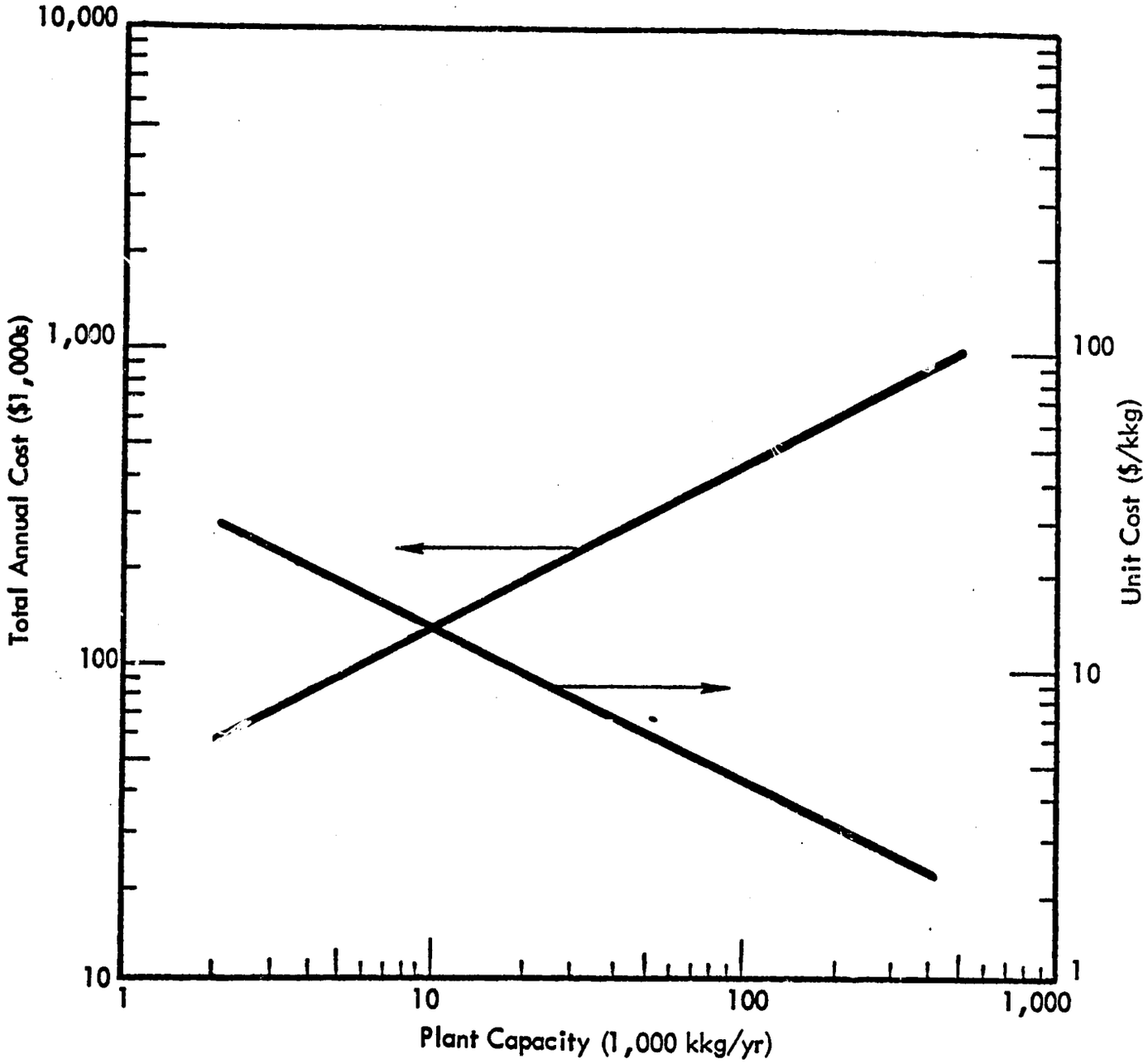
Subcategory	Cost Multiplier
Fruit	1.00
Vegetable	2.91
Specialty	1.36

FIGURE 4-54
WATER POLLUTION CONTROL COST:
FRUIT, VEGETABLE AND SPECIALTY
CANNING
PRIMARY TREATMENT



Subcategory	Cost Multiplier
Fruit	1.00
Vegetable	2.91
Specialty	1.41

FIGURE 4-55
WATER POLLUTION CONTROL COST:
FRUIT, VEGETABLE, AND SPECIALTY
CANNING
SECONDARY TREATMENT



Subcategory	Cost multiplier
Fruit	1.00
Vegetable	2.91
Specialty	1.41

FIGURE 4-56
WATER POLLUTION CONTROL COST:
FRUIT, VEGETABLE, AND SPECIALTY
CANNING
TERTIARY TREATMENT

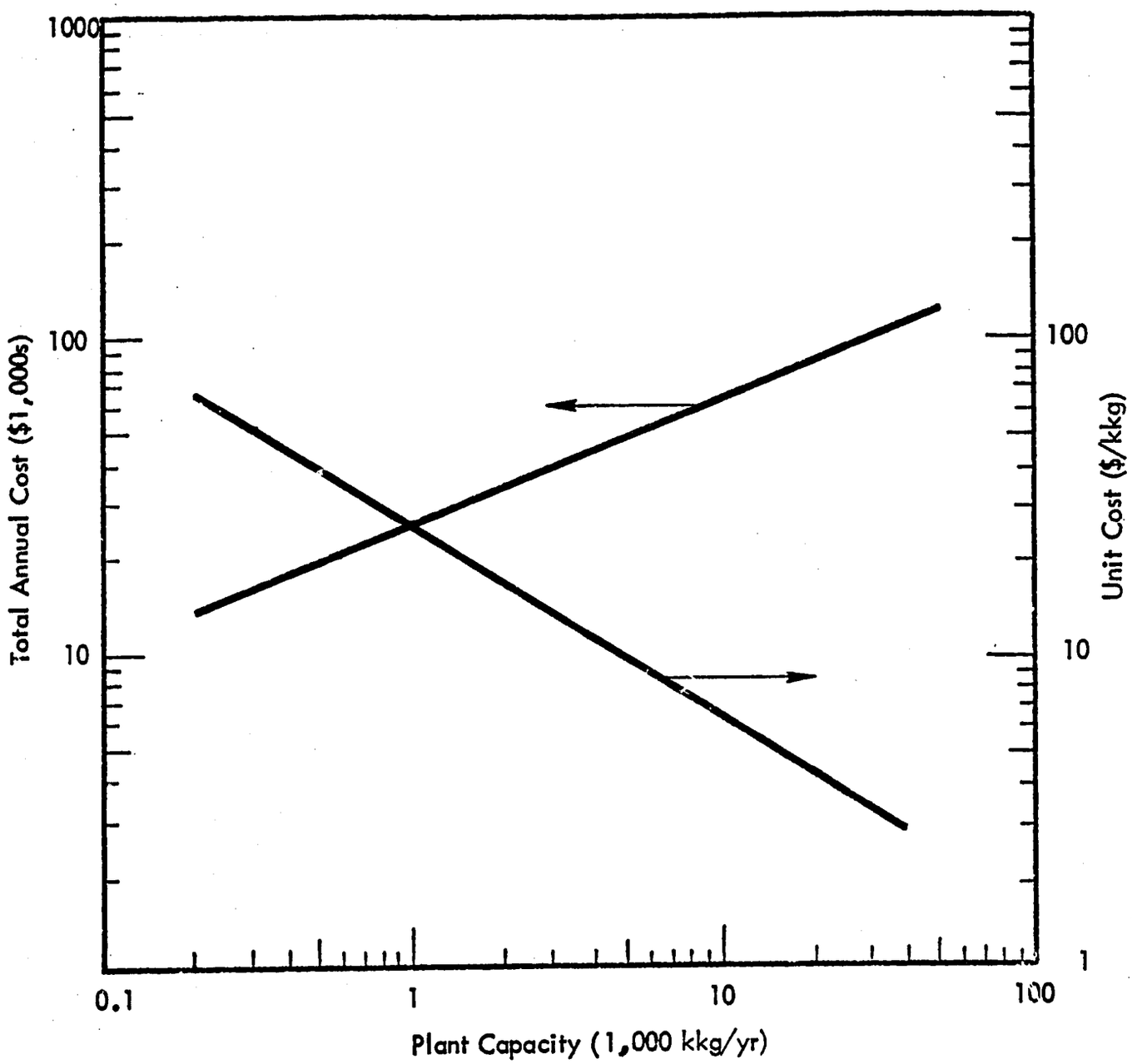


FIGURE 4-57
WATER POLLUTION CONTROL COST:
CAT FISH CANNING
PRIMARY TREATMENT

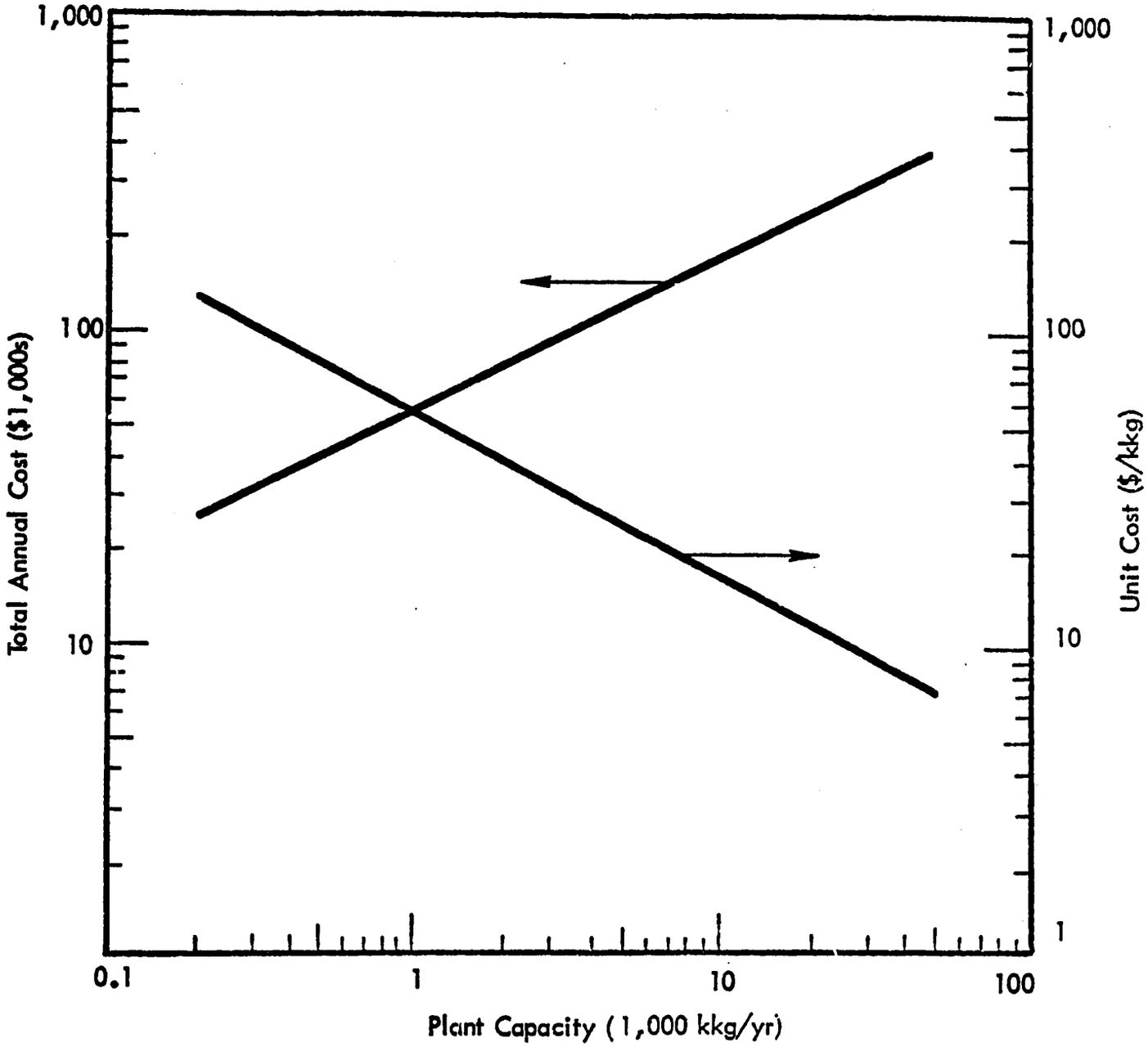


FIGURE 4-58
WATER POLLUTION CONTROL COST:
CAT FISH CANNING
SECONDARY TREATMENT

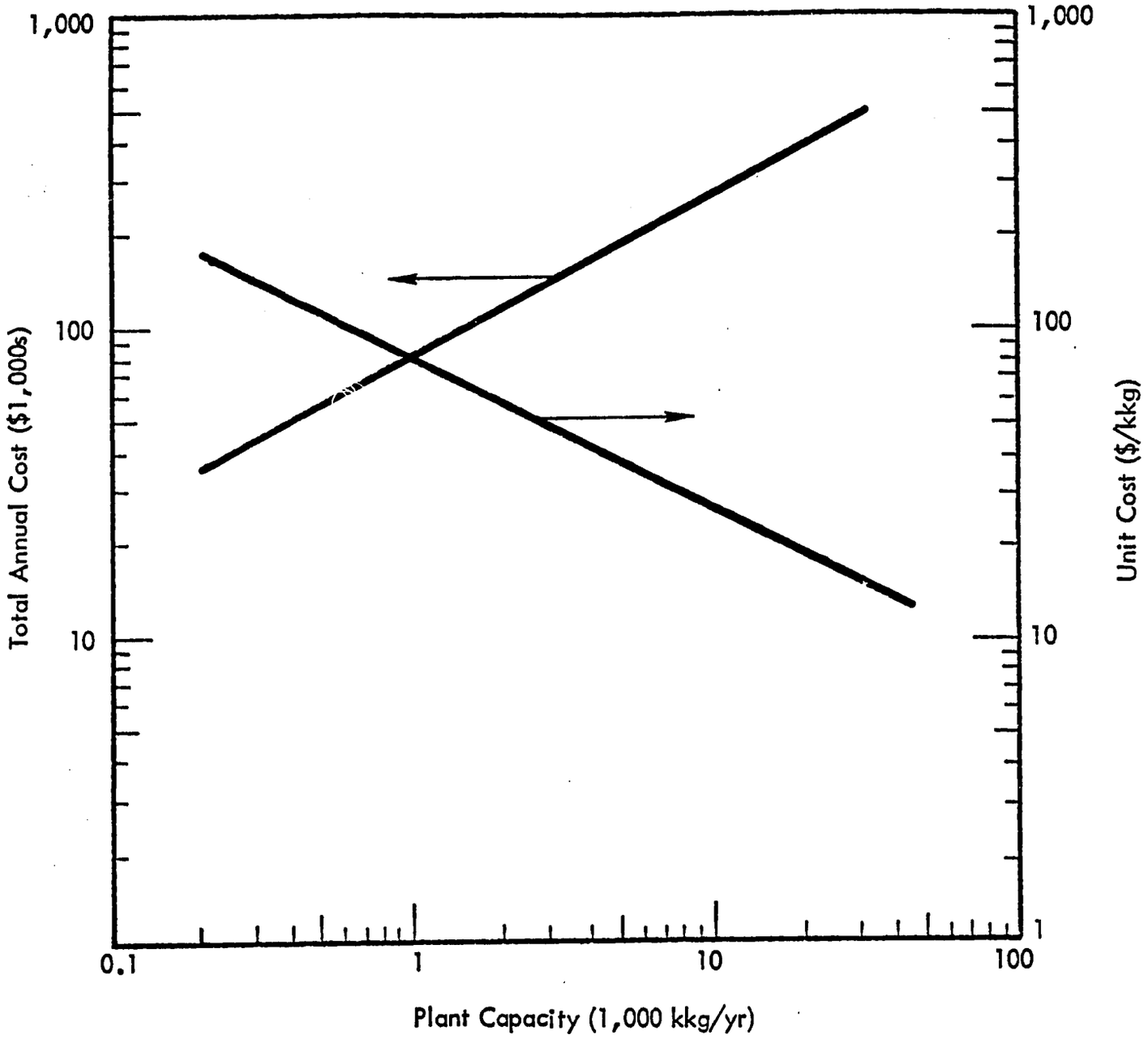


FIGURE 4-59
WATER POLLUTION CONTROL COST:
CAT FISH CANNING
TERTIARY TREATMENT

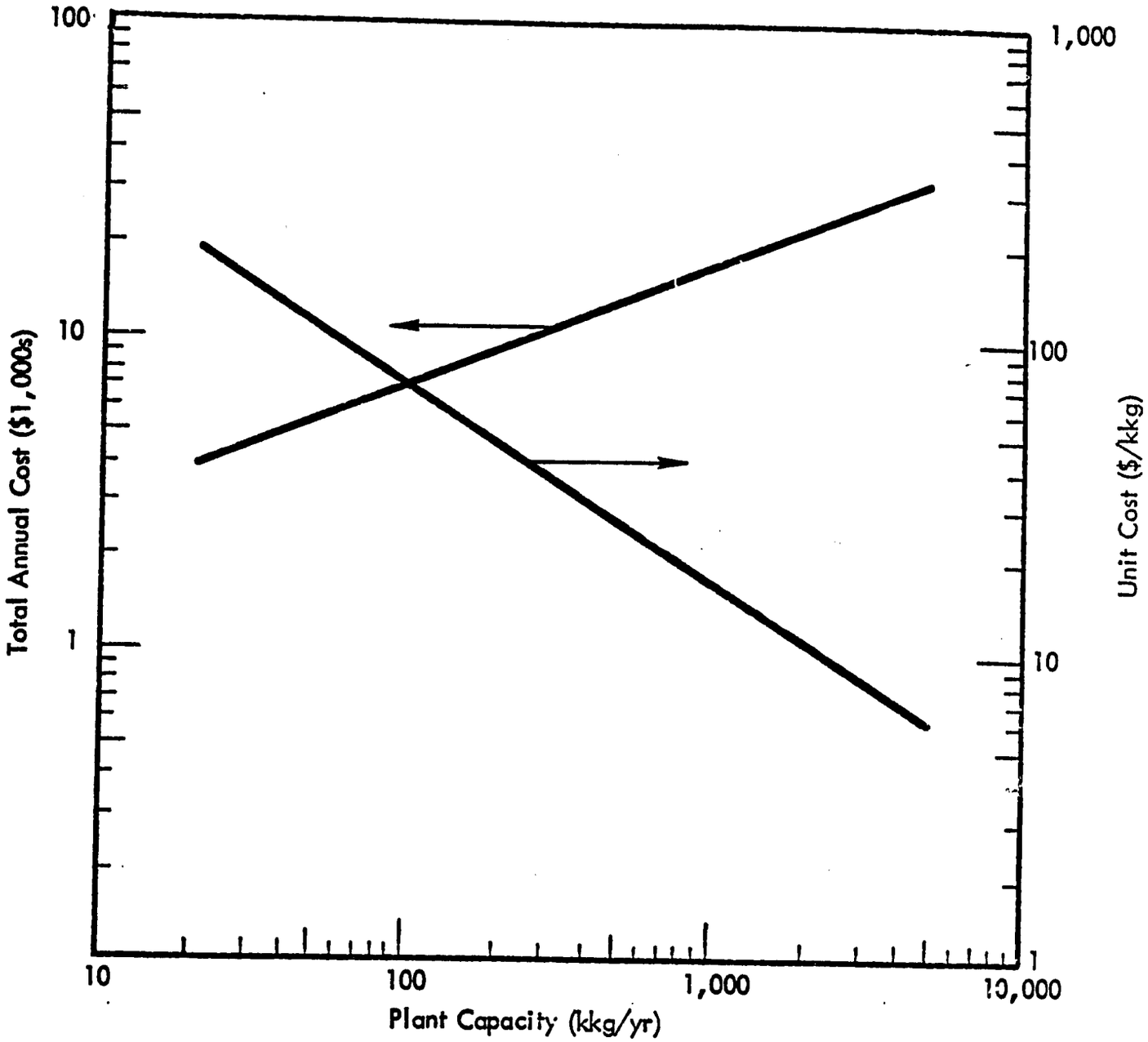


FIGURE 4-60
WATER POLLUTION CONTROL COST:
BLUE CRAB CANNING
PRIMARY TREATMENT

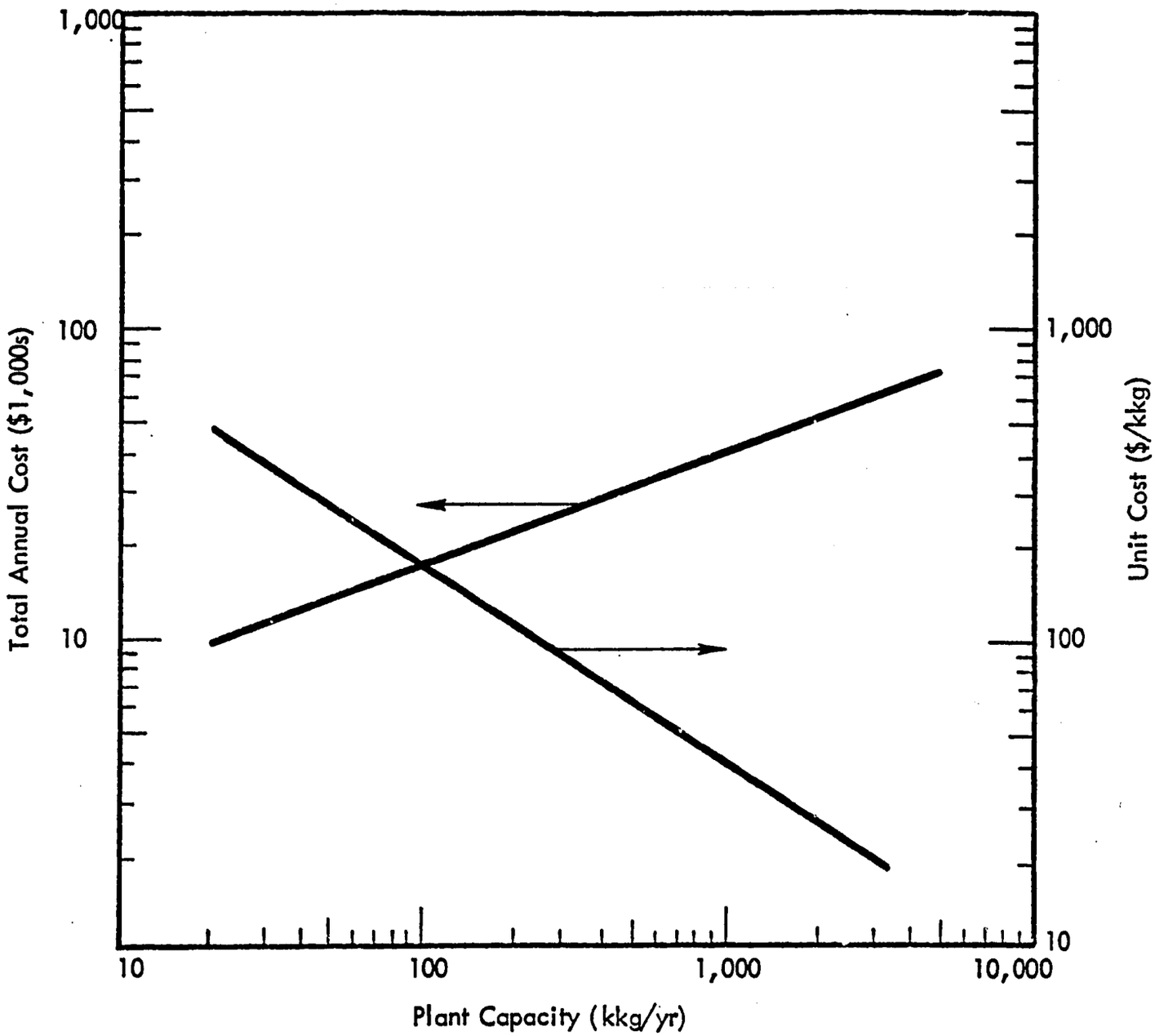


FIGURE 4-61
WATER POLLUTION CONTROL COST:
BLUE CRAB CANNING
SECONDARY TREATMENT

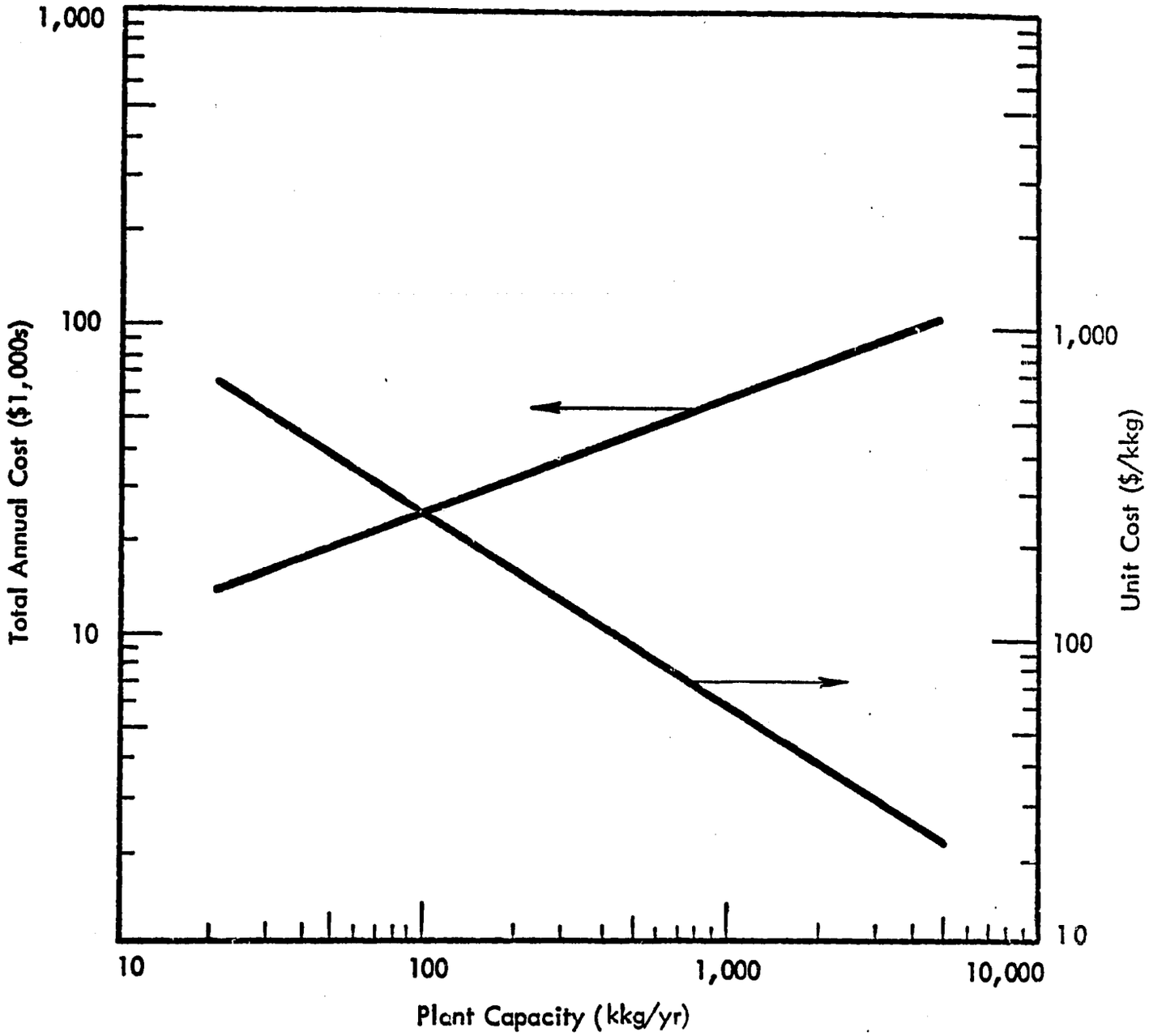


FIGURE 4-62
WATER POLLUTION CONTROL COST:
BLUE CRAB CANNING
TERTIARY TREATMENT

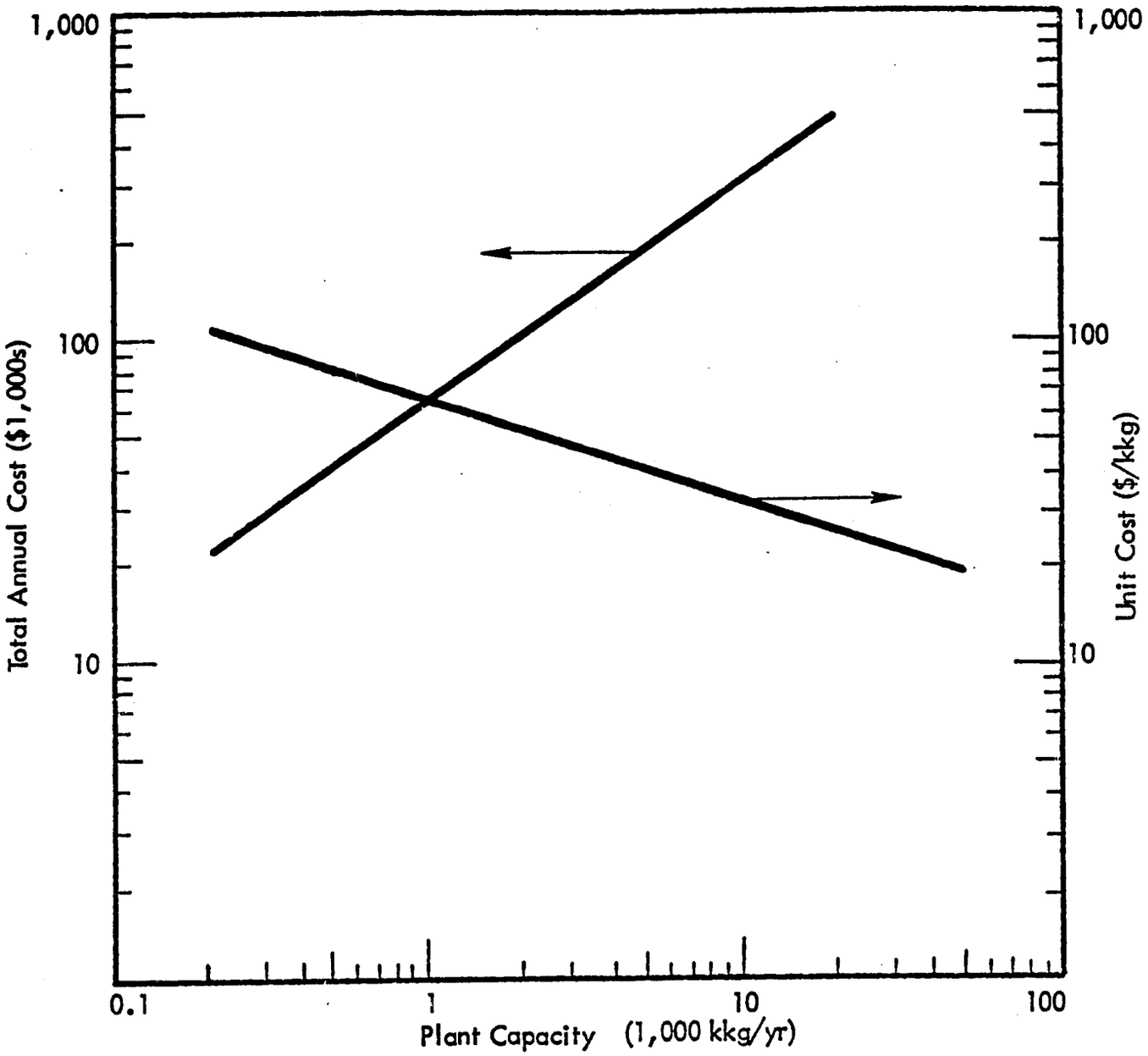


FIGURE 4-63
WATER POLLUTION CONTROL COST:
SHRIMP CANNING
PRIMARY TREATMENT

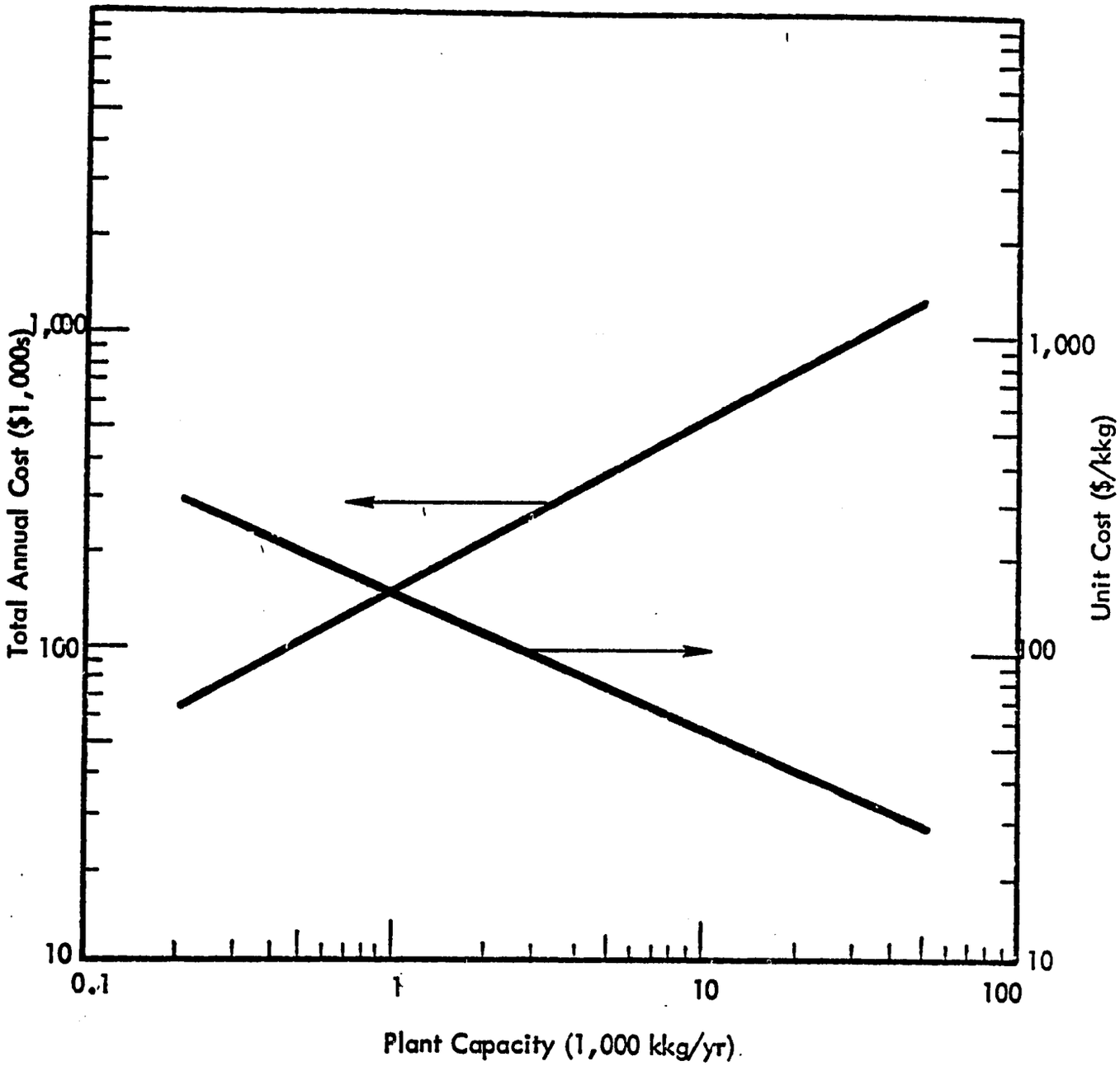


FIGURE 4-64
WATER POLLUTION CONTROL COST:
SHRIMP CANNING
SECONDARY TREATMENT

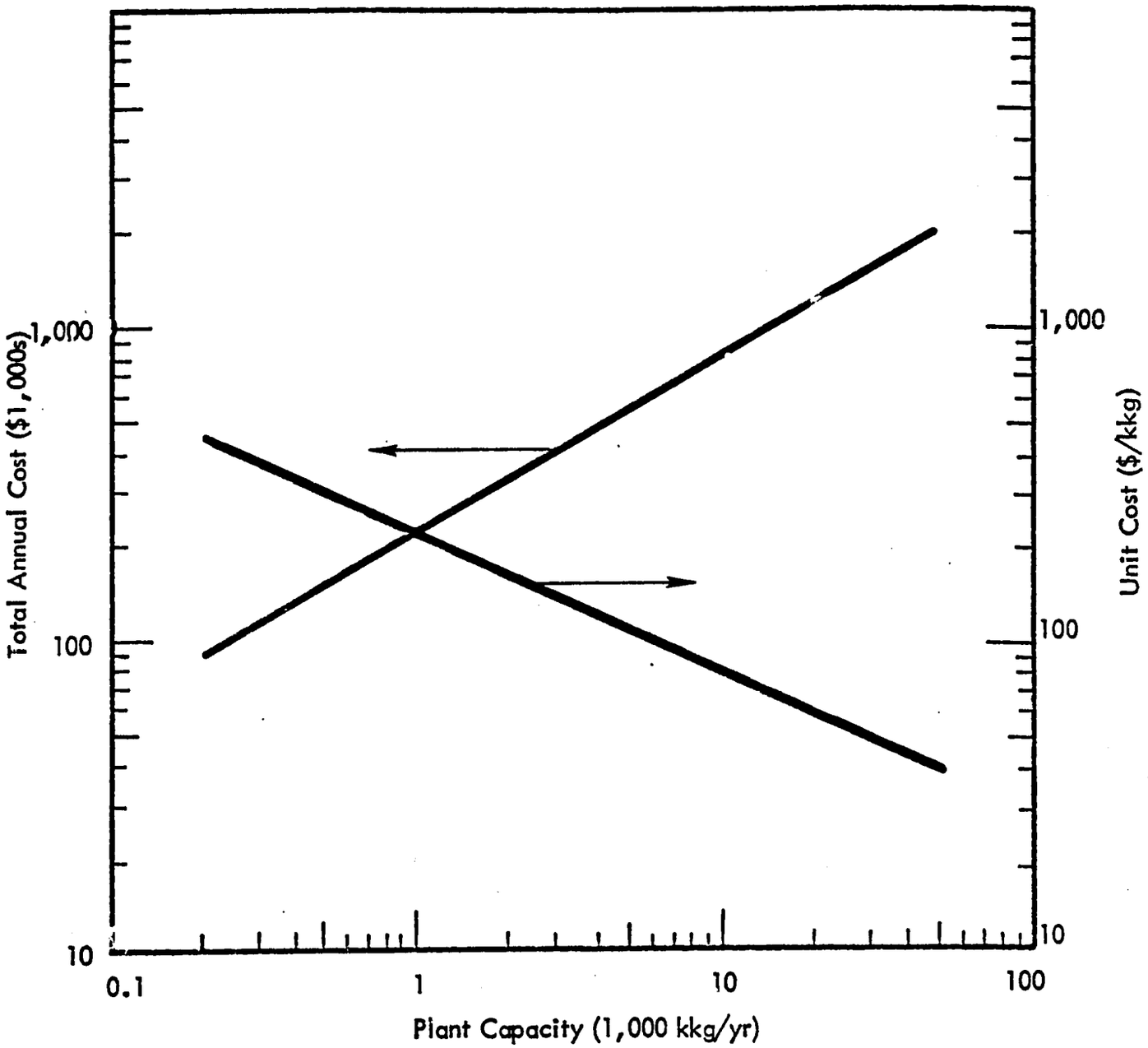


FIGURE 4-65
WATER POLLUTION CONTROL COST:
SHRIMP CANNING
TERTIARY TREATMENT

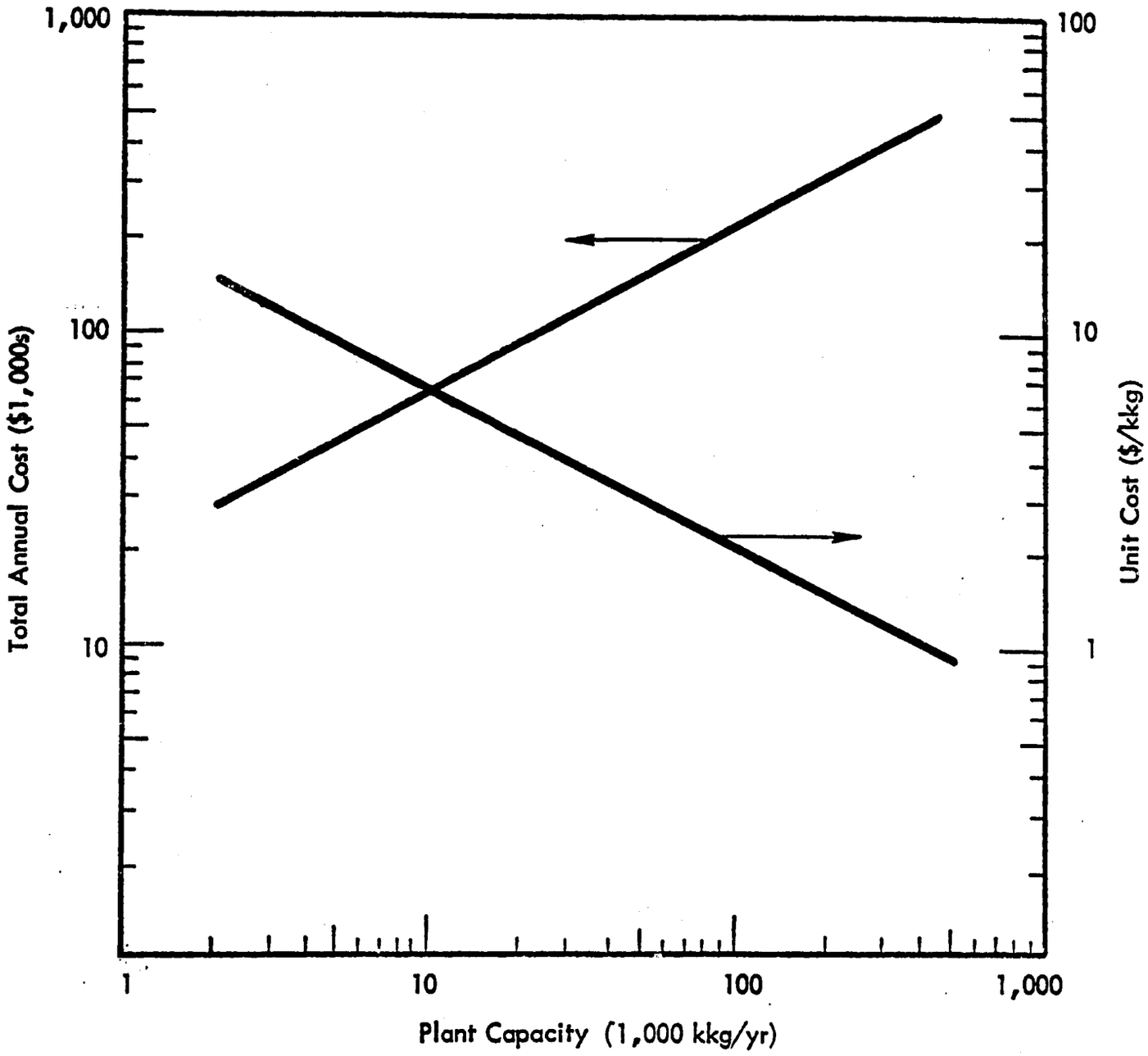


FIGURE 4-66
WATER POLLUTION CONTROL COST:
TUNA CANNING
PRIMARY TREATMENT

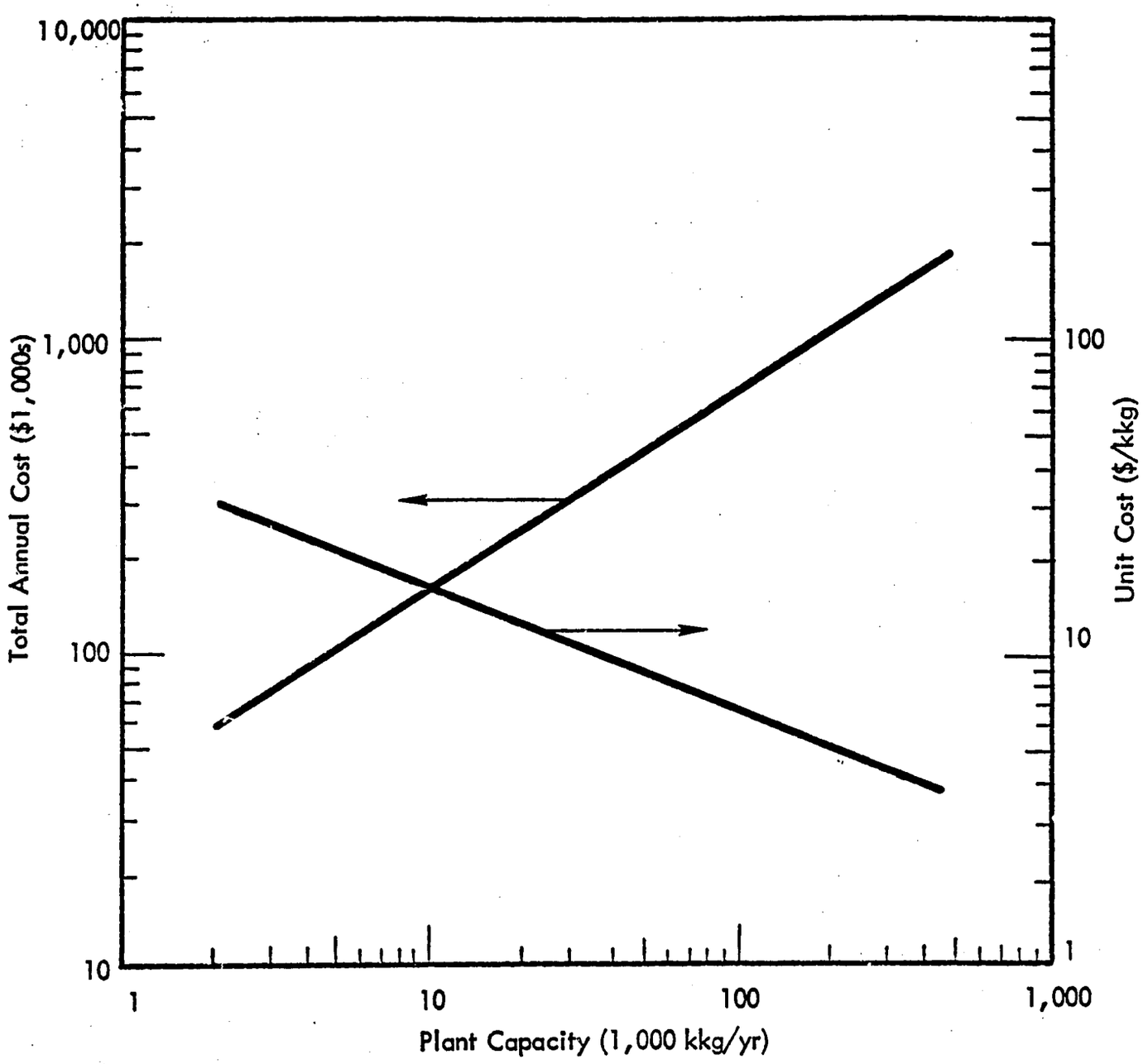


FIGURE 4-67
WATER POLLUTION CONTROL COST:
TUNA CANNING
SECONDARY TREATMENT

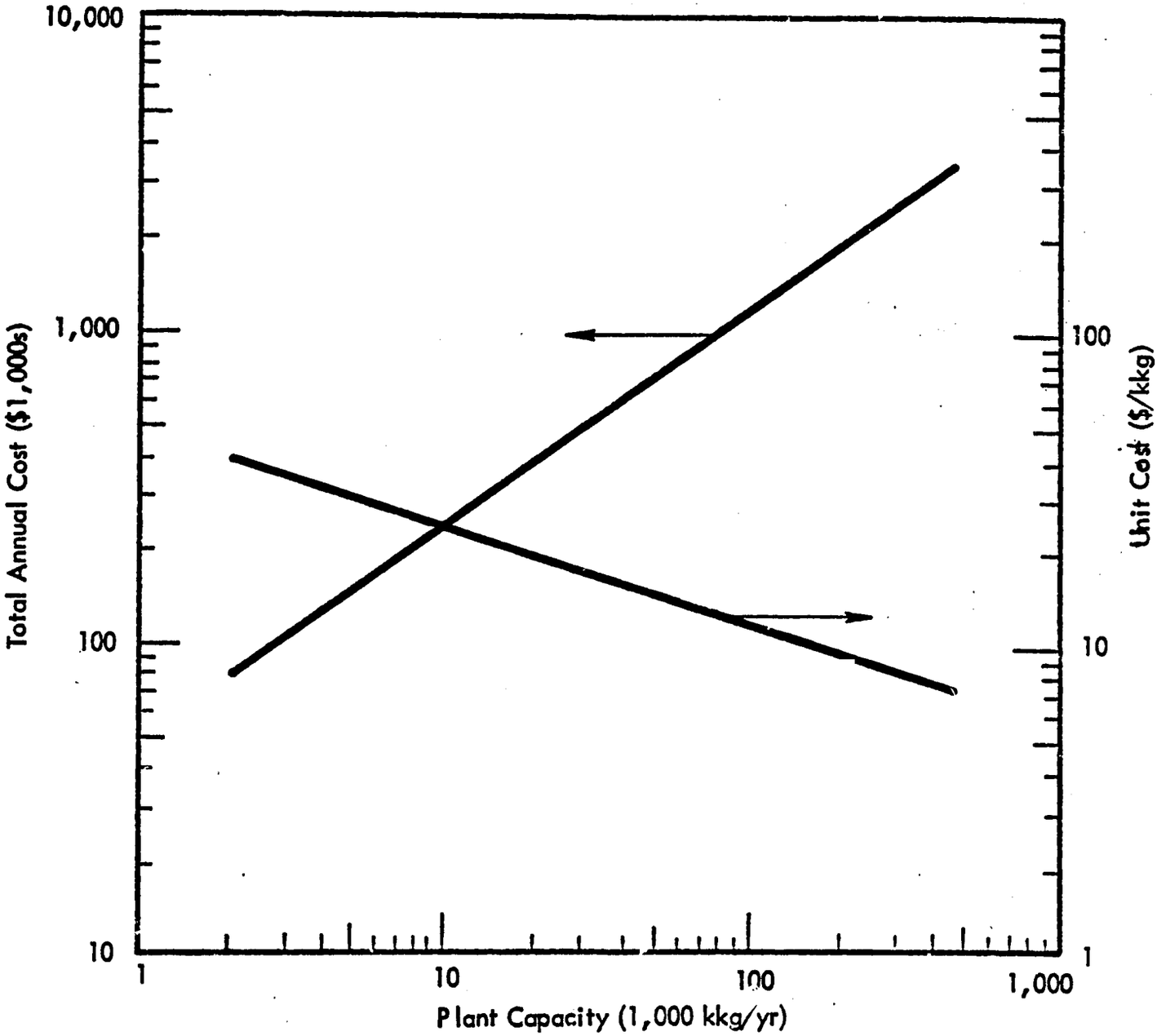


FIGURE 4-68
WATER POLLUTION CONTROL COST:
TUNA CANNING
TERTIARY TREATMENT