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Treatment of Wood Preserving Wastewater

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Texas A&M University

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TREATMENT OF WOOD PRESERVING WASTEWATER

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ABSTRACT

The wastewater produced by the wood preserving industry presents a difficult problem to treat economically. A review of the literature indicates the size of the industry has limited the pursuit of an orderly and economic solution. Atmospheric evaporation was one possible means of treatment which had not been studied to any great degree.

Two bench scale evaporation units were employed to determine the fundamental relationships affecting wastewater quality during such treatment. In batch evaporation tests, it was repeatedly demonstrated that a constant rate of total organic carbon and chemical oxygen demand removal occurred as the wastewater was evaporated.

A procedure for designing atmospheric evaporation ponds was developed and applied to a hypothetical wood preserving plant. From this example design estimates of equivalent hydrocarbon concentrations in the air downwind of the pond are made. Various other design considerations such as the input data, modifications to the design procedure, solids accumulation, and miscellaneous design aspects are discussed. A treatment scheme incorporating atmospheric evaporation ponds after chemical coagulation and settling is proposed.

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CHAPTER I

INTRODUCTION

In the past decade environmental pollution has become a major national issue. The concern for the environment exists on both local and national levels. Extensive legislation has been passed which provides for regulations, monitoring programs, discharge limitations, treatment plants, and research. Furthermore, goals which call for eliminating pollution sources and cleaning-up the environment have been set by Congress (12). As a result of such concern and in an effort to make man more compatable with his environment, the following research has been conducted in conjunction with the Texas Water Resources Institute (Project Number A-031-TEX) and the Environmental Engineering Division of the Civil Engineering Department at Texas A&M University.

Background Information

Pollution control in the wood preserving industry presents a complex and challenging problem to all involved with it. The wastewater discharged by the industry is very high in pollutants and their nature makes it very difficult to remove them. Also, the industry is very small in relation to the other industries of our industrial nation. This introduces many restrictions which interfere with an orderly and economical solution to the problem. Some of the restrictions are marginal economics, unskilled plant labor, and a strong competition in the market.

A better understanding of the problem can be developed by looking at it from the viewpoint of the three interest groups involved in implementing solutions. They are: (1) the regulatory agency, (2) the industry, and (3) the engineer. The regulatory agencies have been so involved with the pollution caused by major industries that adequate attention has not been directed toward the wood preserving industry. However, they are aware of this industry's problem, and the Environmental Protection Agency has acknowledged that the 1985 goal requiring zero discharge will not be applied to most of the wood preserving industry (11).

The industry, on the other hand, has made some progress in pollution control research and the installation of pollution abatement equipment. In most cases, however, this work has followed the demands of regulatory agenices and has been hastily installed. Many in the industry feel pollution control using current technology may not be economically feasible. The size of the industry requires that the pollution control measures must be not only economical, but effective and simple to operate.

The engineer is charged with developing solutions to each treatment problem. This can be very complex and requires further experimental work because the wastewater generated by each plant is different and, in most instances, toxic. The requirements that the treatment be economical, effective, and simple to operate impose an even greater burden on the engineer. It appears that treatment schemes for treating wood preserving wastes must be developed for the particular circumstances present at each installation.

This paper focuses on the wood preserving industry and the pollution potential associated with it. Specifically, one unit process, atmospheric evaporation, is examined for application to the disposal of wood preserving wastewaters. Atmospheric evaporation may be a feasible solution in some situations.

One advantage to the concept of atmospheric evaporation is that it is very simple. The waste is exposed to the atmosphere by spraying and disposed of by the process of evaporation. Spraying increases the surface area of water exposed to the air resulting in higher evaporation. A pond with spray nozzles and a recirculation pump would require very little attention for operation or maintenance. In southern regions natural conditions are such that the volume of waste produced could be evaporated without any discharge. Also, this treatment method would be dependable and relatively easy to construct.

A disadvantage to atmospheric evaporation is the land required. In rural areas this would not present a problem, but urban plants may be tightly confined. Also, the pumping required to spray the waste would result in an operational cost, and any pretreatment to prepare the waste for spraying would detract from the desirability of evaporation from an economic viewpoint. In addition, since the waste is being evaporated into the air some of the volatile compounds present in the raw waste would also evaporate and this might create an air pollution problem.

From this discussion it can be seen that there are some tangible complications to be dealt with in implementing atmospheric evaporation for wood preserving waste treatment.

This Study

Objectives

The purpose of this work is to closely examine the feasibility of applying atmospheric evaporation to wood preserving waste treatment. To fulfill this purpose several objectives have been established. These are to:

1. Examine the industry and characterize the wastewater generated by the industry.
2. Examine atmospheric evaporation as a treatment for wood preserving wastes by determining process fundamentals and a design procedure.
3. Examine the limitations in applying atmospheric evaporation to this industry's waste.
4. Propose feasible treatment schemes and design criteria for atmospheric evaporation systems.

Scope

The scope of the study consisted of: (1) a thorough literature review, (2) visiting numerous plants, (3) laboratory studies involving coagulation, settling, and evaporation, (4) evaluation of the data, and (5) developing a design procedure and criteria.

This report is organized into three major sections. The first section, the literature review, covers available information on the industry, its wastewater, and treatment technology. The second section is the experimental program which examines the wastewater and the treatment to develop pertinent relationships. The last section presents the design procedure for spray ponds and considerations to be used in designing atmospheric evaporation systems for wood preserving wastewaters.

CHAPTER II

LITERATURE REVIEW

This chapter presents an industrial waste survey based upon the existing literature on wood preservation and the pollution resulting from it. The chapter contains three major sections. The first is a description of the industry, the preserving processes, the perserving equipment, and the preservatives. The second discusses the wastewater, its characteristics and sources. And the third presents the treatments which have been tried on this wastewater. Together these three sections provide an insight into the problem of pollution control in the wood perserving industry.

Description of the Industry

The wood preserving industry plays an important role in America today. Such industrial groups as railroads, telephone companies, electric companies, and builders are all dependent upon treated wood to continue producing their products and services. Agriculture also utilizes large volumes of treated wood. Yet very few people realize that wood preserving products are so essential to modern lifestyle. The importance of preserving wood is to make it last until a replacement tree can be grown.

In Europe and the Old World, wood preserving has been practiced for centuries. However, the American wood preserving industry has only existed for about 140 years. In 1838, John Bethell first patented a wood preserving process in the United States. Twenty years later the first U.S. pressure treating plant was built (48). As the nation grew industrially in the nineteenth century, the importance and growth of wood preserving became significant. The twentieth century saw continued growth until the Great Depression. Following the recovery from the depression, the demand for preserved wood has plateaued. In recent years, the demand has fluctuated considerably as shown in Figure 1.

Based upon a 1974 survey (54), there are approximately 450 wood preserving plants in the United States; however, only 387 plants are known to be active. Over 350 of the active plants use pressure preserving processes and 96 percent are commercial operations. The geographic distribution of wood preserving plants in the United States closely follows that of the major forested areas as shown in Figure 2. Approximately 65 percent of the plants are located in the southern and southwestern states. This is a significant statistic concerning the feasibility of treatment by evaporation.

The most recent production figures (54) show that the total amount of wood treated in 1974 was close to 275 million cubic feet. The treating chemicals used were 208 million gallons of liquid preservatives and 85 million pounds of solid preservatives including fire retardants. Typical categories of products in order of volume produced are: lumber and timbers, railroad crossties, utility poles, fence posts, pilings, railroad switch ties, and utility pole crossarms. Typical liquid preservatives in order of volume used in 1974 are: creosote, creosote-coal tar, and creosote-petroleum.

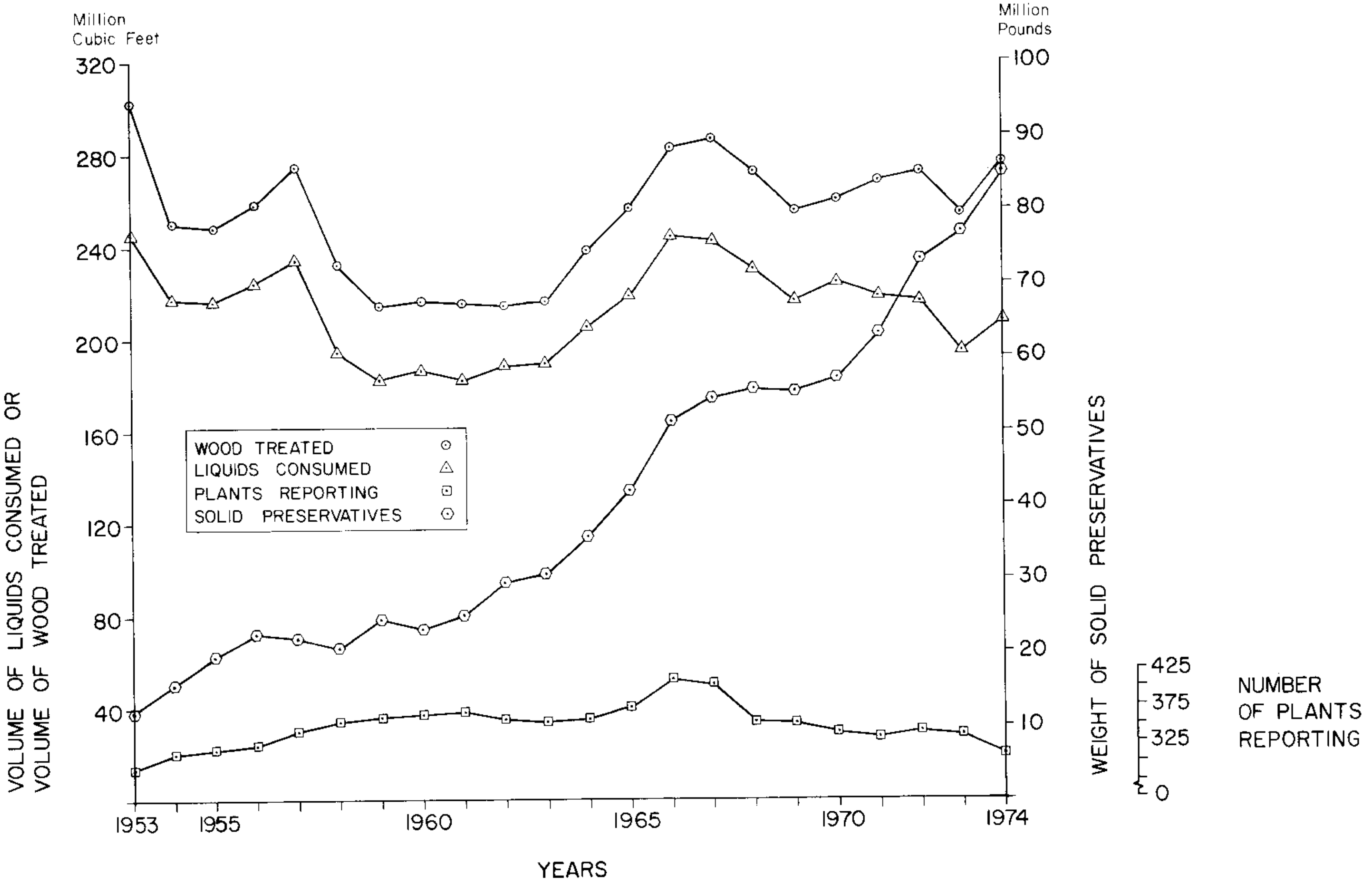


FIG. I. – Recent Production Trends in the Wood Preserving Industry (54)

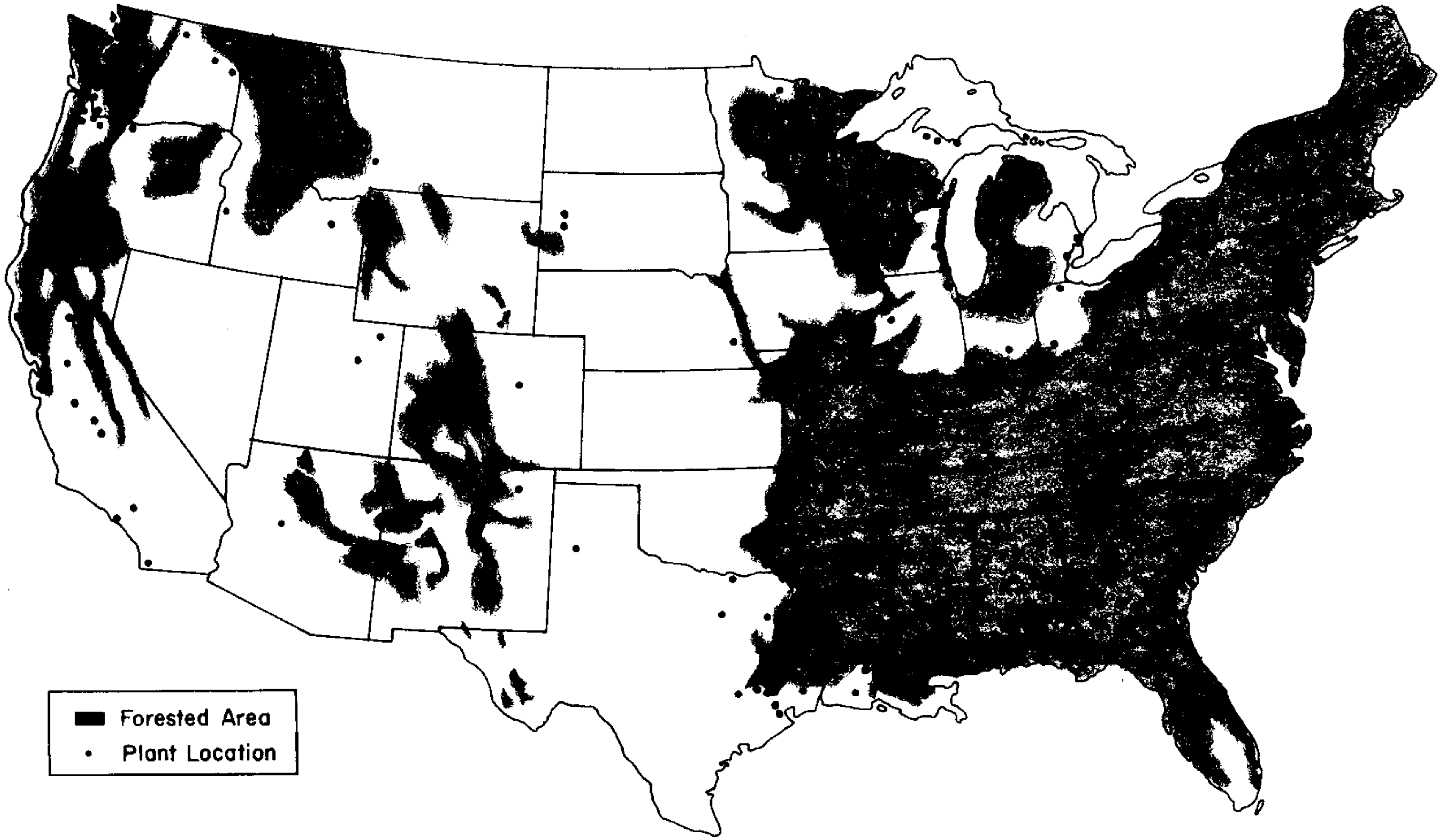


FIG. 2.– Geographical Distribution of Major Forested Areas and Wood Preserving Plants in the United States (5, 54)

Solid preservatives are pentachlorophenol, fire retardants, chromated copper arsenate, acid copper chromate, fluor chrome arsenate phenol, and chromated zinc chloride. Figure 1 depicts a graph which shows the amount of wood treated and the preservatives used over the past two decades.

The 1972 Census of Manufacturers (2) reports that there are 11,300 people employed by the industry. Table 1 shows a classification of establishments by number of persons employed. Also this table shows the high ratio of production workers to the total workers employed. Equally significant is that the majority of plants employ less than twenty persons.

Economic Considerations

The economic nature of the wood preserving industry has already been described in a general sense. In Table 2 some specific Bureau of Census (2) statistics are given. Although the volume of business has increased, as evidenced by the changes in the value of the industry's shipments, the margin of profit has remained relatively the same from 1967 to 1972. Considering five years of inflation, a net decrease in profit is realized. Such statistics show that the industry may be somewhat justified in minimizing expenditures on non-productive operations like wastewater treatment plants. However, there are many pollution control practices which are economically justifiable. For example, gravity settling of the raw wastewater allows some of the valuable preservative to be recovered. Good

TABLE 1. - Employee Distribution in the Wood Preserving Industry (2)

Average Work Force (1)	Total Number of Establishments (2)	Total Number of Employees: All Employees (3)	Total Number of Employees: Production Workers (4)
1 to 4	116	200	200
5 to 9	48	300	300
10 to 19	67	900	700
20 to 49	90	2,900	2,300
50 to 99	57	3,900	3,200
100 to 249	20	3,100	2,500
250 to 499	1	-	-
Total	399	11,300	9,200

TABLE 2. - Economic Status of Wood Preserving Industry in 1967 and 1972 (2)

Item (1)	1967 (10^6 dollars) (2)	1972 (10^6 dollars) (3)	Increase (percent) (4)
Manufacture	135.6	175.8	29.6
Payroll	61.9	74.5	20.4
Operational Costs	214.5	303.6	41.5
Capital Costs	10.7	14.8	38.3
Shipments	344.2	475.8	38.2

in-plant housekeeping practices require no added expense but help control pollution. Efficient treating procedures stop pollution at its source. So, while there may be an economic restriction, much can be done with little monetary investment, and the returns may be realized financially.

Preserving Process

The process of preserving wood is relatively simple in concept. The outer layers of a piece of wood are impregnated with a solution which will inhibit the deleterious growth of microorganisms. The penetration of a preservative solution may be accomplished by soaking or by pressure impregnation. Pressure treatment processes are by far the more popular and effective. Approximately 91 percent of the plants surveyed in 1975 had pressure preserving equipment (54).

Equipment. A pressure preserving system is usually composed of the following basic elements: the pressure cylinder (retort) and trams, the boiler system, an air compressor, pressure pumps, a vacuum source, and the working tanks. The retort is a steel cylinder usually from three to eight feet in diameter and from 30 to 150 feet long (54). One end of the cylinder is closed while the other has a circular door which opens on hinges and is either bolted or hydraulically sealed. Often at the closed end there is a drain or tail valve. Inside the cylinder, there are usually steam coils in the bottom and two ledges which support the tram wheels. The trams are carriages which are loaded with wood and rolled into the retort. The tram tracks have a removable section at the retort door which are put in place when the door is open.

Steam is used to heat the preservative, to maintain pressure in the retort, to prepare the wood for treating, and to clean the treated wood. The boiler system may be open or closed. In an open system, the boiler steam enters the cylinder live and forms a condensate which is removed through a steam trap. In closed steam systems, the steam is kept segregated in coils which run through the bottom of the cylinder.

The air compressor, when present, is usually a large industrial type. In other uses, air pressure may be used to force the preservative or other liquids out of the retort.

The pressure pumps commonly are positive displacement piston types or centrifugal types. They provide the pressure used in preserving and may serve to move the preservative between the cylinder and the working tanks.

A vacuum is usually supplied by a barometric condenser or a vacuum pump with a surface condenser. In a barometric condenser system, a vacuum is produced by a steam ejector. The vacuum lowers the pressure and draws vapor out of the retort. These vapors are condensed by a spray of water in a barometric condenser or by heat transfer in a surface condenser. The resulting liquid is referred to as condensed vapor and contains volatile organic compounds and water. This is distinguished from condensate which is the steam which condenses inside the cylinder and is removed from the tail valve. A vacuum is also a necessary step in some preserving processes.

The working tanks hold the preservative while it is not in use. These tanks are similar to large oil storage tanks, except that they usually have steam coils to maintain the preservative at or near the preserving temperatures.

In addition to these major components, there is a conveyance system of pipes which transport steam, preservative, air, vapors, and waste to and from the cylinder. Many valves and steam traps make this system susceptible to many repairs.

Process description. There are many different processes and variations which are used in pressure treating wood. Each installation will have its own preserving procedure, but some generalizations and trends can be made. The preserving process can be broken into six different operations: (1) debarking, (2) seasoning and preparation, (3) preconditioning, (4) preserving or impregnation, (5) cleaning, and (6) cooling. The operations are assembled into a process flow chart in Figure 3. Each operation is identified by the various subprocesses associated with it. One or more of these subprocesses may be used to accomplish a particular operation. Also, the type and quality of wastewaters (dashed lines) that could be generated by each step are indicated. Of course, the wastewater characteristics are dependent on the subprocess and the equipment

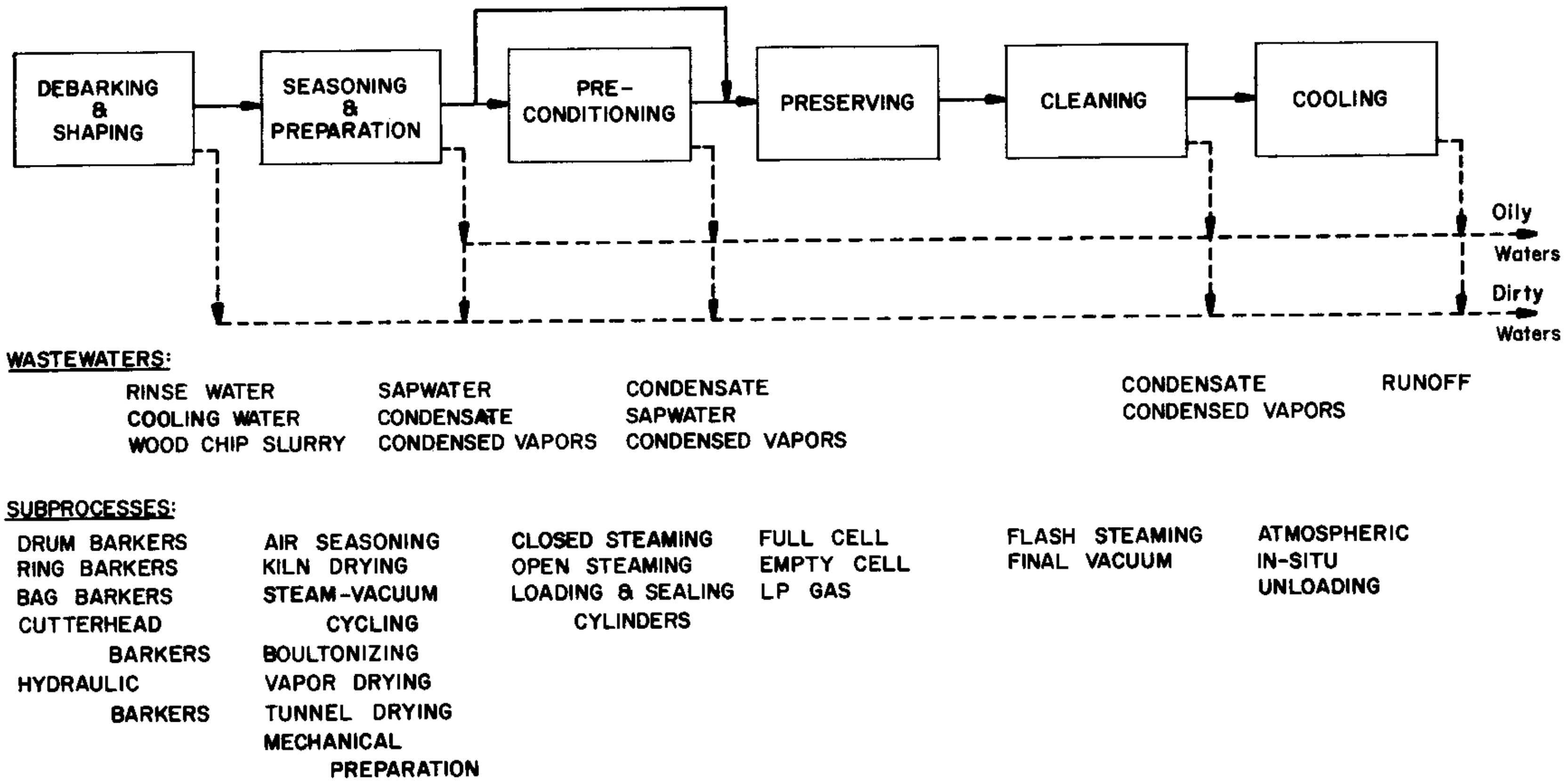


FIG. 3. – Typical Pressure Wood Preserving Process Flow Chart

used. This flow chart should evidence the many combinations of sub-processes which could and do exist.

The fresh sap wood after being felled and debarked has a moisture content of one to two times the dry weight. This water must be removed to allow the preservative to enter the pores and cells of the wood. Moisture removal is commonly accomplished by air-seasoning, kiln-drying, or steam-vacuuming. Air-seasoning involves allowing the wood to dry under natural conditions out of doors. This takes from one to twelve months and requires large areas of land for stacking the green wood. Also, unfavorable climatic conditions during wet months may greatly increase seasoning time (29). Kiln-drying is a rapid and effective method in which the wood is placed in an oven at 150-220°F and dried to the proper moisture content (25). The third method, steam vacuum drying, is conducted in a pressure vessel. This drying process is diagrammed in Figure 4 for closed and open steaming. Live steam is introduced into the retort or cylinder and the wood is steam-cooked for several hours. This softens the fibers and solubilizes the sap, resins, and bonding materials. Then the vessel is vented and a vacuum is applied to draw the sapwater from the wood. Successive cycles of steaming and vacuum can lower the moisture content to the desired level for preservation.

Boultonizing is a means of seasoning, shown in Figure 5, which is applicable only to oil-borne preservatives. The cylinder is filled with preservative and stabilized with steam at 150-210°F,

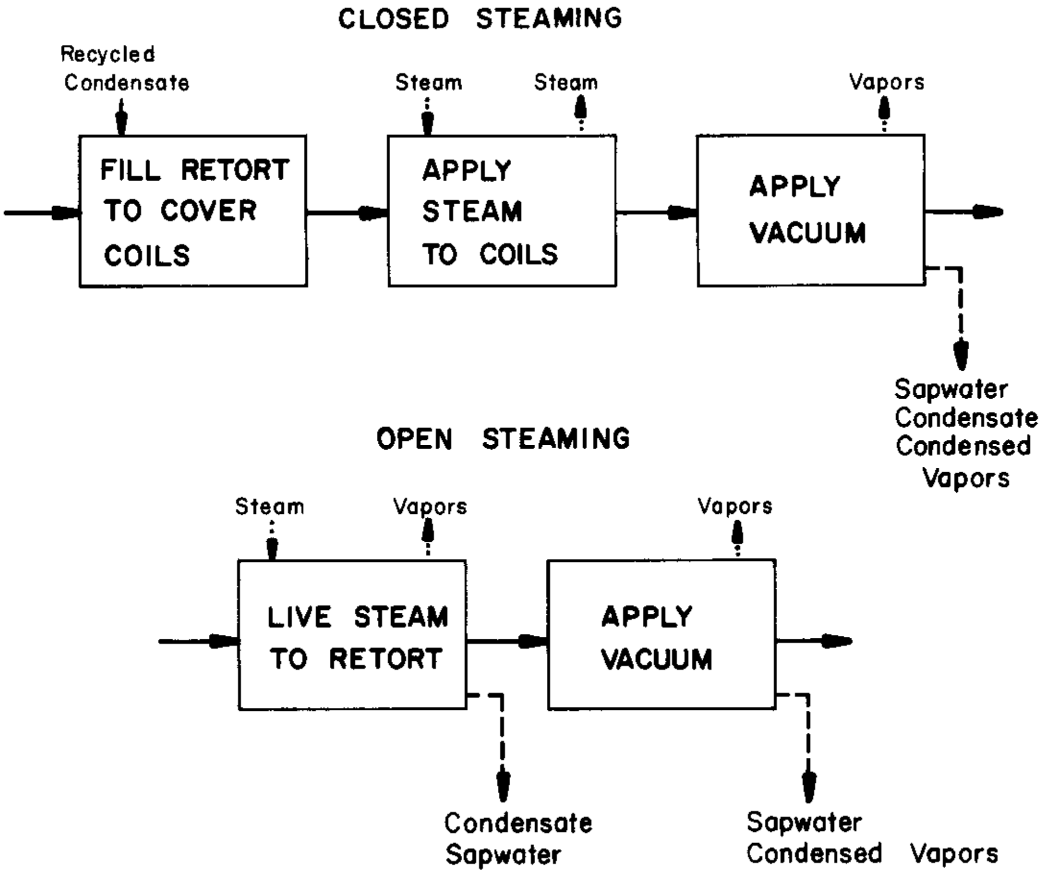


FIG. 4. — Steam-Vacuum Drying Process Diagram

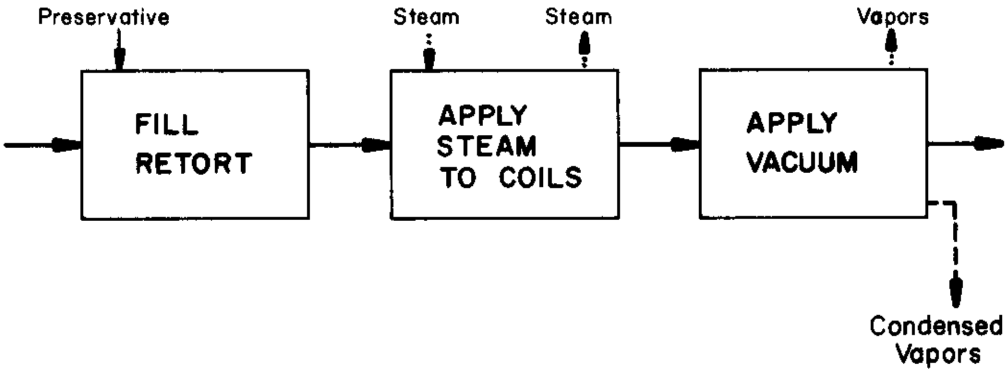


FIG. 5. — Boultonizing Process Diagram

then a vacuum is applied. The reduced pressure and high temperature cause the entrained moisture to evaporate. After seasoning, the charge can be immediately impregnated with preservative for full cell treatment. Empty cell treatment requires draining the cylinder before preserving. The vapors generated are condensed and create an oily wastewater. Boultonizing, when employed, is used mainly on Douglas fir and oak.

The vapor drying process uses a high boiling point solvent to evaporate the moisture within the wood. It is commonly used to prepare hardwood cross and bridge ties prior to oil-borne preservative treatment; however, either softwoods or water-borne preservatives can be used. In Figure 6 the vapor drying process is diagrammed. First the retort is purged, then the solvent is allowed to flow into the cylinder until the steam coils are submerged. Steam is applied to the coils boiling the solvent. The solvent vapors condense on the surface of the wood and heat the wood until the moisture boils out of it. The steam-solvent vapor mixture is withdrawn from the cylinder and condensed (25). Once condensed the solvent and wastewater separate readily by gravity. The liquid solvent is returned to the cylinder, and the wastewater leaves the process. When the drying process is complete, the cylinder is drained of solvent, and a vacuum is applied to remove the solvent vapors to the condenser. The wastewater produced is mostly sapwater appearing milky with a low pH.

After the moisture content has been lowered, the wood may be pre-conditioned to make it more penetrable. This step is generally

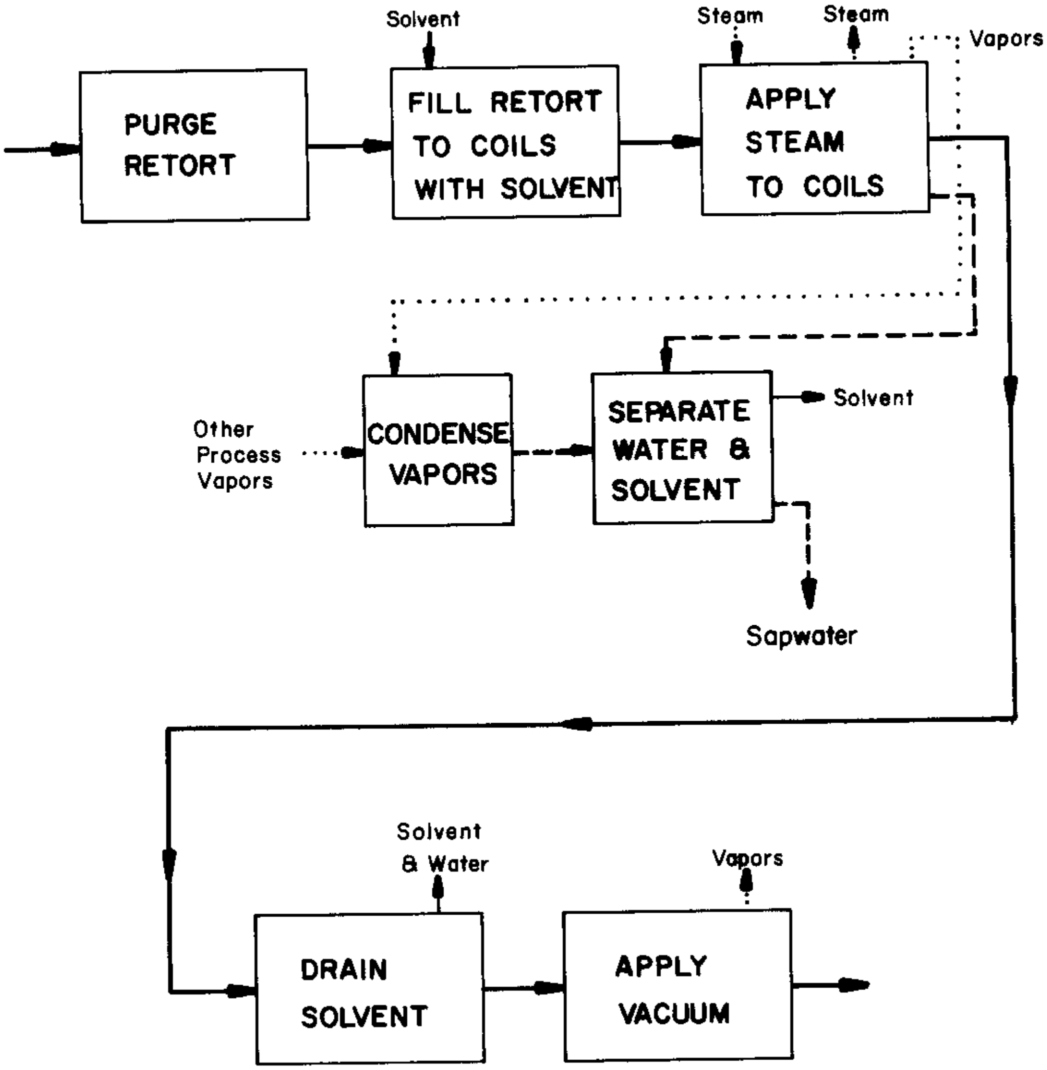
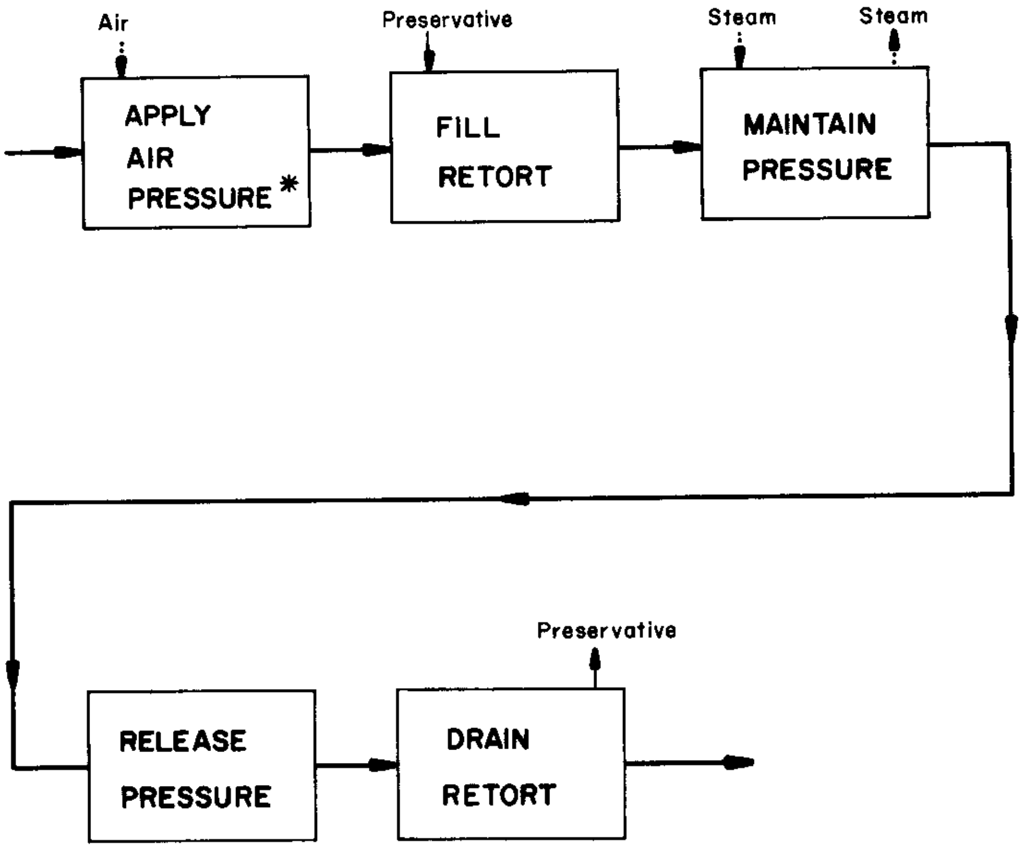


FIG. 6. — Vapor Drying Process Diagram

practiced but is not always necessary. The charge of wood is loaded into a pressure vessel or retort where steam and pressure are applied for several hours. Steam conditioning prepares the wood by opening the pores and passageways and dissolving portions of the intercellular resins. Following steam conditioning the wood is ready for preservative treatment.

The next operation is preserving which consists of impregnating the wood with the preservative. There are many variations to this operation, but basically, the cylinder is filled with hot preservative and steam is used to keep the preservative hot. Either steam or mechanical pressure is applied to force the preservative solution into the outer layers of wood. Common ranges of operating conditions are: a pressure of 90 to 200 psi, a temperature of 175 to 220°F, and a duration of 1 to 12 hours. The major treatments employed are the empty cell process, the full cell process and a patented LP gas system.

The empty cell preserving process, shown in Figure 7, is so called because the interior walls of the wood's cells are left coated with, but not full of, preservative. Producing a coated cell wall is accomplished by pressurizing with air prior to filling the retort with preservative solution. Air pressure is maintained as the preservative is added. This forces air into the center of the wood. After the wood has been penetrated with preservative to the desired degree, the pressure is released, and the air trapped inside the wood forces the preservative out. The cell cavities are left coated with preservative; yet, much of the treating liquid is



* No preliminary air pressure is used in some plants. Retort filled at atmospheric pressure.

FIG. 7. — Empty Cell Preserving Process Diagram

recovered. The same effect may be achieved without an initial air pressure by using the air entrained in the wood at atmospheric conditions, but more preservative is retained in the wood. The empty cell process is used on regular service items like telephone poles, fence posts, railroad ties, and lumber.

For heavier service conditions, especially marine exposure, the full cell preserving process, shown in Figure 8, is employed. Full cell treatment leaves the wood cells and pores nearly saturated with preservative. This is done by drawing an initial vacuum on the cylinder removing much of the air. The preservative is introduced without any air. Pressure is applied along with closed steam heating and maintained until the desired penetration is reached; then, the pressure is released, and the preservative is drained from the cylinder. Some air is left in the cell cavities, but a substantial amount of the preservative is retained. Typical uses of full cell treated woods are marine pilings, dock timbers, and any other timbers which are exposed to severe conditions.

Liquified petroleum (LP) gas systems utilize a low boiling point solvent such as butane to carry the preservative into the wood. An intermediate solvent may be required to make the preservative soluble in the LP gas. In this process the cylinder is initially filled with treating solution. Pressure is applied to force the solution into the wood until the desired penetration is attained. Then the pressure is relieved, the retort drained, and a vacuum applied. At the elevated temperature and lowered pressure,

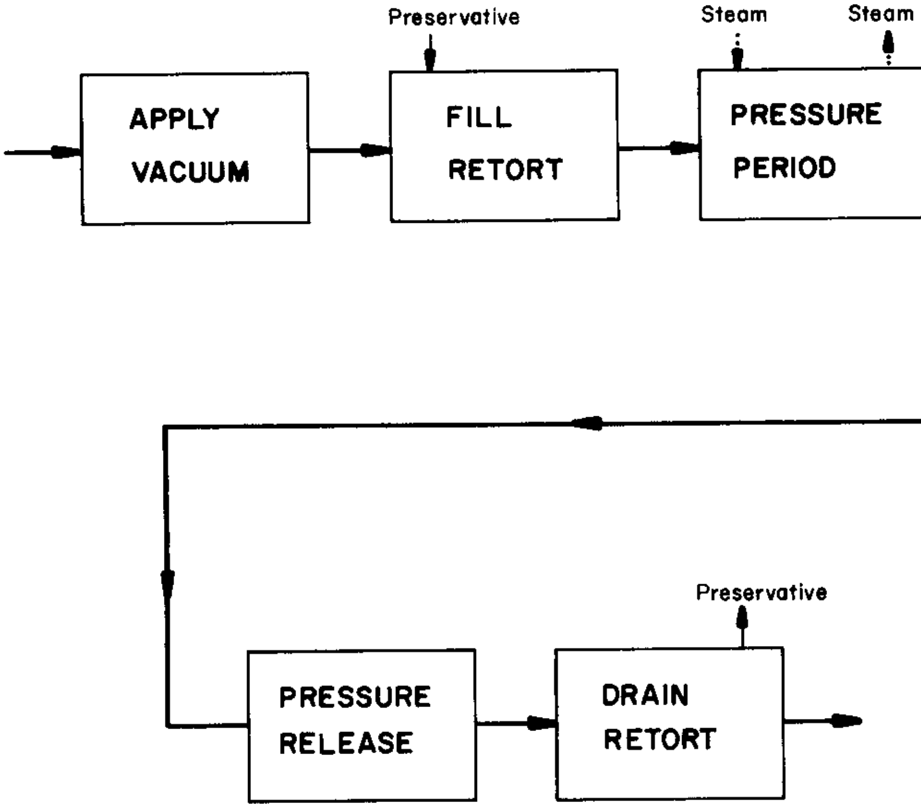


FIG. 8.— Full Cell Preserving Process Diagram

the carrier solvent boils off leaving the preservative impregnated in the wood. The solvent vapors can then be condensed, separated from any water, and recycled to the working tanks.

The next operation is cleaning which is shown in Figure 9. Upon completion of the impregnation step, the cylinder is drained. Steam is sometimes introduced then a vacuum is applied for one-half to three hours. The vacuum is then released. This final step cleans the surface of the poles to remove excess preservative which might bleed out eventually.

After cleaning, the cylinder is then opened and the treated charge removed. When cool the charge is unloaded from the trams and placed in the yard awaiting shipment.

Each wood treating plant has its own treating procedure which varies somewhat from the general cases above. However, there are several variations which alter the effectiveness of the treatment and the quality of the wastewaters generated. The principal variations encountered are open steaming and closed steaming. Open steaming employs live steam from the boiler in the conditioning and preserving cycles. A waste source is generated by the steam condensate. Open steaming may be employed in either the empty or the full cell treatment process. In closed steaming, live steam from the boiler is kept in a closed system of coils in the bottom of the retort. For conditioning, the coils are covered with recycled condensate water which boils, thus creating steam inside the cylinder. For preserving, the coils exchange heat with the treating solution

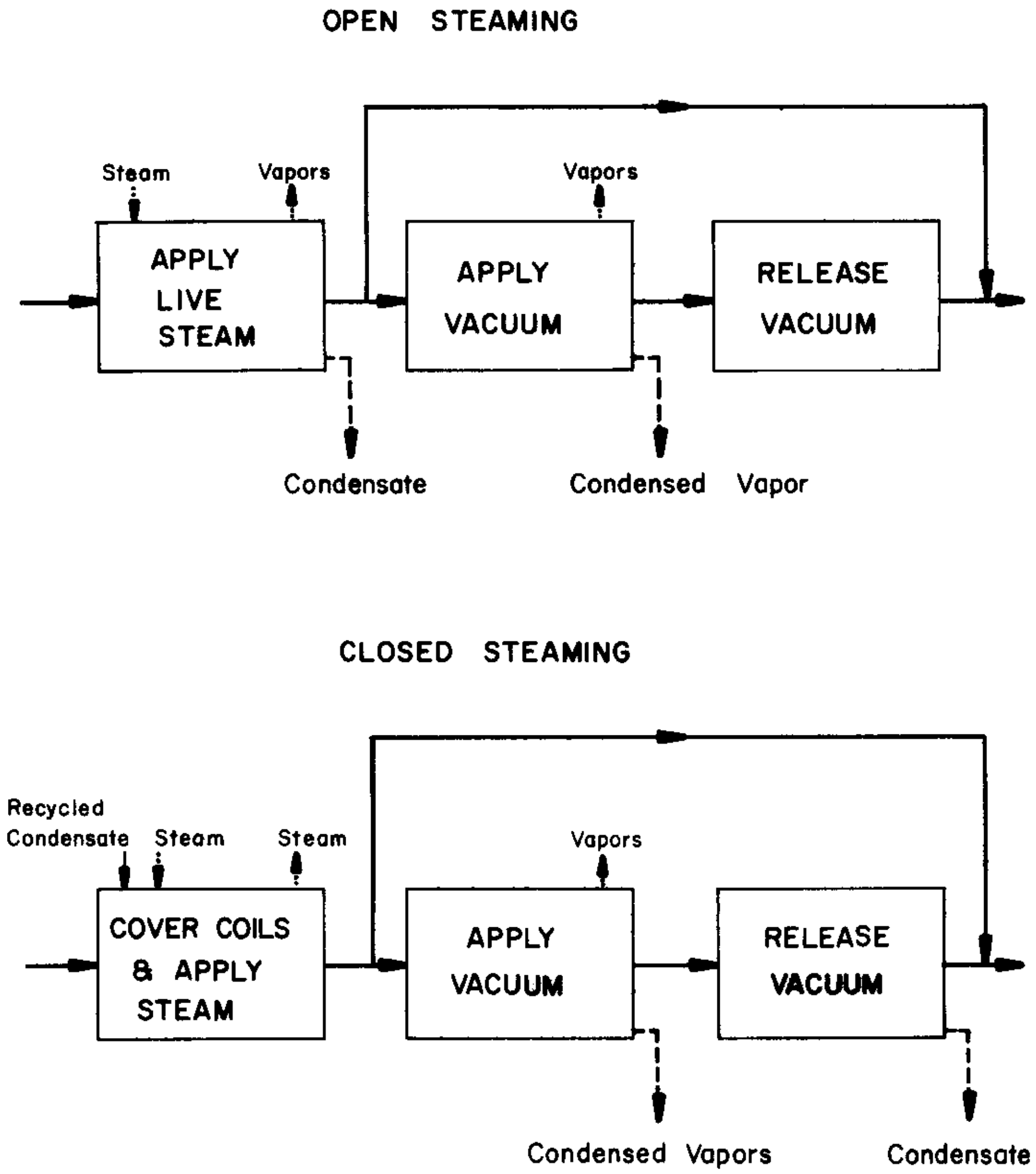


FIG. 9. — Cleaning Process Diagram

maintaining its temperature. Live steam may be required to maintain pressure within the retort. Closed steaming reduces the amount of condensate to a minimum thus decreasing the wastewater volume. It is applicable to both full and empty cell treatments.

Preserving Plant Wastewaters

The wastewaters from a wood preserving plant typically exhibit a high oxygen demand, a high turbidity due to emulsions, and an acid pH. They may contain considerable amounts of preservatives, phenols, oils, solids, and heavy metals. These characteristics vary considerably for each wastewater as shown in Table 3. The flows from various plants range from 2,000 to 60,000 gallons per day (gpd). These variations are due to the following factors: (1) the operations or process used, (2) the seasoning method employed, (3) the extent of water recycling and reuse, (4) the preservative used, (5) the time required for each operation, (6) the amount of wood treated per charge, and (7) the type of wood treated.

Wastewater Sources

One way to classify wastewaters in a wood preserving plant is by their point of origin. Sources of wastewater include: process waters, boiler system wastes, and plant runoff (drainage). Each source category contains wastewaters of varying volume and characteristics. The process waters are the most significant source of

TABLE 3. - Reported Characteristics of Wood Preserving Wastewaters from Oil-borne and Water-borne Preservative Treatments

Parameter (1)	Oil-Borne (2)	Water-Borne (3)
Flow, gpm	1-45	20-50
COD, mg/l	900-110,000	1,700-4,100
BOD_5, mg/l	350-26,800	-
Phenols, mg/l	13-2,350	<1.0-30
Oils, mg/l	6-3,060	-
Dissolved Solids, mg/l	243-18,350	-
Suspended Solids, mg/l	8-1,844	-
pH	2.1-7.4	5.0-5.3
Copper (Cu), mg/l	-	0-170
Chromium (Cr), mg/l	-	375-475
Arsenic (As), mg/l	-	180-300
Fluorine (F), mg/l	-	590-740
Phosphates (PO_4), mg/l	-	640-820
Ammonia (NH_3), mg/l	-	1,260-1,340

Note: Oil-borne values based on 26 wastewaters reported in the literature including creosote, pentachlorophenol, and mixed wastewaters. Water-borne figures after Jones and Frank (27) and Russell (37).

pollution in a wood preserving plant. They include condensates and emulsions drained from the cylinder bottom, condensed vapors from the vacuum system, liquids extracted from the wood, and retort door drips when collected. The wood treating operations which generate process wastewaters are indicated on the flow charts for various wood preserving processes, Figures 4 through 9. The general nature of the wastewater (i.e., condensate, sapwater, etc.) is also indicated on the diagrams. The type of condenser and means of applying steam heat can affect process wastewater characteristics considerably. Boiler system wastes are primarily blowdown, cooling water, and water softener recharge brine if needed. Plant runoff waters typically are intermittent and result from rainfall upon the treating area and yard, steam cleaning and washing of facilities, and mechanical equipment leaks. All or a certain portion of these runoffs may be added to the wastewater system. Otherwise, they might be discharged separately as drainage. Although the general source classifications are fixed, specific sources vary widely from plant to plant.

Wastewater Volumes and Characteristics

Most of the wastewater sources contribute wastewaters that may be classified as oily, dirty, or clean. Oily wastewaters contain emulsions of preserving oils in water. They are commonly generated when hot condensates and steam come in contact with preserving solutions or surfaces coated with such oils. Typical properties are a high oil content, extreme turbidity, phenols, and a characteristic "coffee with milk" color. Usually sapwater is present in oily wastewaters. Sapwater is the water extracted from the wood containing wood sugars, lignins and tannins, acetic acid, and other such soluble plant material. In addition, a considerable number of cellulose fibers are present. Typical characteristics for sapwater are high organic content, low pH, little color, and low suspended solids. Dirty wastewaters include some process wastewaters, contaminated plant runoff, equipment cleaning wastes, and other polluted waters which do not fit into the above categories. Characteristics may vary widely but generally will include moderate oxygen demand, low suspended solids (depending upon the soil, amount of paving, etc.), slightly acid pH, and possible oils, phenols, and detergents. Relatively clean wastewaters are those which have low contamination, usually only one contaminant. These waters are suitable for recycling with very little or no treatment. Examples are cooling waters and runoff from plant building roofs.

Unfortunately, because of the small plant size the three wastewaters of varying quality are mixed together in one wastewater collection system. However, a small amount of data has been collected identifying the characteristics of the various quality waters. This data is very specific, usually being from the equipment and processes of one plant. Table 4 shows some wastewater parameters for creosote, pentachlorophenol, steam-vacuum drying, and vapor drying processes.

TABLE 4. - Wastewater Characteristics for Specific Types of Processes

Parameter (1)	Creosote Wastewaters (2)	Pentachlorophenol Wastewaters (3)	Steam-Vacuum Drying Wastewaters (4)	Vapor Drying Wastewaters (5)
Flow, gpd	2,000-10,000	-	15,000-50,000	5-9(gpm)
COD, mg/l	1,700-110,000	1,000-2,000	180-3,600	2500
BOD_5, mg/l	800-3,800	300-500	- -3,800	3480
Phenols, mg/l	35-1,700	0.5-50	2.5-380	145-160
Oils, mg/l	36-3,060	-	-	-
pH	2.1-7.4	-	4.8-5.6	3.8-4.2
References	63, 68, 49	58	63	2, 56, 68

In Figure 10 the results of tesing done by Thompson (42) on two plants illustrates the nature of the wastewaters generated. Figure 10 (a) shows the effluent from a single cylinder over a complete treating cycle of steaming, preserving, and cleaning. Figure 10 (b) shows the effluent fluctuations over one day in a plant with multiple cylinders employing modified closed steaming. While the effluent from one cylinder has a characteristic pattern, the overall plant flow behaves very irratically.

In-plant modifications which reduce pollution loads and improve wastewater quality have been studied by the industry (1,8,15, 16,43,45,49). The modifications fall into the following groups: (1) closed steaming, (2) modified-closed steaming, (3) steaming time reduction, (4) condenser water reuse, and (5) plant sanitation. Closed steaming is a practice which is very effective at plants using steam-vacuum drying. It consists of reusing condensate in the steaming cycle by covering the coils with condensate and generating steam from this water. No live steam is entered into the cylinder and this eliminates the formation of emulsions which occurs in the steam trap during open steaming. Also, the volume of wastewater is reduced because boiler system steam condensate does not enter the wastewater. Typically, the COD is reduced to a third, oil content is reduced by up to 10 times, and the volume is reduced by 30 to 75 percent when closed steaming is practiced. These changes in the characteristics of a creosote wastewater as reported by Francingues (16) are shown in Table 5. The main disadvantage to closed-steaming

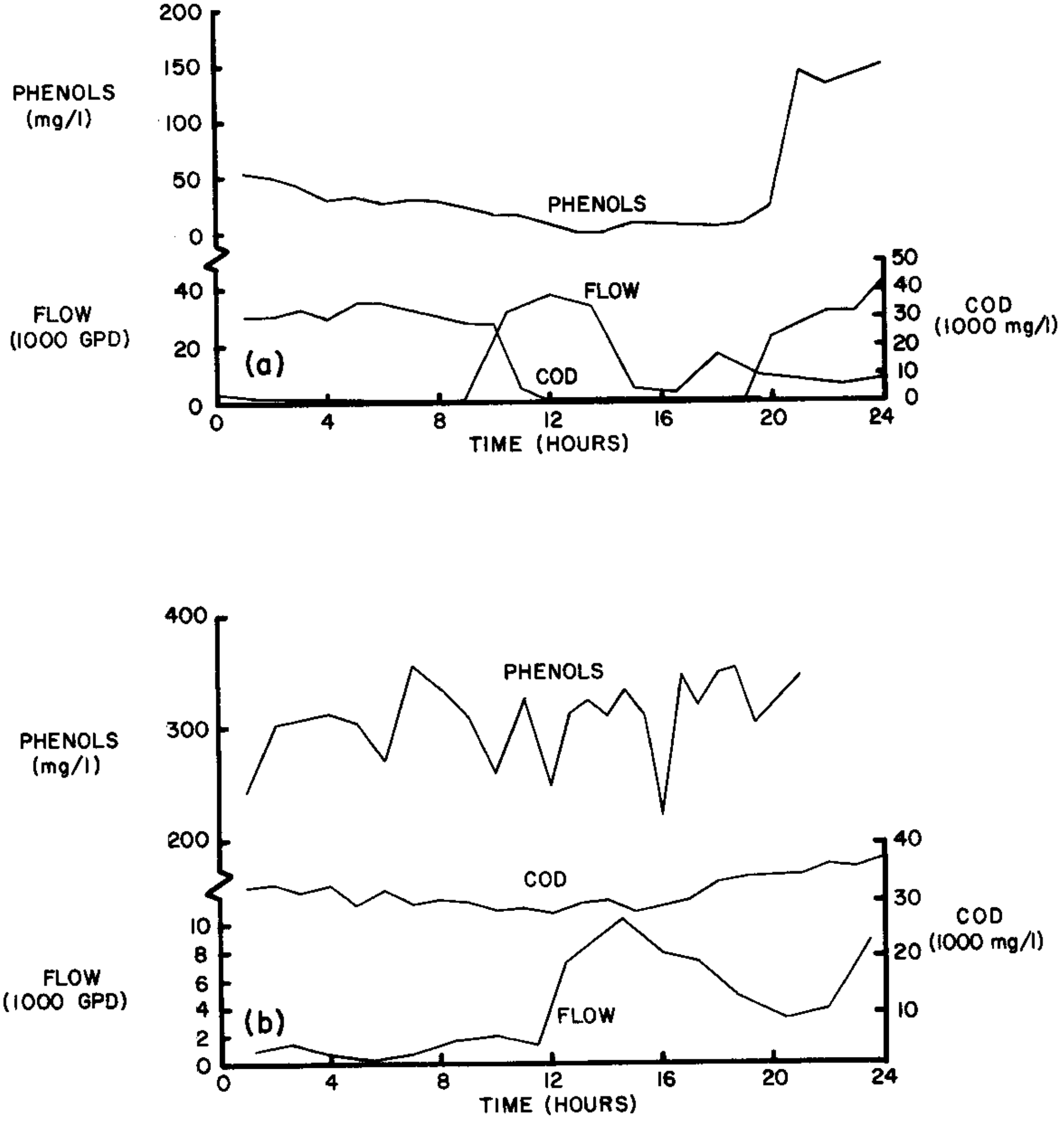


FIG. 10.- Variations in Wastewater Characteristics at Two Plants: (a) a single cylinder during a treating cycle; (b) plant flow from several cylinders using modified-closed steaming (42)

TABLE 5. - Effect of Changing to Closed Steaming on a Creosote Wastewater (49).

Parameter (1)	Open Steaming		Closed Steaming	
	Range (2)	Average (3)	Range (4)	Average (5)
Flow, gpd	-	10,000	-	7,000
COD, mg/l	10,200-69,500	42,400	3,030-29,800	17,200
Phenols, mg/l	50-208	143	35-323	137
Oils, mg/l	285-3,060	1,050	36-571	161
pH	2.1-5.9	4.5	3.7-5.2	4.1

is that it increases steaming time in the steam-vacuum drying process by 30 minutes to 2 hours to heat the condensate in the cylinder.

Modified-closed steaming was developed to overcome this problem. In this modification, live steam is allowed to enter the retort until the condensate covers the coils, then the live steam is discontinued and the coils are heated to produce steam from the condensate. This results in similar reductions in COD and oil content, but the volume reduction is not as significant.

Any reduction in steaming time reduces the pollution contributed by steam-vacuum drying. Some process modifications of temperature and pressure to reduce steaming time have been studied but further research is needed in this area (45). The use of kiln-dried or air seasoned stock reduces the amount of steaming necessary.

Barometric condensers produce a large volume of wastewater if the cooling water is not recycled. Recycling increases the phenol content of the water, but greatly reduces the volume. Another alternative is to replace the barometric condenser entirely with a surface condenser and vacuum pump; thereby, reducing wastewater generation from the condenser to a minimum.

The final in-plant modification is plant sanitation or good housekeeping. By containing equipment leaks and spills and controlling storm runoff, the contamination of relatively clean waters can be prevented. Since storm runoff volumes can be quite high, every effort should be made to contain and treat contaminated runoff, and prevent uncontaminated runoff from coming in contact with preservative saturated areas. Covering the treating and cylinder area and maintaining preservative collection pits around the retort are methods commonly used to control this problem. Runoff from the pole yard may vary from dirty to relatively clean water. Preliminary measurements by Thompson (43) gave COD concentrations of 34 to 335 mg/l and phenol contents of 0 to 7.7 mg/l in runoff from pole yards. Thus, on-site measurements of runoff quality are necessary to classify these waters.

Treatment Methods

The waste generated by the preservation of wood presents many problems to conventional treatment schemes. The combination of high organic loading, variable flows and characteristics, emulsified and free oils, and toxic materials make the wastewater difficult to treat efficiently. The cyclic nature of waste generation is difficult for most processes to handle. Many treatment processes cannot tolerate excessive oils. The toxic materials, and high organic loading impair biological treatments. Therefore, a combination of processes is usually necessary to effectively treat the waste to acceptable levels for discharge.

Present Status

A recent study by Thompson (46) gives insight to current treatment practices in wood preserving plants across the nation. The mail survey, conducted in 1974, covered replies from 270 out of 413 plants contacted. The categories and percentages for disposition of wastewater were: (1) release without treatment, 6%, (2) storage in ponds, 31%, (3) discharge to municipal sewer, 17%, (4) secondary treatment, 12%, (5) evaporation, 20%, and (6) miscellaneous methods, 16%. Miscellaneous methods included incineration and complete reuse. Plants which apply on-site treatment number 45 out of the 270 surveyed. By far the most popular on-site treatment was biological treatment (over 70%). Other secondary treatments were flocculation only (6 plants), unspecified chemical treatment (5 plants), and all three treatments combined (2 plants). Forty percent of the plants indicated they plan to change their means of treatment. The following shifts in treatment practice were indicated: five percent plan to discharge to municipalities, 11 percent will employ secondary treatment, 10 percent are to use evaporation, and 14 percent have a combination of other treatments. Pretreatment is employed by approximately 50 percent of those plants which discharge to municipal systems.

Based upon these figures and a survey of the pertinent literature, waste treatment in the wood preserving industry can be divided into six phases or technologies: equalization, free oil recovery, emulsion breaking, biological oxidation, chemical oxidation, and physical treatment. These six groups contain the basic unit operations and processes of environmental engineering which are classified as being physical, chemical, or biological treatments. Figure 11 presents the various treatments which can be applied to

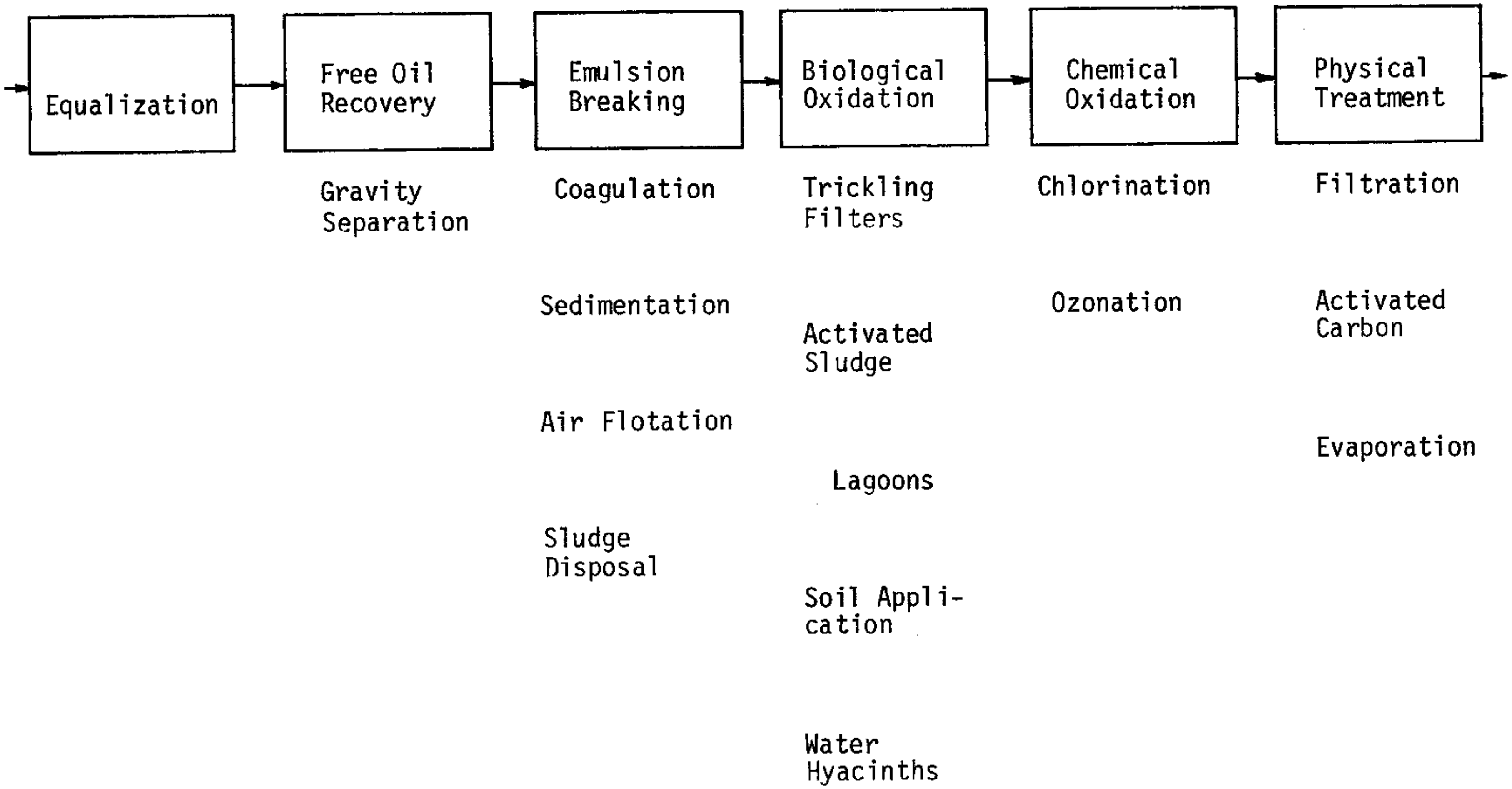


FIG. 11.– Wastewater Treatment Technologies in Wood Preserving

wood preserving wastewaters. Since these treatments are applied in the framework of technologies common to wood preserving, they shall be presented in that way.

Equalization

The wide variation in quantity and quality of a wastewater sometimes requires the use of a tank or basin to average out fluctuations. This is a prerequisite for many types of treatment. Common equalization practices include using separators for equalization also, batch operations with holding tanks, and holding ponds.

Free Oil Recovery

Treatment for removal of free oils is most commonly implemented by gravity separation or settling. It is a necessary step in any treating scheme and is usually implemented due to the economics of preservation recovery. Separation can be a batch or continuous-flow operation. In either case, a large tank volume is necessary to provide the required detention time and overflow rate and to reduce velocity gradients and turbulence. Fortunately, the majority of bulk oils present in the wastewater separate readily when quiescent conditions exist. Creosote and coal tar settle to the bottom, while pentachlorophenol-petroleum solutions float. Penta and creosote waste streams must be kept segregated, or the free oils will react forming a difficult emulsion which is neither bouyant nor settlable. Steck (40) points out that fluctuations in inlet temperature may affect the efficiency of oil spearators. Maintaining higher temperatures may improve the settling of many wood preserving wastes.

Dust and Thompson (8) describe the basic equipment for oil-water separation. For pentachlorophenol-petroleum wastes, one or more tanks in series with the capability of skimming oils from the top and withdrawing water from the bottom are all that is necessary. For creosote wastes, a horizontal tank with over and under baffles and provision for oil removal from the bottom and the surface usually suffices. Often an American Petroleum Institute (API) type separator is adequate. Free oil recovery from 60 to 99 percent has been reported for API separators used on refinery wastes (5,45). Efficiency is principally a function of time in a quiescent tank. Detention times greater than one day are common for separators in wood preserving plants.

Another means of recovery is air flotation. This is used to a limited degree in wood preserving plants. Air flotation is accomplished by saturating the wastewater with air, then discharging the air saturated water into a large tank. Upon exposure to lower pressure, the gaseous air in solution forms bubbles which rise, and these minute air bubbles attach to oil droplets which float to the surface. A skimming device then removes the surface layer of oil.

Emulsion Breaking

The source of and problems associated with emulsions have been previously discussed. After the recovery of free oils, as much as

1000 mg/l of oil may remain in the wastewater in an emulsified form. This suspension must be broken and the oils removed before further treatment is possible. Methods for recovery of emulsified oils are chemical treatment with de-emulsifiers and acid, hot and cold settling, and elaborate distillation-type system (23). Since most emulsion removal in wood preserving occurs after primary oil recovery, very little attention has been paid to recovering emulsified oils. Instead, the trend is to remove the emulsion without regard to recovering entrained oils. Chemical treatment with alum, lime, ferric chloride, polyelectrolytes, other iron salts, and acids is the predominant means of emulsion removal.

Many researchers have investigated various combinations of chemicals to coagulate emulsions into flocculent particles. Results vary widely and oftentimes information is not specific. It is recommended that each waste be tested to determine the best combinations of coagulants and coagulant aides. Lime has been very popular for wood preserving wastes. A brief review of prior work indicates concentrations of lime from 0.75 g/l to 2 g/l have removed from 50 to 70 percent of the COD in wood preserving wastes (6,9,30). Middlebrooks (30) found that alum with lime did not result in any better removal than lime alone. Caustic soda from 0.4 g/l to 1.0 g/l with about 0.5 g/l of lime was successfully used to achieve from 60 to 96 percent COD removal by von Frank and Eck (49). Dust (6) reported little improvement over lime alone occurred when an unspecified polyelectrolyte was used with lime. Gaskin (17) had success using caustic soda with lime.

Results from polyelectrolytes have varied from very poor to good, with removals of 80 percent or more (5,30,44). Recently developed polymers are generally much more successful. Ferric chloride is reported by Thompson as being effective but only within a narrow pH range (44). Some flocculated emulsions float and the addition of bentonite clay or lime may help settle this floc. Removal of flocculated emulsions is usually accomplished by sedimentation; but, in some cases, air flotation (5,17,23) and diatomaceous earth filtration (22) have been successfully employed.

Some COD removal data has been reported but a considerable amount of work has focused on phenol and pentachlorophenol (PCP) removal. Values for phenol removal range from relatively none or erratic behavior to 90 percent removal (6,9,17,27,30,35). PCP concentration after coagulation has been reported at undetectable levels (6), but generally it can only be lowered to its soluble concentration in water at that pH. Most PCP is associated with entrained oils due to its non-polar nature. In solvent theory, like substances attract, thus PCP will prefer oil to water. PCP is soluble in water to about 14 mg/l at 20°C.

Dewatering and ultimate disposal of the sludges is a necessary operation in any chemical coagulation process. Sludge drying beds resembling those used in municipal treatment are normally quite effective. Dust (7) found in field tests that a solids content of 25 percent could be produced in 18 hours on a sand bed overlaying gravel. Gaskin (17) describes an existing facility where 12 inches of sand over 9 inches of gravel has been used successfully for dewatering sludges.

Various mechanical units are available for sludge dewatering. Halff (22) achieved solids contents greater than 80 percent with vacuum filtration. Another filter-type device (38) produced a dewatered sludge with a 19 percent solids content using paper pulp and a polyelectrolyte. Centrifuging is another means available but little work has been done using wood preserving sludges; however, lime sludges from water or wastewater treatment are often centrifuged for dewatering. Ultimate disposal of sludges is normally by sanitary landfill. In the case of preserving sludges, efforts should be made to prevent contamination from leaching and percolation. This is particularly true at plants which use PCP.

Biological Oxidation

The use of biological oxidation to remove the organic materials found in wood preserving wastes has received much attention. In most cases, removal of emulsified oils to about 100 mg/l is necessary for biological processes; therefore, coagulation is a necessary preparation. Biological treatments which have been used are trickling filters, activated sludge, oxidation ponds, land application, and even lagoons with water hyacinths. Since all of these are biological systems, these treatments have some similarities. First, they are susceptible to upsets from variations in influent quality.

Second, toxic materials present a problem. And finally, all produce biological solids which usually require solids handling. Most require oxygen either artificially or naturally supplied.

The use of trickling filters on wood preserving wastes has been effective. A pilot plant study by Francingues on a creosote wastewater which had been flocculated with lime and a polyelectrolyte was conducted in 1970 using plastic media (14,16). COD removals from 40 to 75 percent were achieved with recycle ratios of 7, 14, and 28. Phenol removal was more sensitive to pH and nutrients but varied from 45 to 85 percent for the same recycle ratios. Loading rates of 121 lbs. COD/ft^3-day and 1.2 lbs. phenol/ft^3-day resulted in COD and phenol removals of 77 and 99 percent, respectively. Halff (21) applied the Galler and Gotaas equation to this data and had success predicting results, thus, providing an equation for filter sizing. Applications of trickling filters are common in refineries and petrochemical industries for reduction of phenols and other organic compounds (5,44).

The principal advantages of trickling filter are ammenability to shock loading, small land use, and low operating costs. However, initial investments which include the necessary pretreatments may be expensive.

Activated sludge is also a promising method for treating preservating wastes. Completely-mixed activated sludge gives maximum protection against shock loading. Dust and Thompson (10) conducted reaction rate studies on creosote wastewaters at Mississippi State University. Completely-mixed 5 liter reactors were used without sludge recycle. Activated sludge seed from a municipal wastewater treatment plant was acclimated to the waste which required nutrient addition. Detention times of 5, 10, 15, and 20 days were studied. Influent COD and the mixed liquor volatile suspended solids were below 450 mg/l throughout the testing. A first-order reaction rate constant, K, of 0.30 days^{-1} was exhibited. Based on this constant, COD removal efficiencies from 60 percent for 5 days detention to 85 percent for 20 days detention can be expected. Evaluation of snythesis and endogenous respiration coefficients for oxygen utilization resulted in values of 0.57 and 0.42, respectively. Another similar test on pentachlorophenol (PCP) wastes was conducted. Influent COD ranged from 2180 to 2735 mg/l and pentachlorophenol from 5.8 to 40 mg/l. Two reactors were operated and the detention times and loadings were 10 days at 500 ml/day and 5 days at 1000 ml/day, respectively. Removal efficiency for COD was 68 to 90 percent. Pentachlorophenol removal varied from 20 percent to 94 percent in the first test and from 77 percent to 99 percent in the second. In the more effective test, PCP removal efficiency was at least 90 percent most of the time.

Kirsh and Etzel (5) also established the effectiveness of activated sludge for degrading PCP wastewaters. With an 8-hour detention time and 150 mg/l PCP feed, removal rates in excess of 97 percent were obtained. The feed also contained 100 mg/l phenol which was completely removed. The COD removal efficiency was 90 percent.

Based on the above data alone, treatment with activated sludge can be very effective. Such treatment may be carried out in basins of concrete or earth with diffused or mechanical aeration devices. Also, oxidation ditches of the race track configuration with rotating brushes or cages providing aeration will have the same treating capacity. However, some existing systems require dilution of the wastewater before treatment (3). When dilution is required, activated sludge is less desirable since volumes must be increased, additional pumps are required, and there is more wastewater to be handled. It is normally a common practice to concentrate wastes rather than dilute them prior to treatment.

Lagoons and oxidation ponds have been used extensively as holding basins, polishing ponds, evaporation basins, and biological treatment units. Typical parameters are a depth of 2 to 5 feet and BOD loading of 20 to 30 pounds per acre per day. Although these lagoons are common, no research on optimizing design and operational parameters has been reported. Several authors have described some typical applications (18,19); and, in some instances, rather unusual or unorthodox applications have been tried (3).

Soil application has also been applied to a certain extent for treating wood preserving wastes. Spray irrigation, soil percolation, overland flow, land spreading, and wooded spray areas have been used. Apparently in the wood preserving industry many engineers have a belief that the natural cleansing and assimilation capacity of the soil can be used to treat a wastewater in a manner similar to a stream's natural purification capacity. This is dealing with an extremely delicate balance. The soil is a reservoir for bacteria, the same bacteria which are commonly used to treat wastewater in activiated sludge treatment. They can be used to remove organic materials and other soluble matter by the processes of biooxidation. Also, a filtering capacity exists inherent in the soil to remove suspended soilds. The soil is not an easily controlled system, and delicate balance exists between nutrients, synthesis, decomposition, and the atmosphere. A soil can be permanently destroyed by misuse. Many uses of the soil's treatment properties have been reported in the literature (10,13,18,44). Most of them are without prior knowledge or full awareness of the biological system being used. Five factors must be considered in designing a soil treatment system: (1) hydraulic loading, (2) solids loading, (3) nutrient loading, (4) maintaining aerobic conditons, and (5) toxic substances. Little research is reported where appropriate parameters and relationships have been established for wood preserving wastes. While soil treatment of wastes can be very economical, provided adequate land is present, there are many technical and enviornmental ramifications of this type of treatment which need attention. Continued use of this treatment without some background research may bring about some difficult problems.

Gaudy (18,19) and Crane (3) describe a plant where wastewater was applied to a forested area. Biological action accounted for phenol and BOD removals of 50 percent from an influent with 70 and

615 mg/l, respectively. However, this action probably occurred in the surface mat of forest debris and much of it may have been due to absorption and adsorption (18).

Miller (31) describes an irrigation field which produces no runoff from 13,000 gallons per day of creosote wastewater from a plant using vapor drying for seasoning. The field is preceeded by an activated sludge plant and a three-stage lagoon system. An application rate of 3,500 gallons per acre per day (1 inch per week) was used. Grass and corn have been successfully grown on the irrigation field, but no test results on percolation and ground water contamination have been published.

In another application, Fisher and Tallon (14,15) report a plant that irrigates a "swampy" area with a hard rock layer two to eight feet beneath the surface. The irrigation is preceeded by creosote separators and lagoons with several months detention time. Application rates are not given, but the range of 2000 to 4000 gallons per acre per day is recommended. Effluent concentrations of BOD_5 were from 1 to 70 mg/l; COD values were 20 to 280 mg/l; and phenol contents were 0.01 to 1.6 mg/l. The irrigated soil had higher concentrations of microorganisms, but no other ecological effects such as species diversity or toxic inhibition were reported. General recommendations for soil treatment included are: (1) a quality of water that does not affect the soil due to oils, preservatives, and toxic metals, (2) the need to avoid innundating the soil creating anaerobic conditions and runoff, (3) the desirability from the standpoint of assimilation and evapotranspiration of vegetative cover, and (4) a thorough inspection of possible contamination of ground waters. In such a treatment, all pollutants reaching the irrigation field most remain.

Thompson cites soil irrigation as producing the best overall results among biological treatments. He bases his statement on the high COD and phenol reductions plus the desirable zero discharge which can be achieved (45). In another instance, Dust and Thompson refer to soil irrigation as the "least expensive" yet "one of the most effective" disposal methods (10).

Two other plants reported by Fisher and Tallon (15) irrigate wastewaters. One has a flow of 2000 gallons per day from creosote treating. The waste is separated from bulk creosote, then sent through two ponds where biological degradation and evaporation occurs. The remaining flow goes to an irrigation field. Although application rates are not given, the irrigation is heavy enough to create puddles in the field. Containment, evaporation, and percolation account for all the waste since no runoff occurs. The second plant uses creosote as a preservative and produces 15,000 gallons per day of waste. Prior to irrigating, the waste goes through an activated sludge system followed by lagoons. The overflow from the lagoons is applied to a grass and weed covered field. Again no application rate is given, but the irrigation is less than what is necessary to cause runoff.

Dust and Thompson (10) have conducted laboratory and pilot tests on soil application. Laboratory tests in 55-gallon drums filled with 2 feet of soil showed that removals of 99 percent could be achieved, but a COD breakthrough did eventually occur (in 4 to 20 weeks depending upon loading). Nutrient addition was used. Further testing using a creosote wastewater after gravity separation on a 0.7 acre plot having a 2 percent slope was conducted. A one foot earthen levee around the site prevented surface runoff from entering. A perforated pipe along the uphill side of the plot sprayed a flow of 3,500 gallons per acre per day. Bermuda grass was already established on the site. The waste was supplemented with nutrients and testing covered a ten month period from July to April. Overland flow accounted for 55 percent of the COD reduction while about 40 percent occurred in the upper one foot of soil. Phenol removal paralleled COD removal and influent COD ranged from 1510 to 4480 mg/l with an average of 2550 mg/l. Corresponding values for phenols were from 234 to 923 mg/l with 350 mg/l being an average. The pH of the waste increased in the upper foot of soil, but began to decrease with depth. Anaerobic action was suspected below one foot. Natural grasses predominated over the Bermuda. No effects on soil ecology were examined or reported. The recommended application rate was not to exceed 3,500 gallons per acre per day.

Later testing on the same area with a wastewater which contained PCP and creosote produced similar phenol reductions. The PCP contaminated spray killed vegetation within its periphery. Preliminary results from laboratory studies indicate a pentachlorophenol removal efficiency of only 66 percent (44).

Some interesting results have been gathered from using vascular aquatic plants in lagoons to increase biological oxidation and evaporation. Of particular interest is the ability of water hyacinths to remove phenols and heavy metals. The National Space Technology Laboratory (NSTL) in Bay St. Louis, Mississippi is conducting a program using vascular aquatic plants for sewage and waste treatment. Preliminary results indicate 19.1 pounds of phenol can be removed and oxidized by one acre of mature water hyacinths in 72 hours (51). Also tests on a 0.7 acre domestic sewage lagoon covered with water hyacinths showed the following results: BOD_5 reduction of 73 percent, TSS reduction of 74 percent, and a TOC reduction of 30 percent. These values are impressive when compared with those of a similar lagoon which during the testing period had no aquatic plants placed in it. Corresponding values are: BOD_5 increased 49 percent, TSS increased 15 percent, and TOC increased 15 percent (52). Another factor to be considered is that evapotranspiration through the leaves of vascular aquatic plants increases the evaporation of a body of water from 3.2 to 3.7 times (50). The plants do, however, require harvesting. The design, construction, and testing for devices to harvest and produce either animal feed or methane from vascular aquatic plants is being studied at NSTL (53). Applications to wood preserving wastes are in their infancy, but show promise. The chief interest is the use of a polishing lagoon with vascular aquatic plants as a final treatment for phenolic compounds.

Chemical Oxidation

In the field of wood preserving, chemical oxidation has been mainly used for reducing the phenol content of the waste. The primary oxidizing agents employed are chlorine and ozone. These chemicals can oxidize phenolic compounds when applied in the proper concentrations.

The use of chlorine to oxidize phenolic compounds has received more attention than other means. Gaseous and salt forms of chlorine have been used. Gaseous chlorine would be more suited to continuous flow applications where a considerable volume is to be treated. The theoretical ratio of chlorine to phenol necessary for complete oxidation is 6:1. With different forms of chlorine this number will vary considerably depending upon the chlorine content of the compound applied. Some ratios for typical forms are: chlorine gas (Cl_2) 6:1, calcium hypochlorite ($CaOCl$) 3.6:1, sodium hypochlorite ($NaOCl$) 2.9:1, and the hypochlorite ion (OCl^-) 2:1. The theoretical amount will be less than the actual amount necessary to oxidize phenolic compounds due to the other oxidizable compounds present. Also, pH can affect chlorine oxidation considerably. In particular, salt solutions are sensitive to the pH value.

The effects of chlorination on wood preserving wastes has been reported by Dust and Thompson (9). For creosote wastes, a chlorine to phenol ratio of 14:1 to 65:1 was required to completely oxidize phenols using calcium hypochlorite. Pentachlorophenol wastes required dosages as high as 300:1 for calcium hypochlorite and 700:1

for chlorine gas (44). Phenol removals of greater than 90 percent were attained for creosote waste using 1.5 to 3.0 gm/l of chlorine in the form of calcium hypochlorite. The residual phenol concentration was 5 to 15 mg/l. Using a PCP waste, 3 g/l of chlorine in the form of calcium hypochlorite was necessary to remove 40.7 mg/l of PCP to undetectable levels. Using calcium hypochlorite at a lower pH gave better PCP removal than at a higher pH value, and flocculation followed by chlorination achieved removal to undetectable levels. Chlorine gas was tested on both flocculated and unflocculated samples of PCP wastewater. With unflocculated wastewater, pH had no effect on PCP removal at the optimum dosage of 3.0 g/l. In flocculated samples, complete removal was reported at pH 4.5 with a dosage of 5 g/l (9).

Chemical oxygen demand removal by chlorination is of the same magnitude as that of flocculation with lime and polyelectrolyte. Contact time affects both phenol and COD removals by oxidation (5). Thompson (44) reports that the principal degradation product of PCP is chloranil (2,3,5,6-tetrachloro-p-benzoquinone) which is biodegradable and less toxic than PCP. It should be also noted that recent research indicates that chlorination of organic compounds quite probably creates chloro-organic compounds which may be carcinogenic.

The use of ozone for treating wastewaters is developing rapidly. Ozone (O_3) is a very powerful oxidizing agent which can be used to oxidize many organic compounds, including phenols. The oxidation reaction with ozone occurs quickly. The principal products are of an acidic nature (36). Factors which affect the efficiency of ozonation include pH and the amount of organic compounds present. For phenols the optimum pH is reported as 12.0. Significant increase in the amount of ozone required can result from pH variations. The normal ratio of ozone to phenol required is 2:1, however, this may vary from 1:1 to 10:1 (44). To oxidize the same amount of phenol as chlorine does requires approximately one-tenth as much ozone (20). While ozonation is effective, economic considerations limit its applicability. Ozone is very reactive and must be generated on-site. Power requirements plus the capital cost for generating equipment make ozone practical only for large quantities of wastewater. In the future, however, applications may be seen in the wood preserving industry.

Physical Treatment

Treatment of wood preserving wastewaters using physical methods can usually be accomplished independent of other treatments. In other words, the raw waste can be treated by physical means alone. However, based on economics, physical treatment is usually accompanied by the removal of emulsified oils. Physical methods of treatment are: filtration, activated carbon adsorption, and evaporation. In some additional treatment may be supplied by biological or chemical oxidation.

The use of filters to remove suspended solids has received little attention in treating wood preserving wastes. Filtration is the only physical method which requires other treatments. This is because wood preserving wastes have a high soluble organic content; however, filtration may be used following flocculation and sedimentation to remove suspended solids before other treatments. An example of. such a use is flocculation, sedimentation, filtration, and carbon adsorption. Filtration prevents the carbon column from being plugged with carryover solids.

Several types of media can be used in filters depending upon the application. Typical types are sand and gravel and multi-media filters of crushed coal, sand, and garnet. Commonly, rapid filtration is preferred. Hydraulic loadings for rapid sand filters are 2 to 10 gpm/ft^2, while slow filtration occurs at 0.02 to 0.20 gpm/ft^2.

Halff (22) investigated the use of diatomaceous earth filtration and slow sand filters. He found that a vacuum filter with a diatomaceous earth precoat effectively broke emulsions when accompanied by heat and agitation. The hydraulic loading was 2 gallons per square foot per hour. Also, in the same report, slow sand filtration was investigated. Halff proposed that a slow sand filter could serve the same purpose as a vacuum filter-trickling filter system, only in one unit. A dosing rate of 2 million gallons per acre per day (0.04 gpm/ft^2) was used. The waste was diluted to a 0.5 to 6.0 percent solution (dilution ratios of 16:1 to 200:1). The results of the test showed a clear effluent with about 50 percent removal of toxicity as measure by the threshold limit for minnows. Clogging was a problem and the method was not recommended without further study. No other material on this treatment was found in the literature. Also, no applications of rapid sand filtration for wood preserving wastes was found.

Carbon adsorption is a well accepted advanced wastewater treatment operation for domestic and industrial wastes. Organic compounds, particularly non-polar ones, are usually easily removed by adsorption. Activated carbon can be used to remove trace organic compounds or as a bulk organic removal operation. The effluent from an adsorption operation will be free of any organics until breakthrough occurs. Breakthrough occurs when the available sites for adsorption are exhausted, and the effluent concentration will approach that of the influent. For wastes with high organic content, the cost of activated carbon adsorption may be impractical.

Dust and Thompson (9,44) conducted batch contact tests to determine adsorption isotherms. Phenols and COD were used as organic strength measures. An average loading rate of 1.2 pounds of COD and 0.16 pounds of phenol per pound carbon were observed. The wastewaters used were pentachlorophenol and creosote wastes. Flocculation with ferric chloride and pH adjustment to 4.0 preceeded adsorption. Preliminary cost estimates for carbon adsorption of similarly treated wood preserving wastes have been made by Heuther (26).

One of the more common means of disposal for wood treating wastes is evaporation of the volatile components. Three methods of evaporation are practiced: injection into the boiler furnace, atmospheric evaporation, and pan evaporation. Injection into the boiler furnace has been implemented to a small degree in the industry, but no results or design parameters have been published. The wastewater is injected into the boiler furnace exhaust or an auxiliary furnace; some of the organic compounds will be oxidized. Care must be taken to provide adequate temperatures at all times; however, no information on safe temperatures is reported. Also, the cost of evaporation and incineration by this method is quite high (45), but it can be used without prior treatment.

Atmospheric evaporation employs large, shallow ponds in which the wastewater is retained. The water evaporates due to solar heating, wind action, and the humidity of the surrounding air. This makes atmospheric evaporation quite attractive in southern regions. The rate of evaporation may be increased by spraying the wastewater in the air, thereby increasing surface area exposed.

Thompson (44) cites an example of one plant on the Gulf coast which evaporates 250,000 gallons per month of wastewater. Also, he mentions that solids buildup is reduced by microbial action. Very little work has been done on developing design criteria for evaporation pond systems. The primary disadvantage to atmospheric evaporation cited in the literature is the land required; however, in rural areas this should not present a problem. Air pollution, although not mentioned, may also be a major problem.

Pan evaporation involves the use of steam coils in the bottom of an evaporation vessel. The steam coils provide enough heat to evaporate the wastewater. This is used to a small extent in wood treating plants and, where volumes are small, pan evaporation may be economical.

CHAPTER III

EXPERIMENTAL METHODS AND PROCEDURES

In this study, it was necessary to evaluate the characteristics of the wastewater before treatment and then to evaluate what changes the wastewater undergoes during treatment. The study of the treatment process involved two bench scale evaporation units, one a spray evaporator, and the other a diffused air evaporator. Also, a study of a full-scale evaporation system was conducted in an effort to verify bench scale results. This chapter consists of descriptions of the analyses and apparatus used in the tests.

Wastewater Analyses

The first testing necessary was to collect and characterize some wastewater samples. Several plants were visited and each visit consisted of a tour of the plant, an inspection of their wastewater treatment facilities, and the collection of a grab sample of the process wastewater. Usually, the process wastewaters were collected after removal of bulk oils, since it is a frequent practice to recover as much of the preservatives as possible. Each grab sample was collected in a 5-gallon polyethylene jug and transferred to the laboratory. Characterization tests included: chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD_5), pH, suspended solids (SS), dissolved solids (DS), and oil and grease. The procedures used were in conformance with *Standard Methods for the*

Examination of Waters and Wastes (39). Methods 220, 219, 221, 224C, 224E, 209, respectively were used. Sample preservation for further testing was at 40° F (4° C).

Bench Scale Evaporation Unit I

The first apparatus was designed to monitor the rate of evaporation and the change in oxygen demand of the waste. A spray chamber was constructed which contained one spray nozzle, side walls and a pan to contain the spray, a sump to which the pan drained, and a positive displacement tubing pump. Also, a fan simulated wind action, if desired.

A drawing of the apparatus is shown in Figure 12. Wastewater was pumped from the sump to the spray nozzle. The spray was collected in the pan and flowed by gravity to the sump. The spray chamber was placed in a 100° F (38° C) controlled temperature room. The flow rate was measured at the beginning and at the end of each test run. At frequent intervals the relative humidity, volume in the sump, wastewater temperature, and wastewater specific gravity were measured. Also with each measurement, a 200 ml sample was taken in a 300 ml BOD bottle for COD analysis. In the first test run, samples were acidified to pH 2.0 with sulfuric acid. However, this practice was discontinued for the second and all subsequent runs because a simple test of the acidification procedure showed an unmeasurable difference between acidified and non-acidified samples. Samples were kept at 40° F (4° C) until the COD analysis could be

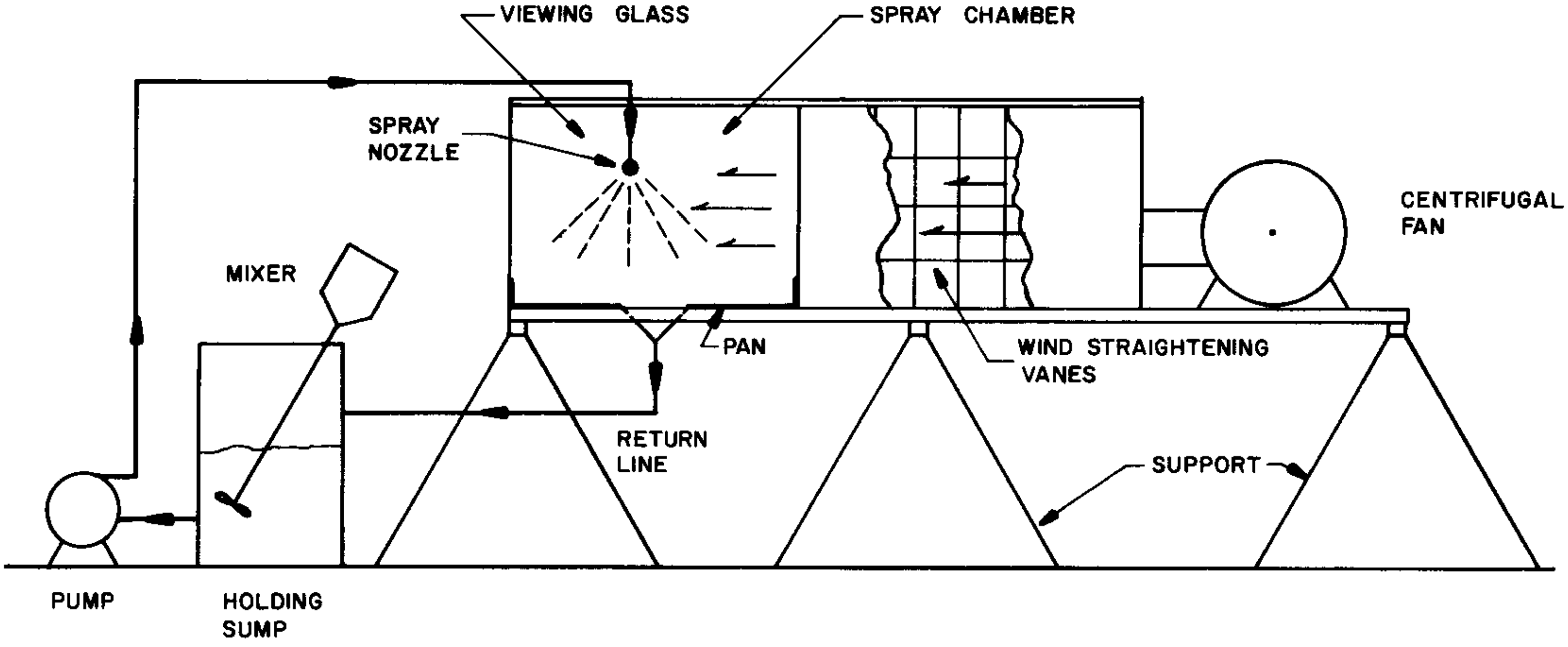


FIG. 12.- Sketch of Bench Scale Evaporation Unit I-Spray Evaporator

made.

In test runs I-A and I-B, the above sampling procedure was used. In test runs I-C and I-D a 20 ml sample was taken in a glass scintillation vial, rather than BOD bottles. This was done to minimize the change in wastewater volume due to sampling. Operational problems with the spray evaporator were numerous. Spills from uncontained spray, hose rupture, and leaks caused interruptions and inaccuracies in each test run. The volumetric measurements in the sump were difficult to make accurately. The amount of water evaporated over each sampling interval was nearly undetectable because the measurement error was of the same magnitude. Fine adjustments in flow rate were difficult to make which made duplicating flows a problem. The volume of evaporation loss each day was too small; therefore, a test run took several weeks to evaporate the required volume. Also, at irregular intervals, the nozzle would become clogged and a partial restriction of flow occurred. This caused variations in flow rate and in the spray geometry. Since there were numerous difficulties with Bench Scale Evaporation Unit I a second apparatus, Bench Scale Evaporation Unit II, was developed and constructed.

Bench Scale Evaporation Unit II

In order to study the changes in the wastewater as water and volatiles were evaporated, a diffused air approach was developed. The basic principles governing the evaporation of water and volatiles is the same whether the wastewater is sprayed in air or bubbled with diffused air. Therefore, a second apparatus using compressed air bubbling through the wastewater was constructed. The apparatus consisted of an evaporation vessel, a temperature control bath, a controlled air source, and an air dispersion device. A schematic drawing of the apparatus is shown in Fig. 13. The evaporation vessel was a 3.8 liter jar with a stopper in the top. A stainless steel tube (1/4 in. I.D.) was inserted through the stopper and was connected to a diffuser stone near the bottom of the jar. Three jars were used and placed in a plastic basin of controlled temperature water. The water temperature was controlled by circulating it between the plastic tub and a constant temperature bath using a positive displacement tubing pump. Water temperature was maintained at 95° F (35° C). Air from the laboratory compressed air tap went through a regulator to the diffuser, bubbled through the wastewater, passed out of the evaporation vessel through a tube connected to an overflow flask, and then was released to the atmosphere. The overflow flask served to catch any liquid which foamed out of the vessel and provided a continuously purged volume at atmospheric pressure from which air pollutants could be sampled. Samples were taken and concurrent measurements were made frequently as the water evaporated from the vessel. A scintillation vial was used to collect 20 ml samples of the wastewater at the selected intervals, and COD and TOC analyses were performed on these samples. Other parameters measured with each sample collection were volume, air flow,

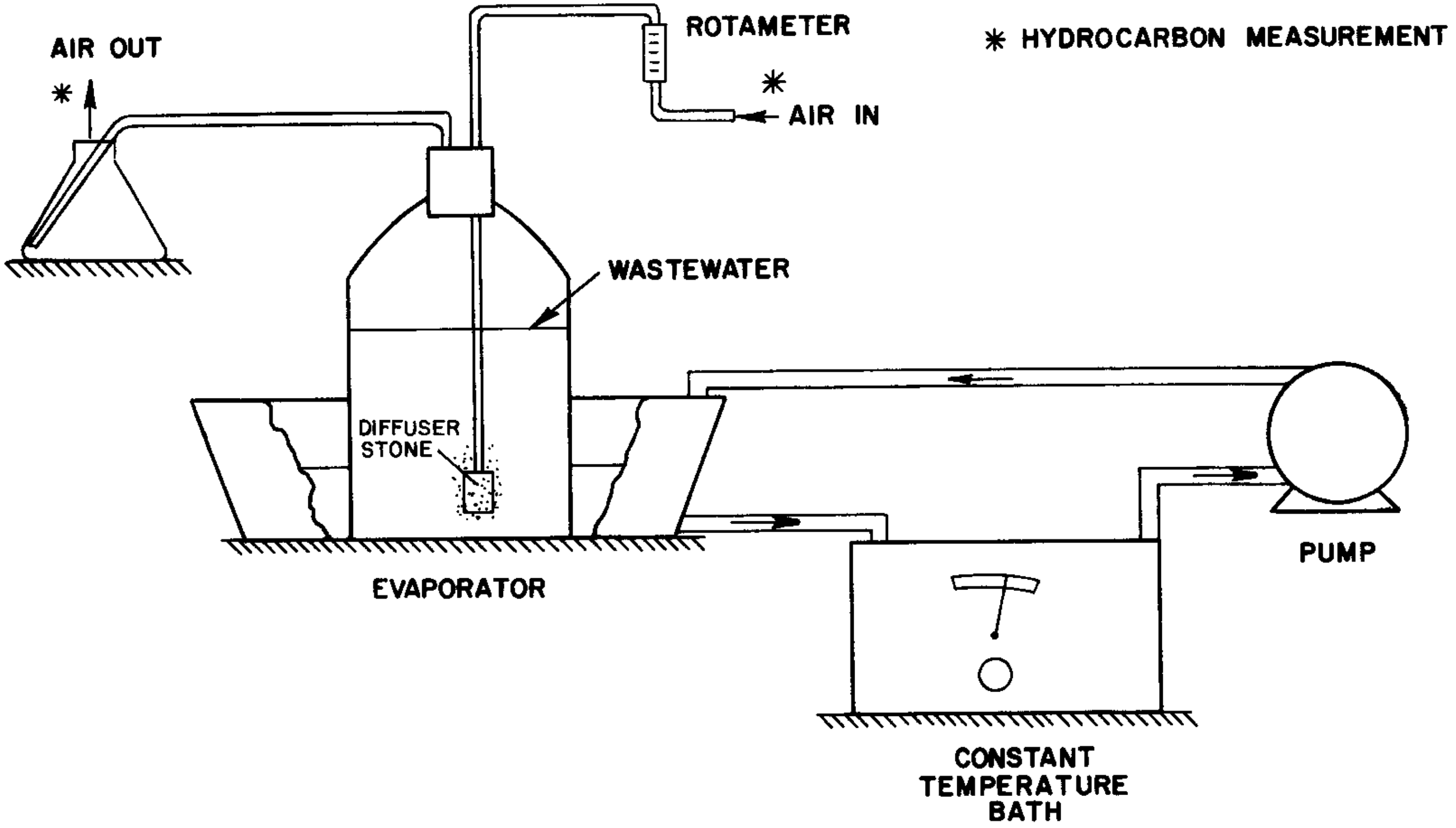


FIG. 13. - Sketch of Bench Scale Evaporation Unit II - Diffused Air Evaporator

entering air hydrocarbon concentrations, exit air hydrocarbon concentrations, and temperature. Volume measurements were made by pouring the contents of the vessel into a pair of 1000 ml graduated cylinders. A rotameter capable of measuring flows between 1.4 and 16.5 liters per minute (3 to 35 cubic feet per hour) was used. Hydrocarbons were measured using a flame photometric device manufactured by Meloy Labs (Model SH101). The air was sampled both before and after passing through the wastewater, so background concentrations could be subtracted. The temperature of the bath around the vessels was kept at 95° F (35° C) and monitored at each sampling time.

Only flocculated samples were used for the second apparatus. Flocculating the wastewater would reduce the level of air pollution and prevent clogging of the nozzles of a real system. Flocculation tests were necessary to determine the best coagulant and the optimum dosage. Batch jar tests were run using various coagulants and the wastewaters were flocculated at various dosages in 1 liter beakers. The stirring and mixing apparatus was made by Phipps and Bird, Inc. Six beakers could be coagulated simultaneously, and the times allowed for rapid mixing, flocculation, and settling were 1, 15, and 60 minutes, respectively. The maximum stirrer speed was used for rapid mixing which was greater than 100 revolutions per minute, and flocculation was at 20 revolutions per minute. The pH of the sample was measured before addition of the chemicals and after settling. In some cases the turbidity was measured, but, in all cases, a description of the supernatant was recorded. COD samples were taken in a 20 ml scintillation vial, and refrigerated at approximately 40° F (4° C) for storage until analysis.

Variations in Analyses

The unusual nature of wood preserving wastes and the laboratory facilities available imposed some constraints upon the testing procedures specified in *Standard Methods for the Examination of Water and Wastewater*. Specifically, the tests for COD, TOC, SS, and oil content required modification. The modifications are given below:

1. COD analyses were conducted in 300 ml boiling flasks without using glass beads. Acid was added to the flask before it was connected to the reflux column. Some oxidation may have occurred before refluxing began, but this must have been constant.
2. TOC aliquots of 5 microliters (μl) were injected into a Beckman Model 915 TOC analyzer with a Beckman Model 215 A infrared analyzer. A 10-microliter syringe was used and the volume injected was drawn into the syringe body so an exact meniscus reading could be made. Standards of 750, 1000, 2000, 3000, 4000, and 5000 mg/l concentrations of potassium hydrogen phthalate ($KC_8H_5O_4$) as carbon were injected in the same manner. A standard dilution water blank was used to account for any TOC response in the water used in preparing the standards. Only the total carbon side of

the analyzer was employed. This is justified because the inorganic carbon content is insignificant in relation to the high organic content.

3. Suspended solids included those oils which adhered to the filtering apparatus. They were removed with hexane and treated as an oil analysis, and the results were added to the suspended solids.
4. Oil analyses were conducted using three hexane extractions from 100 ml of the wastewater. The oil samples were evaporated to dryness in an 80° C temperature bath.

CHAPTER IV

EXPERIMENTAL RESULTS

The results of the experimental program are presented in this chapter. Four field studies and ten laboratory tests were conducted for wastewater characterization and bench scale evaluation. The results are presented in three sections: (1) wastewater characterization, (2) results of bench scale testing with Evaporation Unit I, and (3) results of bench scale testing with Evaporation Unit II.

Wastewater Characterization

Four wood preserving plants were visited and wastewater samples were collected from each. The plants are designated as Plants I, II, III, and IV. Descriptions of each plant are as follows.

Plant Descriptions

Plant I. This facility performs creosote-coal tar, pentachlorophenol-petroleum, and metallic salt treatments. Four retorts are used in the following manner: two for creosote, one for penta, and one for water-borne salts. Some aspects of the plant which affect wastewater quality are: (1) empty cell treatment is used, (2) closed steaming is practiced, (3) wastewater streams from each preservative are segregated, and (4) storm runoff is caught in holding ponds.

The on-site treatment scheme for creosote wastes is shown in

Fig. 14. Raw wastewater from the creosote treating cylinders goes into a series of three horizontal, cylindrical tanks with internal baffles. The tanks serve as a triple-effect separator. Creosote is withdrawn from the bottom of the separators and returned to the working tanks. An oil skimming tank follows separation and this tank provides diffused air and a trap for floatable oils. A pump serves to lift the wastewater into either of two batch neutralizing tanks or a condensate storage reservoir. The neutralization tanks are operated on a batch basis; one tank is filling while the other is either treating or discharging. Caustic soda is used to raise the pH to near neutral. The condensate storage tank holds recycled condensate for closed steaming. After neutralization wastes are discharged through an orifice plate which maintains a relatively constant flow to the city collection and treatment system. A composite sample was collected in January 1975 and a grab sample was taken in June 1975 at the location shown in Fig. 14.

Plant II. Plant II treats with creosote and pentachlorophenol. Four cylinders are used, and no attempt is made to segregate preservatives or wastewaters. The combined wastes along with some plant runoff from the treating area empty into a stack vented sump, as shown in Fig. 15. A pump moves the waste to an elevated tank which has a conical bottom and serves as a primary separator. Penta-oil solution is taken from the top and creosote solution from the conical bottom. The wastewater then flows into a pair of storage tanks which serve as settling basins in series for removal

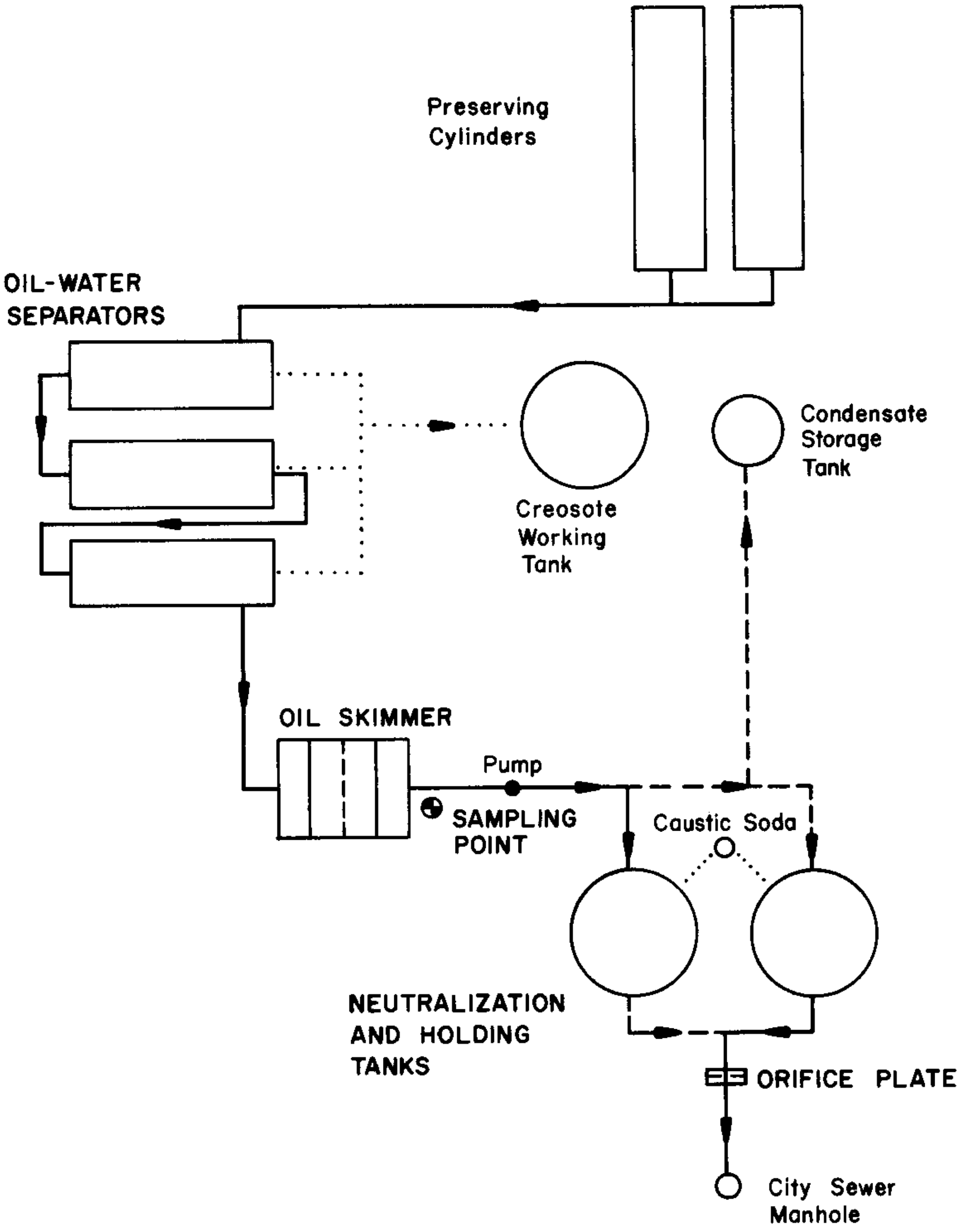


FIG. 14.— Plant I Creosote Wastewater System

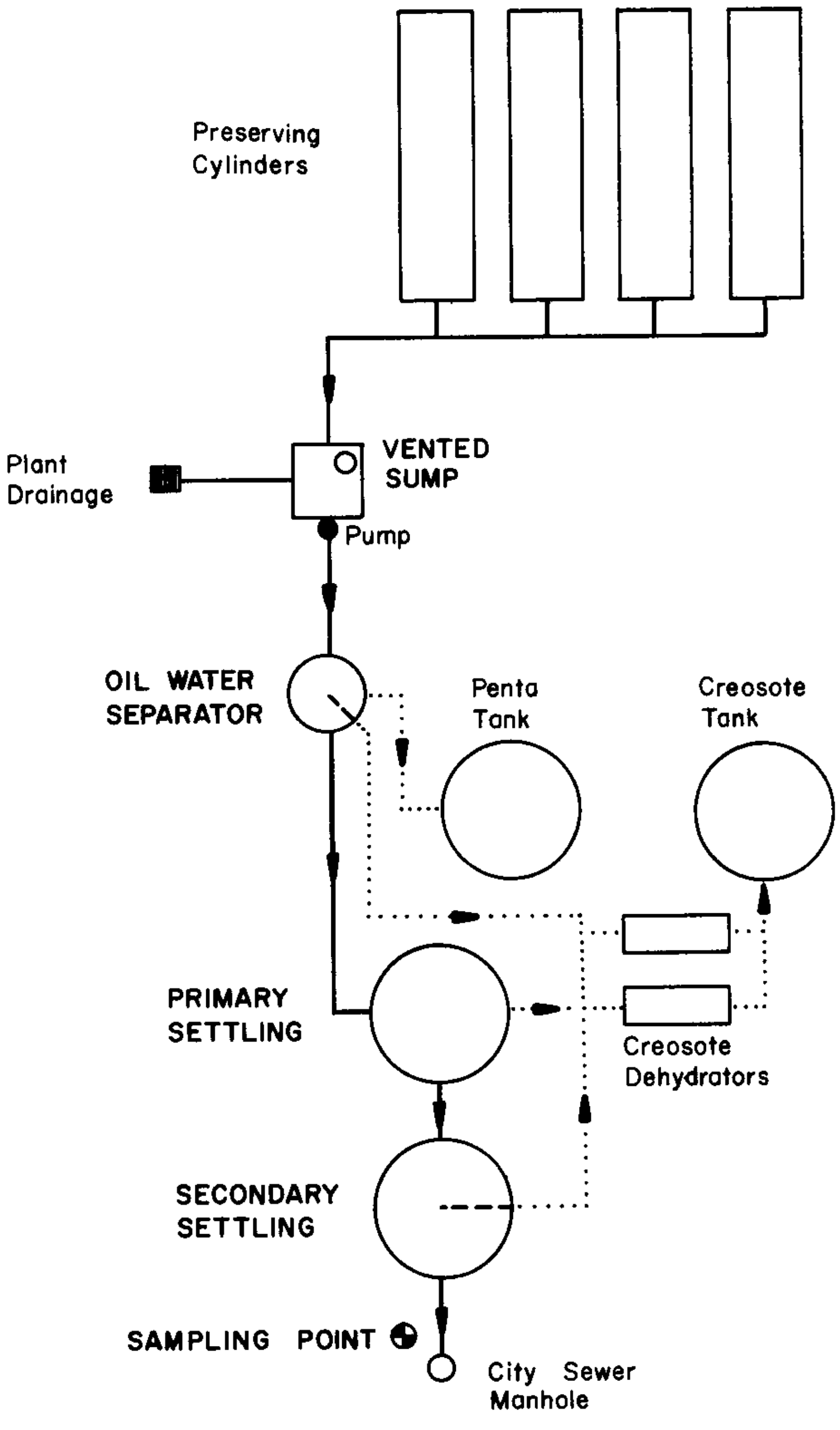


FIG. 15.— Plant II Creosote and Penta Wastewater System

of the remaining creosote. The wastewater drained from the second settling tank flows intermittantly into the city sewer system. The creosote taken from the bottom of the three tanks is sent to dehydrators to evaporate water and then to the working tank. A grab sample was collected in June 1975 at the point shown in Fig. 15.

Plant III. The third plant visited is a railroad tie treating plant where vapor drying is used as a seasoning procedure. Some penta treatment is done, but creosote is the primary preservative. The plant has five treating cylinders as shown in Fig. 16.

The process wastewaters are collected from the solvent-water separators in a sump or holding tank which provides some equalization. From the holding tank the wastewater goes to an open inspection box where free oils can be removed from the water surface. The wastewater then enters a baffled mixing chamber where caustic soda is used to raise the pH to near neutral. The neutralized waste flows into the city's sanitary sewer system. The sample was collected in June 1975 at the effluent weir of the neutralization basin, as shown in Fig. 16. The waste is primarily extracted waters from the wood with little oils or preservative, and neutralization provides adequate treatment.

This particular plant has installed an air pollution control system to eliminate the vapors which are expelled when preservative storage tank levels change. A diagram of the system is given in Fig. 17. The vapors from working and storage tanks are manifolded into an enclosed sump. Newly delivered preservative and excess

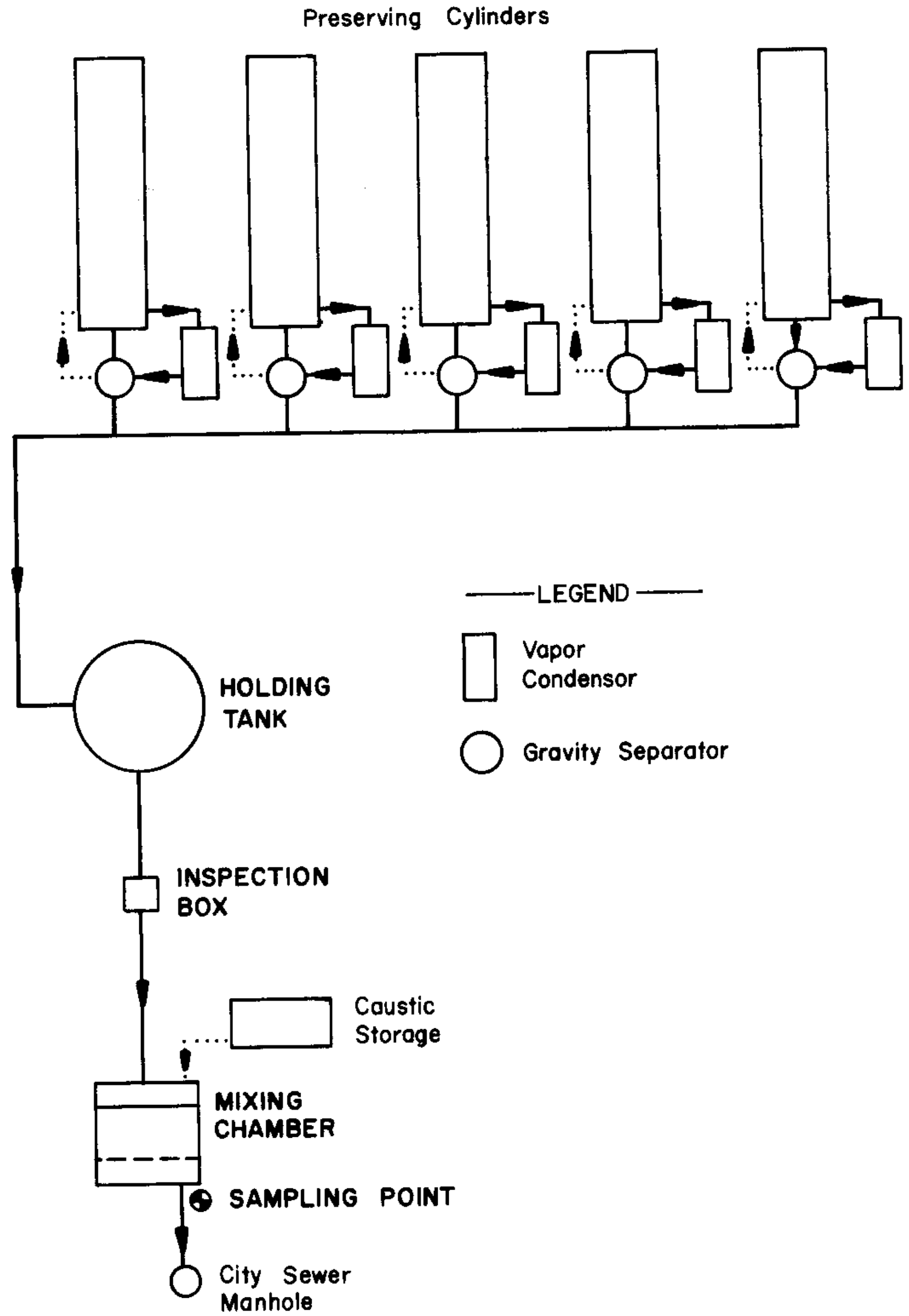


FIG. 16. – Plant III Vapor Drying, Creosote, and Penta Wastewater System

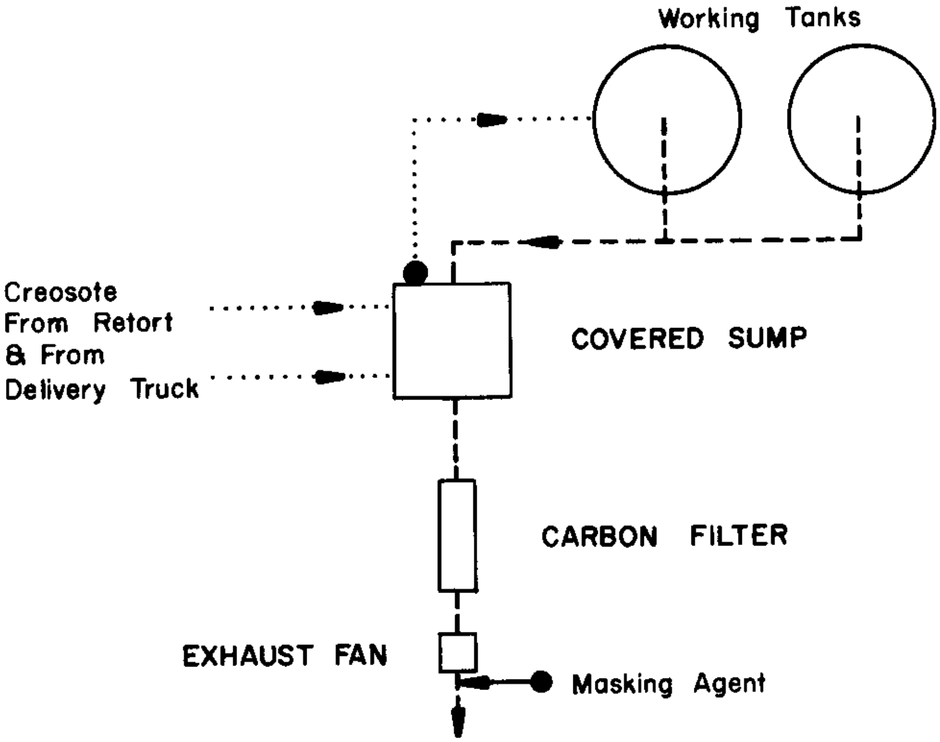


FIG. 17. — Plant III Vapor Recovery System

preservative drained from the retorts also flow into this sump to be pumped into storage. The vapors in the air space above the sump are evacuated by an exhaust fan which draws them through a carbon adsorption filter to remove organic vapors. At the discharge of the fan, a deodorizing agent may be used, if needed, to mask any residual odors.

Plant IV. The final plant visited has three treating cylinders, two for creosote and one for penta as shown in Fig. 18. Empty cell treatment is used, open steaming is employed, and most of the wood treated is kiln dried. The waste streams are kept segregated. Creosote wastewater enters a horizontal, cylindrical tank without baffles. This tank serves as a preservative recovery separator. The waste then enters a basin which serves as a sump. The penta waste goes through a pair of horizontal separators in series similar to the creosote separator. Penta separator effluent flows into the sump basin also. A pump lifts the combined wastes into a holding lagoon where additional separation takes place. Water from the holding lagoon is intermittently discharged into the first spray pond. A small number of nozzles are employed in spraying the contents of the pond to increase evaporation. Water from the second pond flows to the third pond and is sprayed again for evaporation. No discharge occurs from the second spray pond since all of the water is evaporated. Samples were collected from the creosote and penta waste streams at the points indicated in Fig. 18 in June 1975 and again in February 1976. The creosote wastewater is referred to

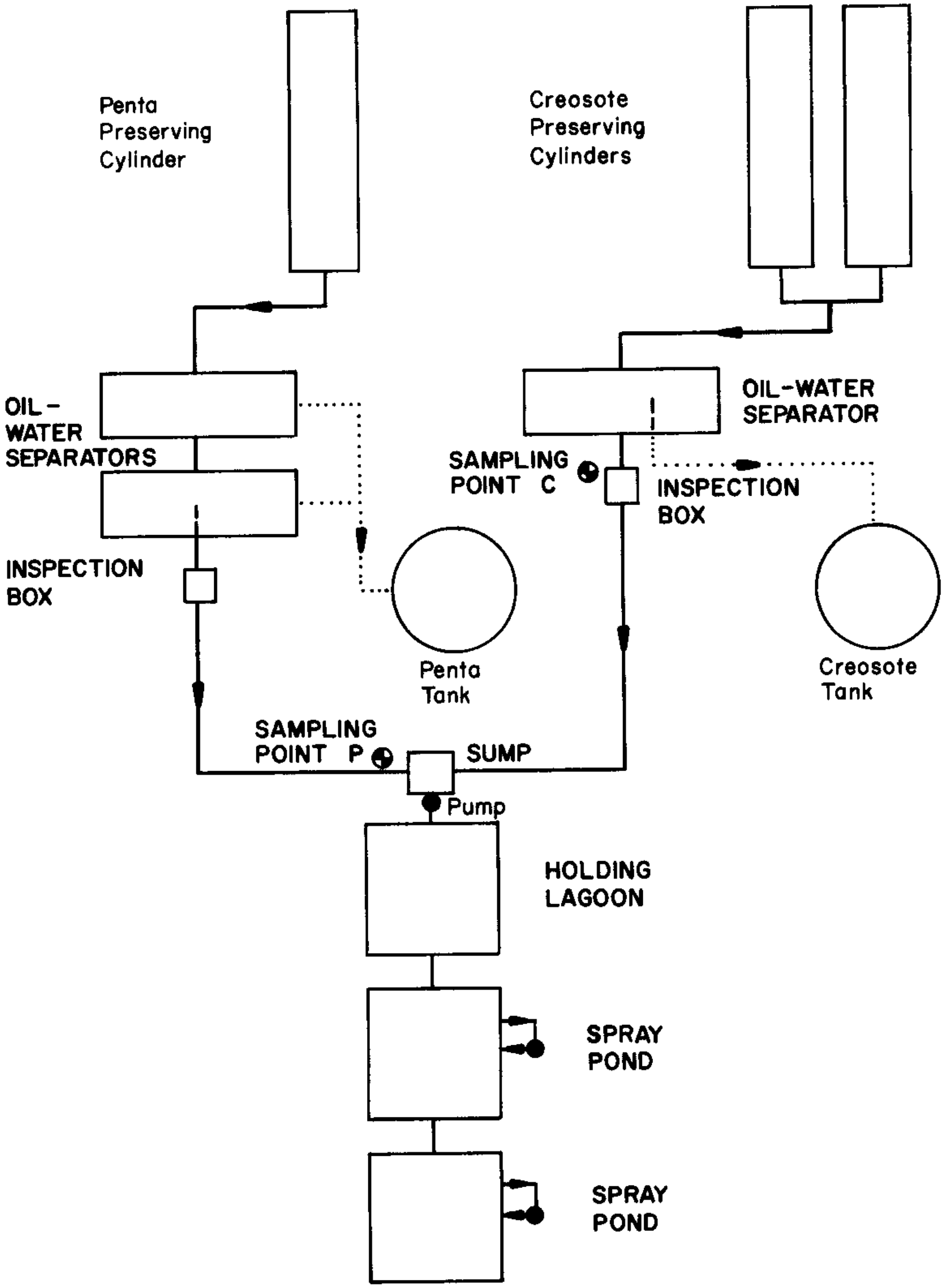


FIG. 18.— Plant IV Creosote and Penta Wastewater System

as IV-C and the penta wastewater as IV-P.

Wastewater Analyses

The results of the laboratory tests on the wastewaters are shown in Table 6. Two analyses are shown for Plant I, one for a sample composited over one week (Col. 2) and the other for a grab sample (Col. 3). Plant III wastewater is entirely different from the others because of the vapor drying process employed at this plant. The other wastewaters' characteristics are typical for wood preserving wastes from oil-borne treatment processes. All wastes were acid in pH, had high organic content, high oil content (except plant III as noted above), and substantial solids. Since these are primarily grab samples and the waste varies in characteristics so much, little can be generalized about any one plant's wastewater. The samples were analyzed so the characteristics of the wastes used in the bench scale testing would be known. For comparison, Chapter II provides the bulk of information on wood preserving wastewater characteristics.

Plant IV Field Study

Since Plant IV was the only plant visited that employed evaporation for wastewater treatment, a study of the pond system was performed to determine wastewater quality characteristics of the process. The following aspects were examined: (1) disadvantages of evaporation, (2) stratification in the spray ponds, and (3) con-

TABLE 6. - Wastewater Characteristics for Four Texas Wood Preserving Plants

Parameter (1)	Plant I[a] (2)	Plant I (3)	Plant II (4)	Plant III (5)	Plant IV-C (6)	Plant IV-P (7)
BOD[b], mg/l	481	890	346	865	-	-
COD, mg/l	3,248	5,696	6,862	3,019	35,828	14,969
SS, mg/l	132	46	267	160	7,280	530
DS, mg/l	1,528	1,976	871	164	8,738	8,376
TS, mg/l	1,660	2,022	1,138	324	16,018	3,906
Oils, mg/l	242	-	264	-	-	-
pH	4.2	4.2	-	-	4.4	4.4

[a] Composite sample collected January, 1975. All others grab samples collected June, 1975.
[b] 5 day BOD without acclimated seed.

centration of dissolved and suspended solids. The results of the analyses are presented in Table 7.

Pond 1, as previously described, serves as a holding pond for the wastewater after preservative recovery. A significant degree of stratification is present in this pond due to sedimentation. The best quality water to transfer into the spray pond is from the surface. The very high turbidities and COD values that were found are due to an emulsion present in the pond.

Pond 2 provides spraying to evaporate the wastewater. Although the water had appreciable color and COD, the emulsion is not present as evidenced by the low oil content, low turbidity, and lack of stratification.

Pond 3 provides additional spraying and water quality improvement; however, the change is not as marked as in Pond 2. The only measurable differences are in COD and color, and no concentrating is apparent.

The disappearance of the emulsion in Ponds 2 and 3 could be caused by spraying, since this has been used to break emulsions. The improvement in water quality is much harder to understand or explain. It is quite possible in this instance that drift loss, seepage, or biooxidation is preventing the accumulation of nonvolatile materials as measured by the COD and dissolved solids analyses.

TABLE 7. - Plant IV Pond System Water Quality

Sample I.D. (1)	Depth (ft) (2)	Temperature (°C) (3)	COD (mg/l) (4)	Solids (mg/l)			pH (8)	Turbidity[a] (FTU) (9)
				Dissolved (5)	Suspended (6)	Total (7)		
POND 1	Surface[b]	26	880				6.7	240
	2	19	912				6.6	270
	3.5(bottom)[c]	--	2,169	752	136	888	6.7	390
	5 (bottom)[c]	19.5	4,221				6.7	590
POND 2	Surface	26	391				6.7	13
	2	21	408				6.7	15
	4	19.5	354				6.6	14
	6 (bottom)	20	320	642	88	730	6.7	14
POND 3	Surface	25	177				6.7	14
	2	--	178				6.9	15
	4	20	165				7.0	15
	6 (bottom)	20	188	565	120	685	7.2	13

[a] Pond 1 samples required dilution to one-tenth strength, therefore, reported value is meter reading times ten.

[b] The dissolved oxygen level at the surface on Pond 1 was 0.4 mg/l.

[c] Samples at 3.5 ft depth and 5 ft depth taken at different locations.

Bench Scale Evaporation Results

Evaporation Unit I Results

Four test runs were made on Bench Scale Model I and all tests were run on the composite samples collected from Plant I in January of 1975. The results of these tests are reduced and presented as graphs in order to establish the pertinent relationships.

Test I-A. This test covered 89 hours of intermittent operation of the unit. Approximately 53 percent of the original waste volume was evaporated. When sump COD is plotted against the amount of waste evaporated expressed as a percent, a normalized plot results as presented in Fig. 19 (a). Initially a high COD removal rate was experienced; however, using the straight line portion of the curve gives an evaporation ratio of 0.00149 gram of COD per gram of wastewater evaporated. The average wastewater evaporation rate in this experiment was 0.417 kilogram of water per hour. Since there were some irregularities, a second test was run.

Test I-B. Fig. 19 (b) shows a graph of the grams of COD remaining in the sump as a function of the percent volume evaporated for Test I-B. A significant change in the rate of COD removal by evaporation occured when approximately 20 percent of the wastewater was evaporated. Prior to this point the rate was high but steadily decreasing; whereas afterwards, it was constant at a ratio of 0.00361 gram of COD evaporated per gram of wastewater evaporated. The average evaporation rate was 0.54 kilogram of wastewater per hour,

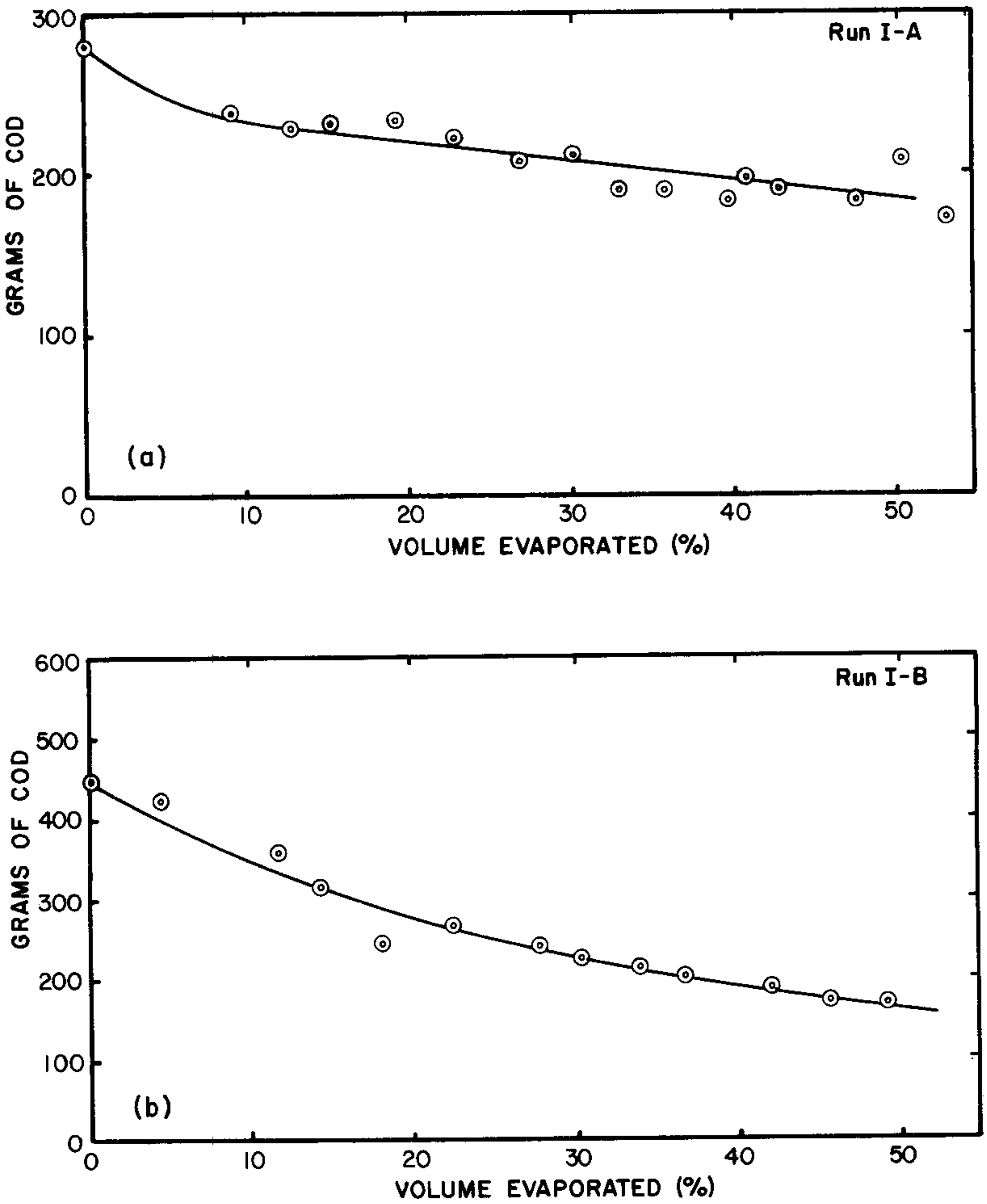


FIG. 19.— COD Remaining in Spray Evaporator: (a) Run I-A; (b) Run I-B

somewhat higher than in the first test.

Test I-C. Fig. 20 (a) illustrates the results of Test I-C. A much slower evaporation rate was used in this test. Approximately 0.166 kilogram of water were evaporated per hour during the last 60 hours of operation which is about one-third of earlier rates. The entire test lasted 80 hours. The evaporation rate for the first 25 percent evaporated was probably higher, approximately 0.23 kilogram per hour, but spills and other irregularities make this hard to substantiate. The COD evaporation ratio became constant during the latter portion of the test and was found to be 0.00689 gram of COD per gram of wastewater evaporated.

Test I-D. Again a lower evaporation rate was used in order to study the phenomena occuring in the early phases. The rate was 0.1499 kilogram of waste per hour. Fig. 20 (b) shows the COD versus the percent of water evaporated, and as shown, a slight curve was produced. The average COD evaporation rate was 0.00975 gram of COD evaporated per gram of wastewater evaporated. The test lasted 78 hours in which 59.8 and 45.3 percent of the COD and wastewater, respectively, were evaporated.

Coagulation Jar Tests

This series of tests was conducted on four different wastewater samples from Plants I, II, and IV. The results of the tests are presented in Tables 17, 18, 19, and 20 in Appendix II. Generally, COD removals of 40 to 80 percent were obtained. Ferric chloride

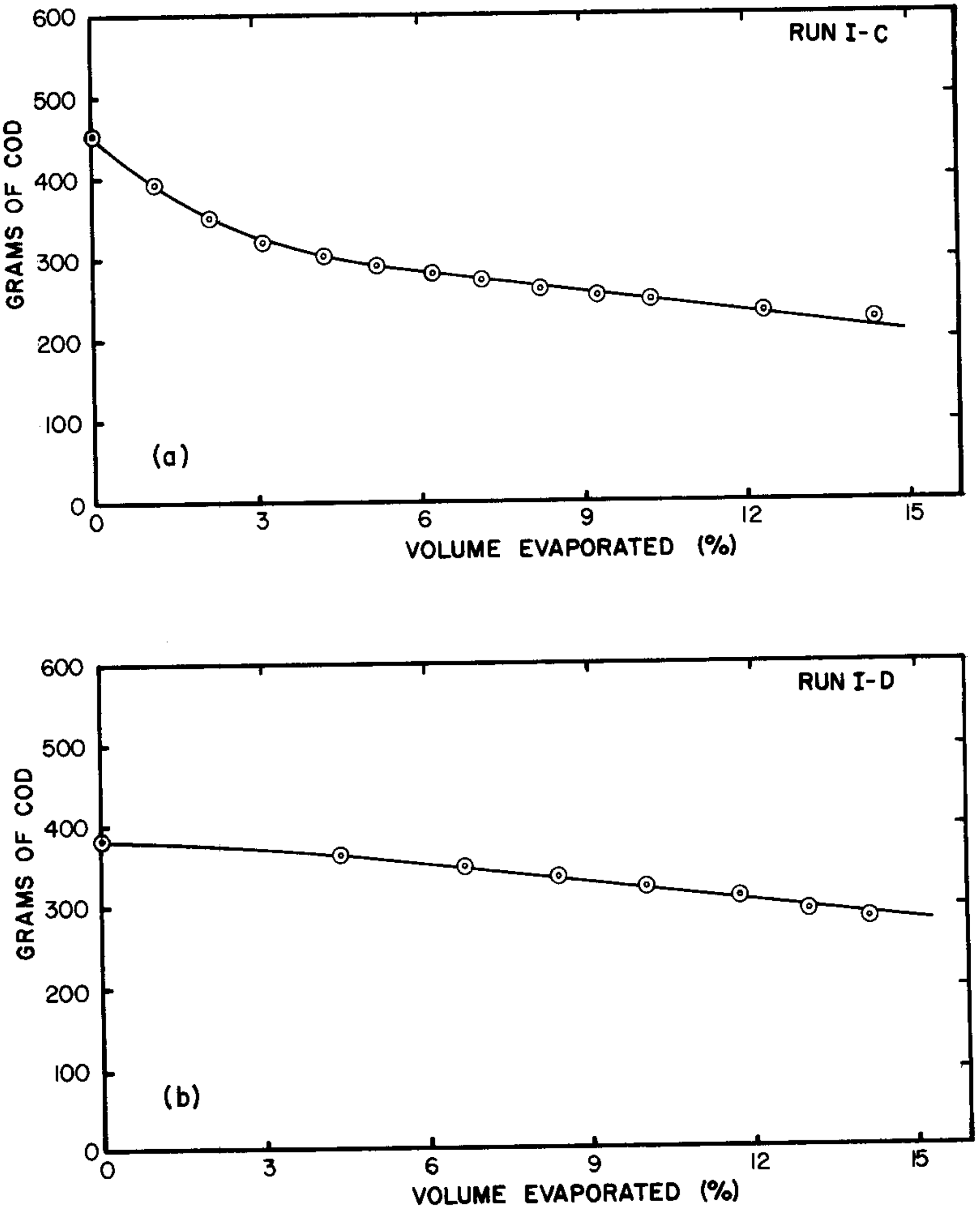


FIG. 20.— COD Remaining in Spray Evaporator: (a) Run I- C; (b) Run I- D

with sufficient lime to maintain a pH of 5 or greater provided the best COD and turbidity removals. Polyelectrolytes worked consistently well but required coagulant aids in some cases to improve settling and floc density.

The coagulant dosages to be used prior to the evaporation studies are as shown in Table 8. The dosages which produced the best results with ferric salts and polymers were selected in each case. The results obtained with these dosages are also reported in this table.

Evaporation Unit II Results

A total of six different samples were evaporated using this laboratory unit. The six samples were obtained by coagulating the wastewaters collected from the various plants. The four wastewaters were flocculated using the results of the jar test studies. Two types of coagulants were used: ferric chloride with lime and polyelectrolytes alone. The Plant IV wastes were flocculated with each coagulant, the others with only one. Table 8 shows the combinations of wastewaters and dosages used in preparing the samples.

The raw data was reduced in the following fashion. The amount of water evaporated in each interval between samples was summed to give the total volume evaporated in the test. Then the percent of this amount evaporated was calculated for each sample. The TOC and COD were calculated by multiplying the concentration by the volume

TABLE 8. - Sample Information for Diffused Air Evaporator

Plant (1)	Date Collected (2)	Type Waste (3)	Coagulant (4)	Dosage (mg/l) (5)	Final TOC (mg/l) (6)	Final COD (mg/l) (7)
I	6/75	creosote	polymer B	75	1,165	2,868
II	6/75	croesote and penta	$FeCl_3 + Ca(OH)_2$	100 + 750	655	1,322
IV-P	2/76	penta	polymer A	150	2,880	6,552
IV-P	2/76	penta	$FeCl_3 + Ca(OH)_2$	100 + 750	3,060	6,511
IV-C	2/76	creosote	polymer A	200	4,185	9,247
IV-C	2/76	creosote	$FeCl_3 + Ca(OH)_2$	250 + 1,750	3,810	8,706

Note: Initial COD values were 5,696 mg/l for Plant I, 6,862 mg/l for Plant II, 35,828 mg/l for Plant IV-C, and 14,969 for Plant IV-P.

remaining at each time interval. The total amount of air passed through the apparatus was obtained by multiplying the average air flow between sample collection periods by the time elapsed. The equivalent total hydrocarbons then were calculated from this airflow by determining the air mass flow rate and multiplying this by the equivalent hydrocarbon concentration. Finally, the values for the above parameters were plotted versus the cumulative percent of water evaporated at each interval.

The graphs resulting from the tests and computations are presented in Figs. 21 through 32. For each sample two series of three graphs are shown. The first graphs show the mass of total carbon, the mass of chemical oxygen demand, and the mass of the wastewater remaining as a function of the percent of water evaporated. The second set of graphs gives the mass of total hydrocarbons as equivalent methane which had been evaporated from the wastewater, the mass of air which has been bubbled through the wastewater, and the mass of wastewater remaining. The wastewater and coagulant used are identified on each graph.

In the typical test the initial rate of TOC and COD removal appeared to be higher than the constant rate which occurred during the remaining portion of the test. This high initial rate is indicated because the initial amount of TOC and COD lie above the straight line established through the other data points. However, this phenomenon only occurred during the evaporation of the first few percent of waste volume.

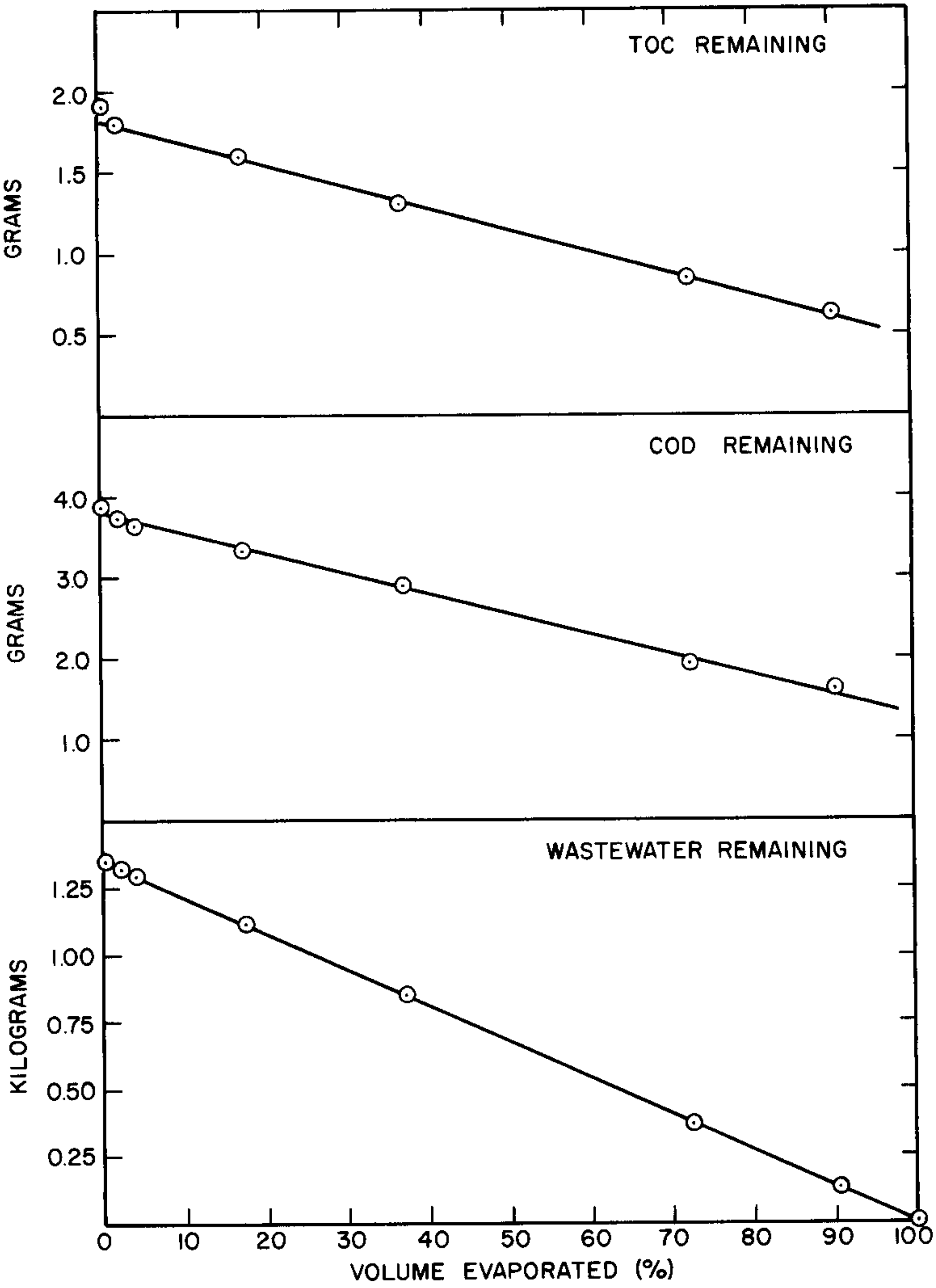


FIG. 21.– TOC and COD Remaining in Batch Evaporation of Plant I Sample Coagulated with Polyelectrolyte

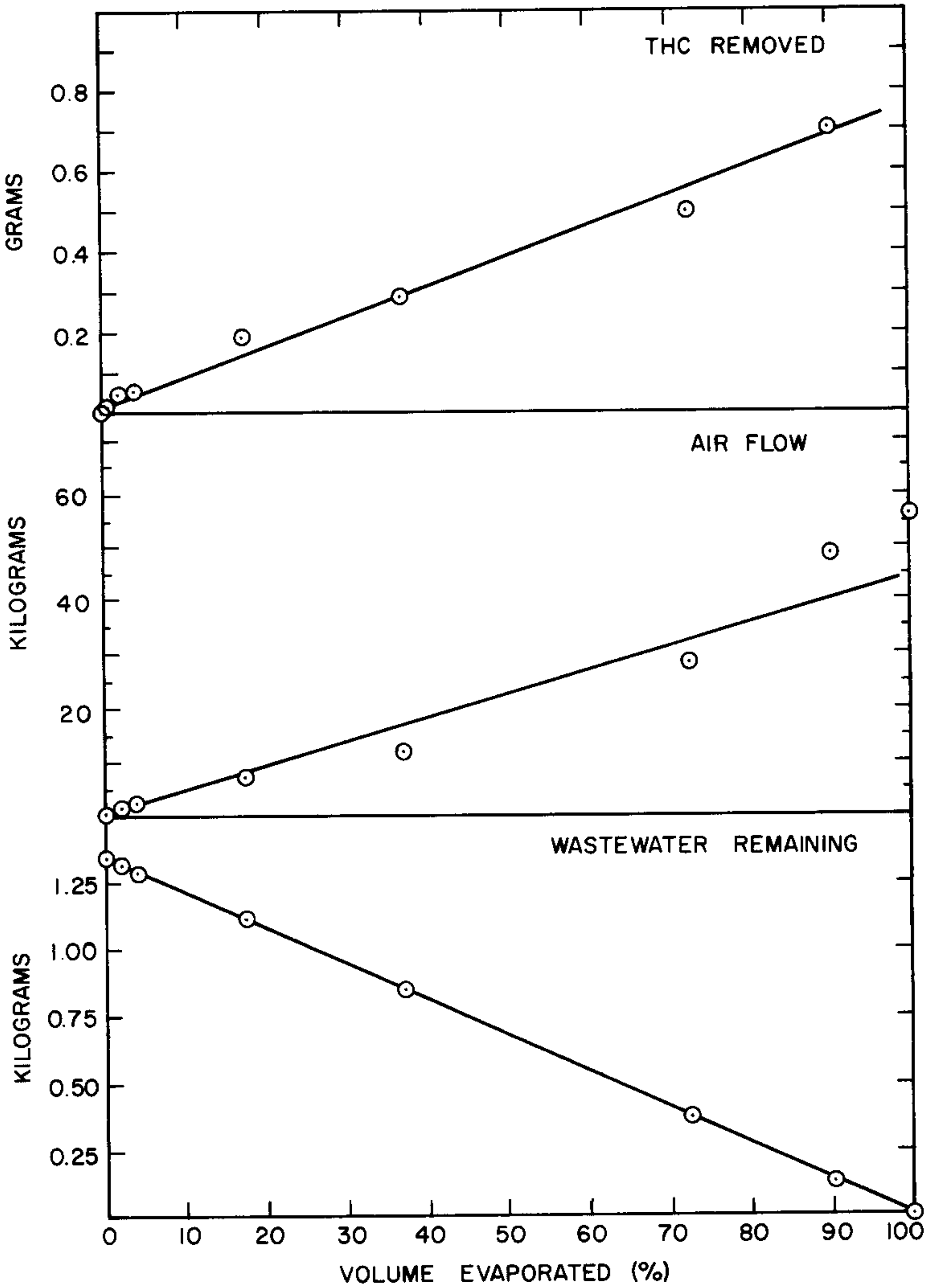


FIG. 22.- THC Removed and Air Flow in Batch Evaporation of Plant I Sample Coagulated with Polyelectrolyte

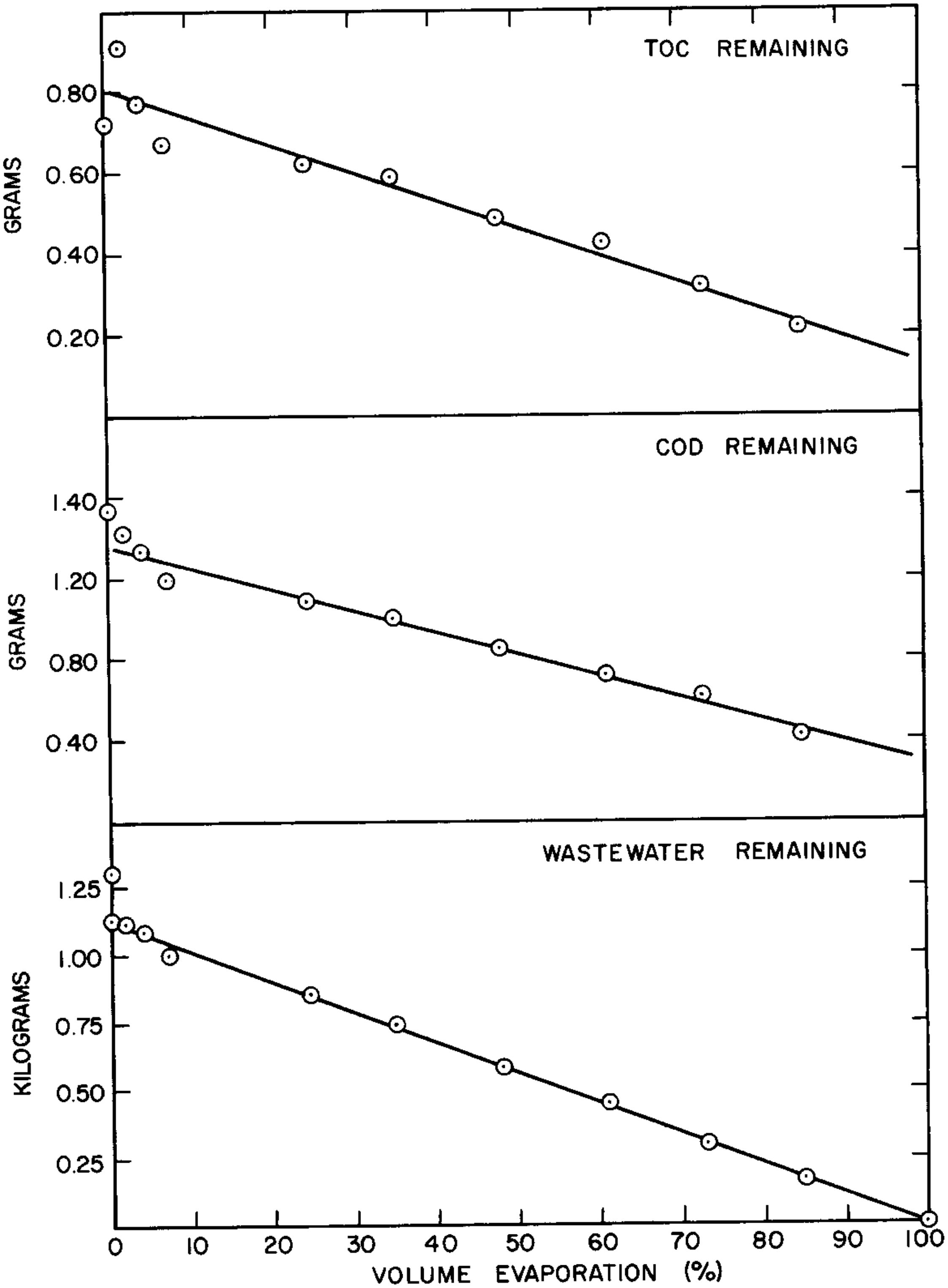


FIG. 23.- TOC and COD Remaining in Batch Evaporation of Plant II Sample Coagulated with Ferric Chloride and Lime

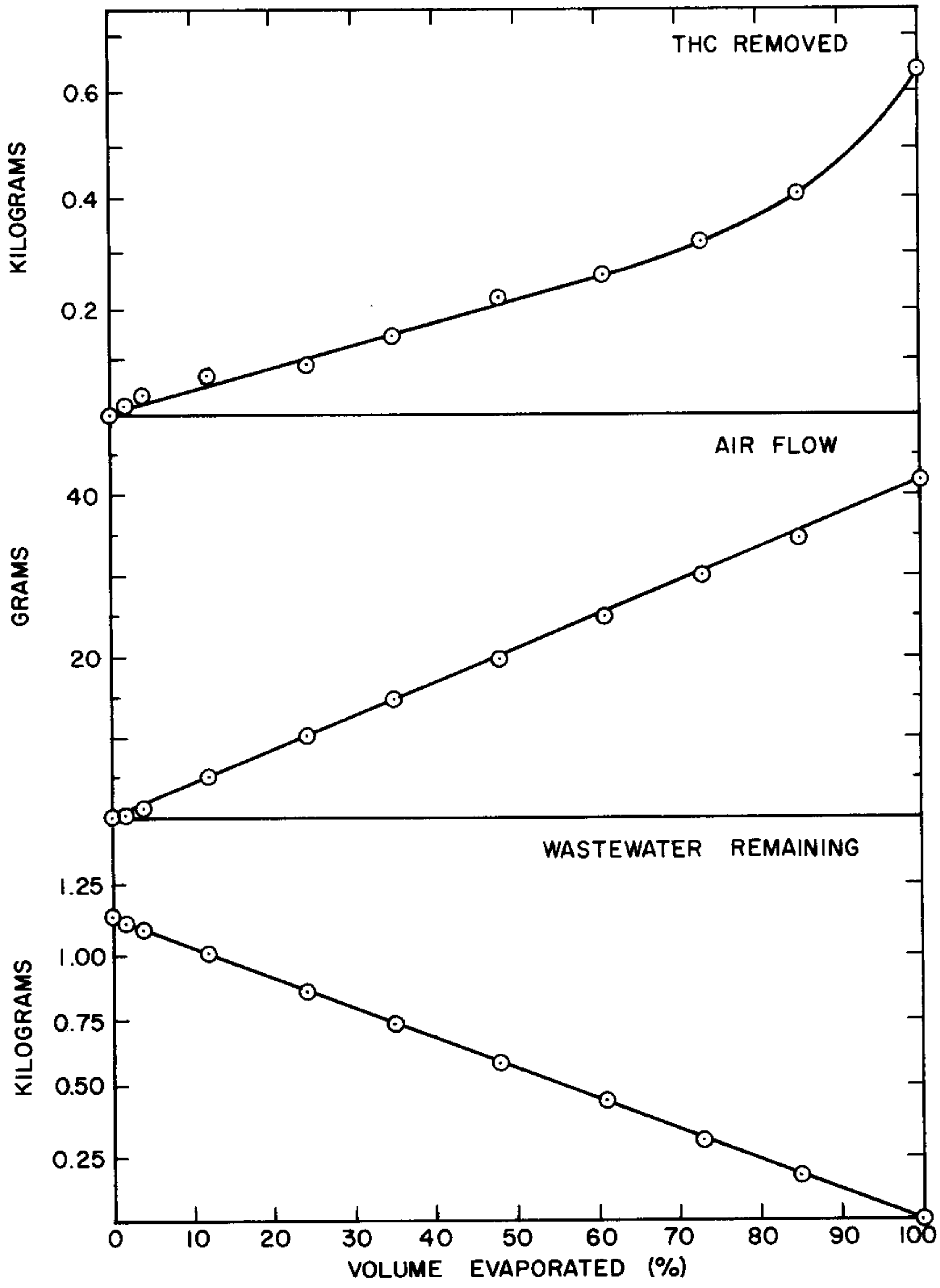


FIG. 24.—THC Removed and Air Flow in Batch Evaporation of Plant II Sample Coagulated with Ferric Chloride and Lime

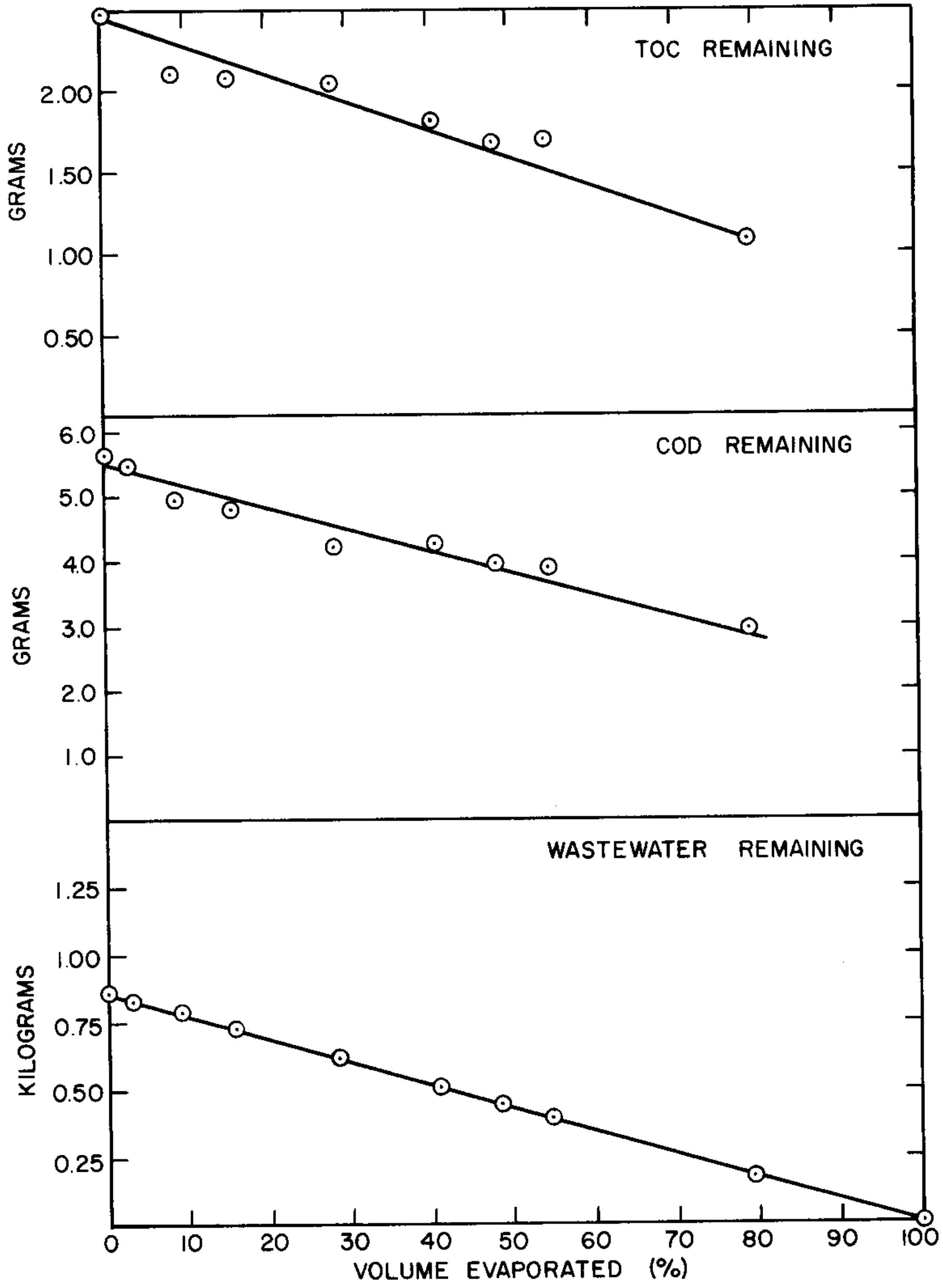


FIG. 25 – TOC and COD Remaining in Batch Evaporation of Plant IV-P Sample Coagulated with Polyelectrolyte

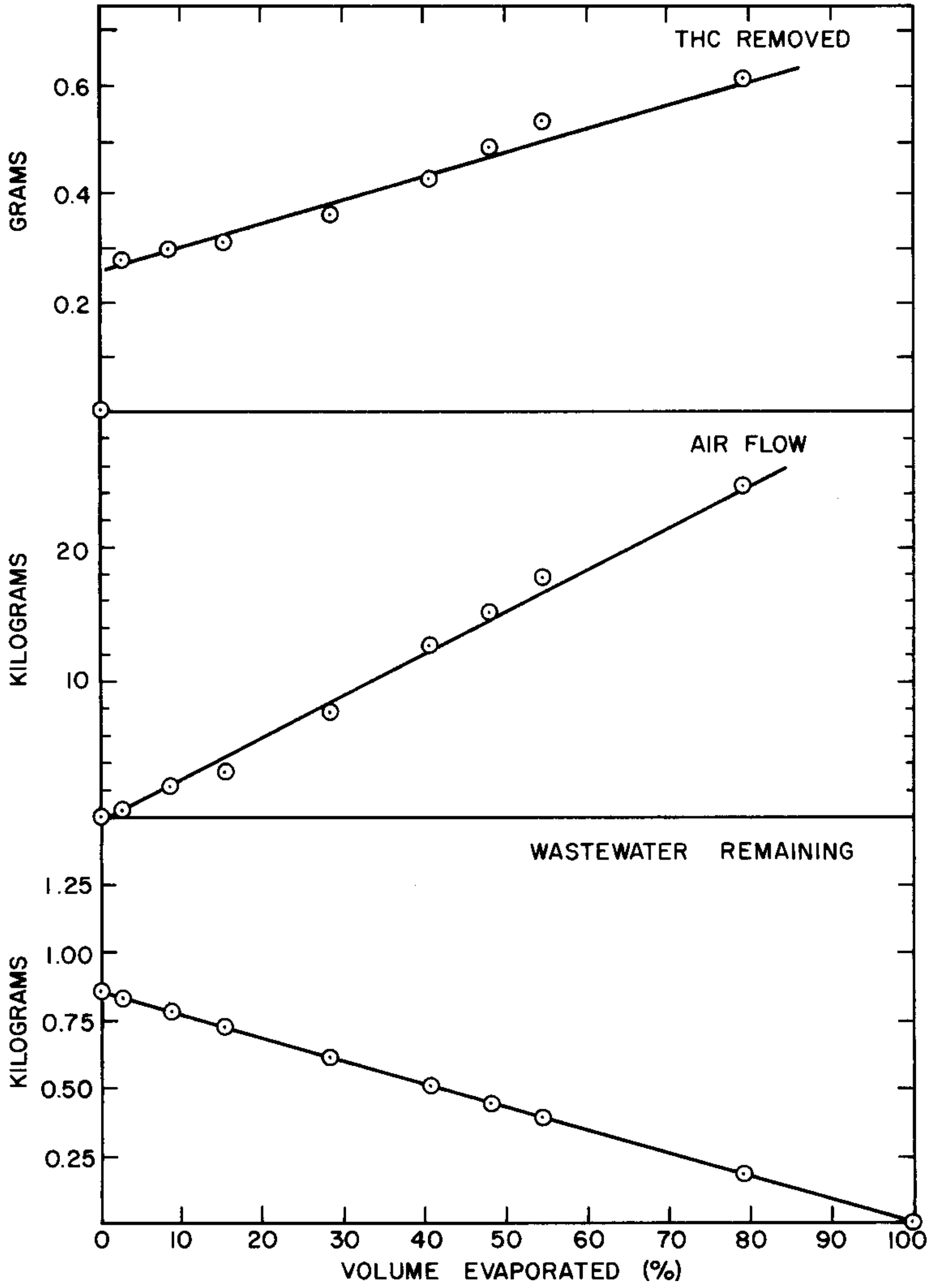


FIG. 26.– THC Removed and Air Flow in Batch Evaporation of Plant IV-P Sample Coagulated with Polyelectrolyte

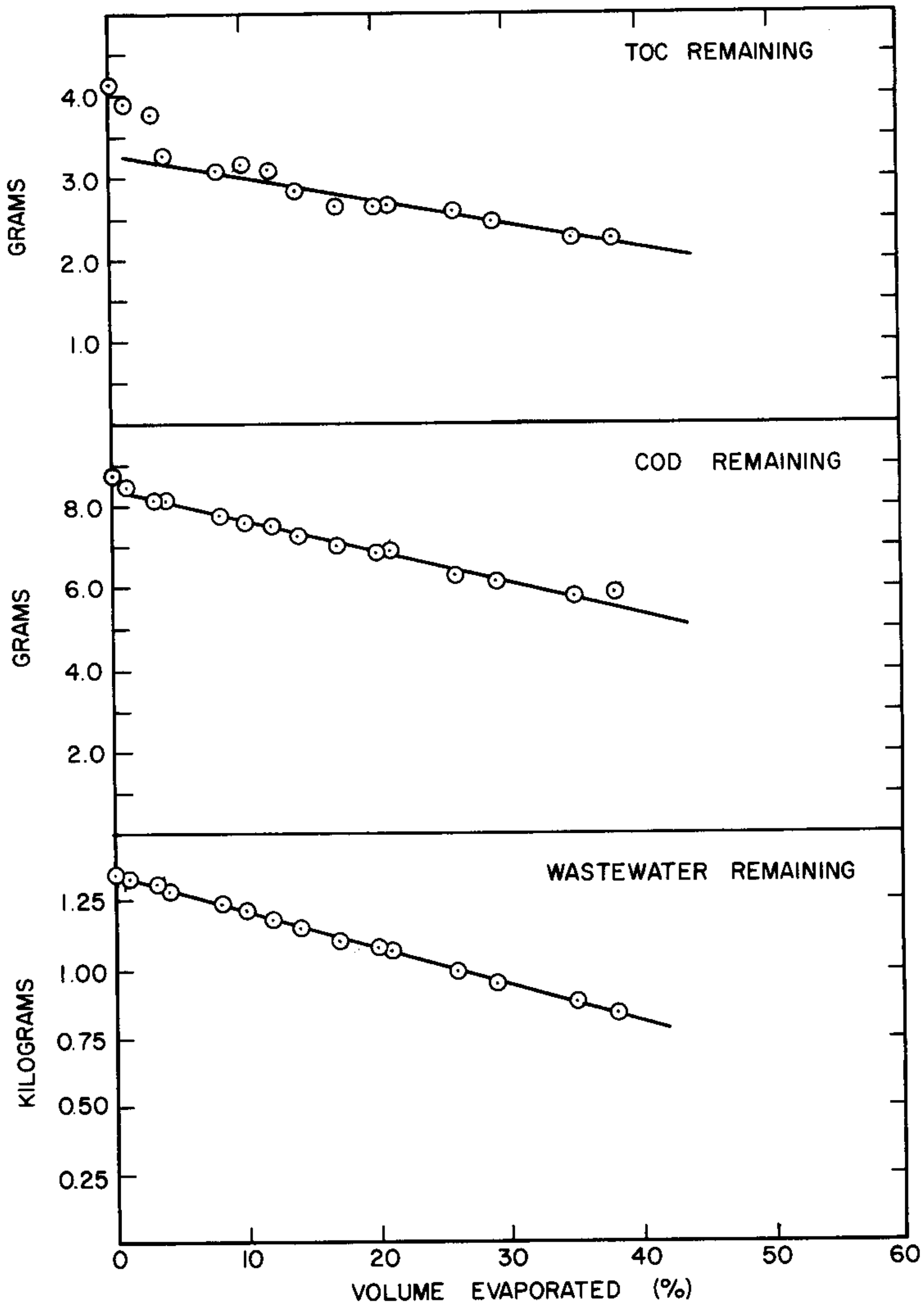


FIG. 27.– TOC and COD Remaining in Batch Evaporation of Plant IV-P Sample Coagulated with Ferric Chloride and Lime

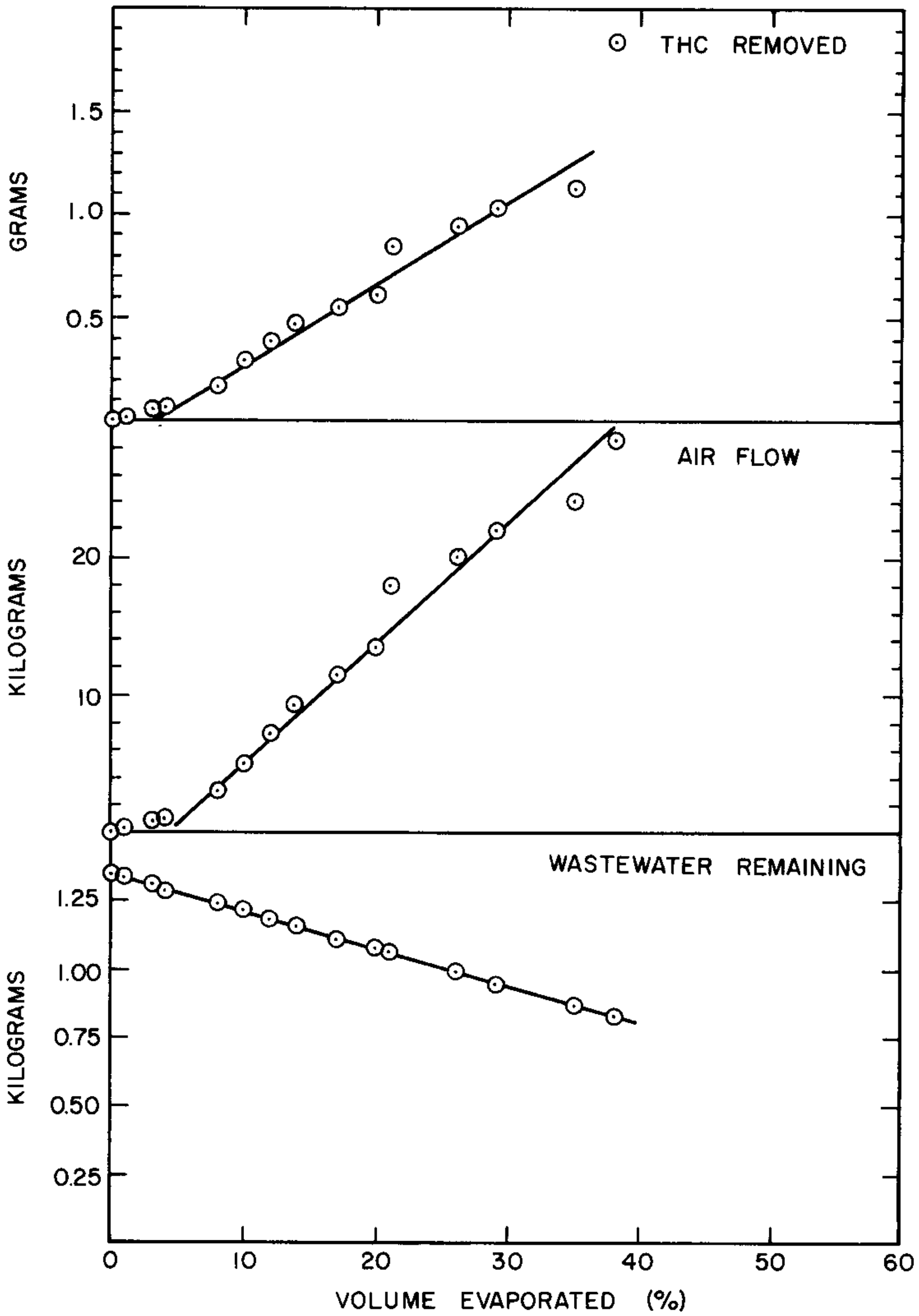


FIG. 28.- THC Removed and Air Flow in Batch Evaporation of Plant IV-P Sample Coagulated with Ferric Chloride and Lime

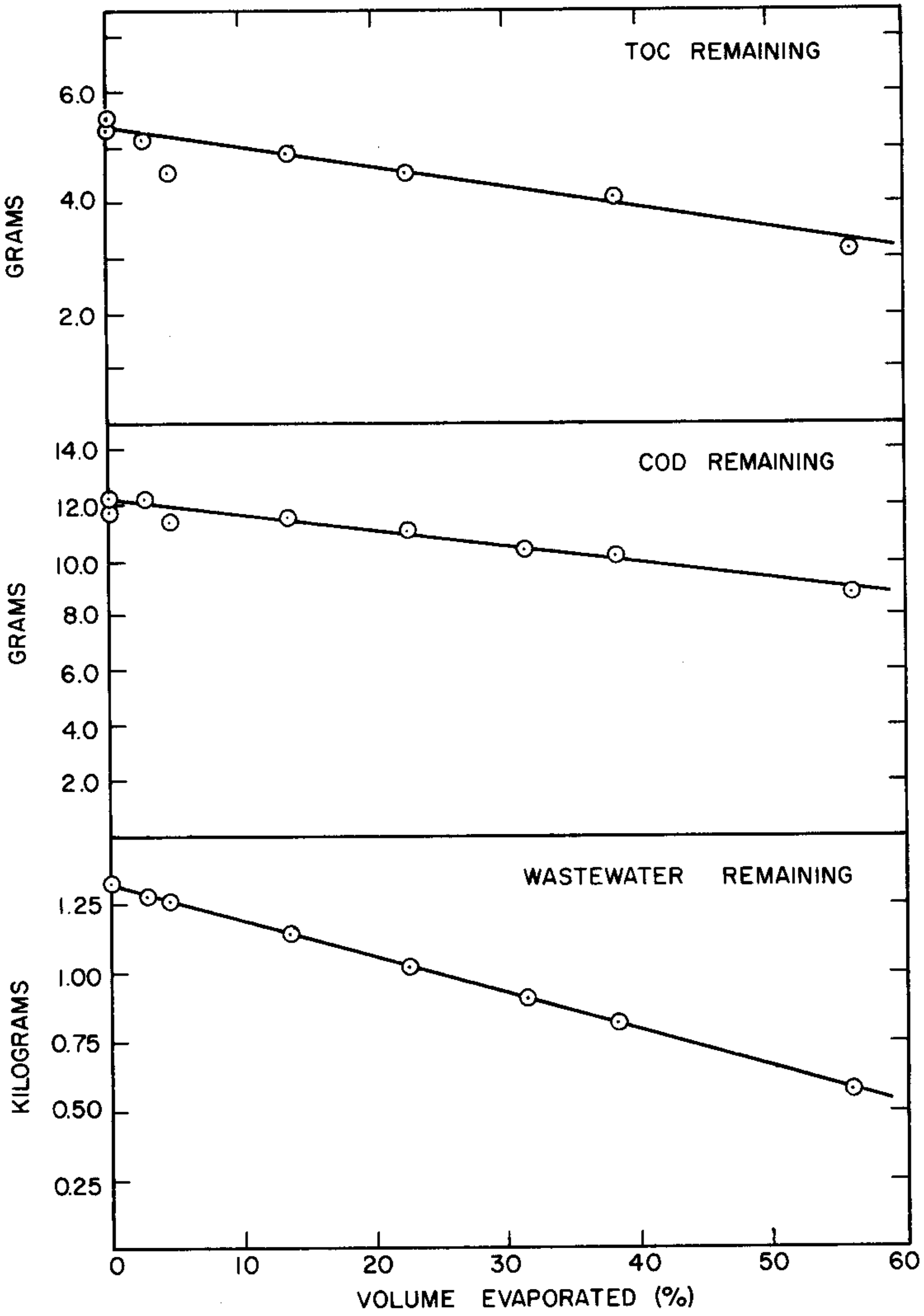


FIG. 29.- TOC and COD Remaining in Batch Evaporation of Plant IV-C Sample Coagulated with Polyelectrolyte

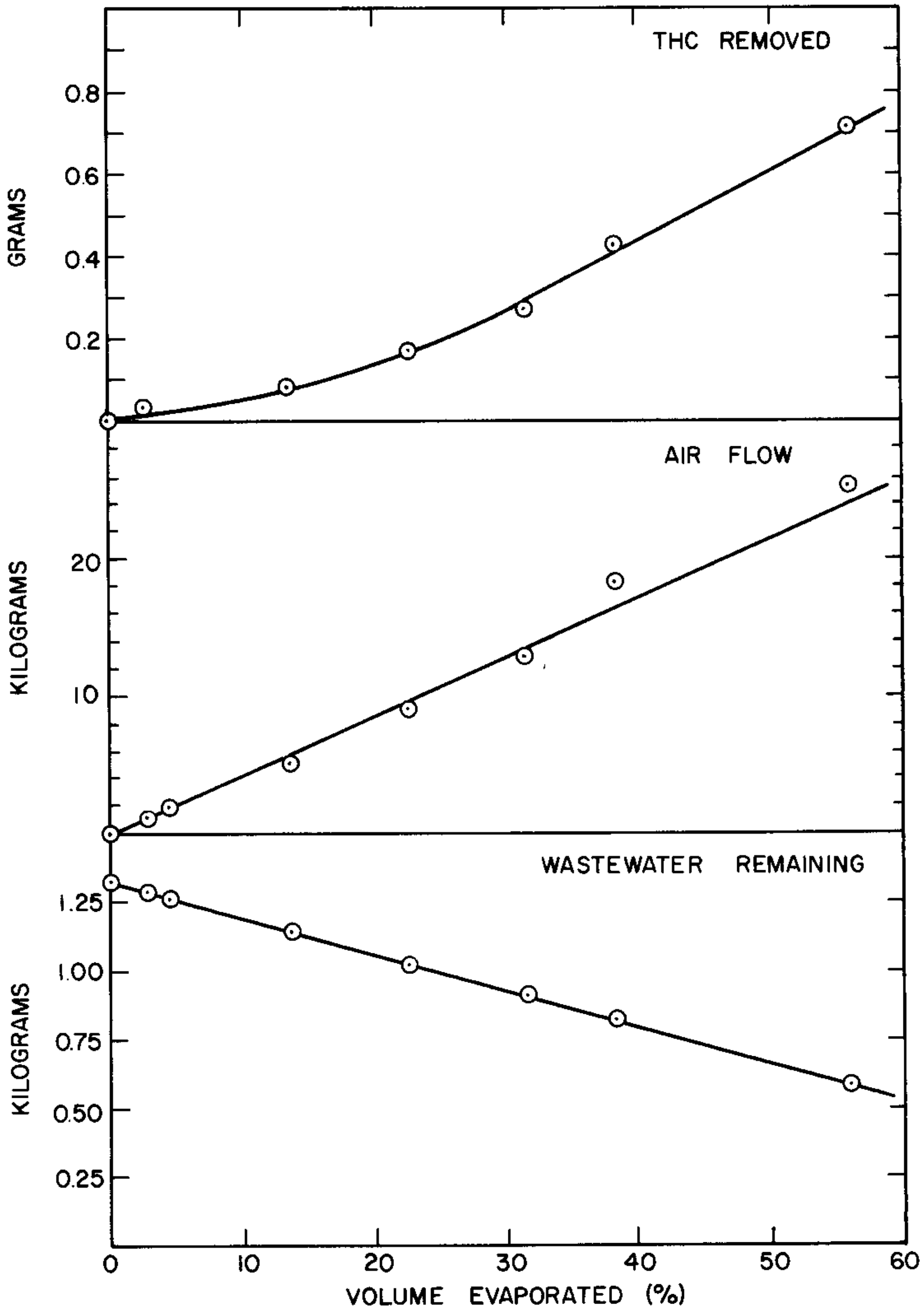


FIG. 30.– THC Removal and Air Flow in Batch Evaporation of Plant IV-C Sample Coagulated with Polyelectrolyte

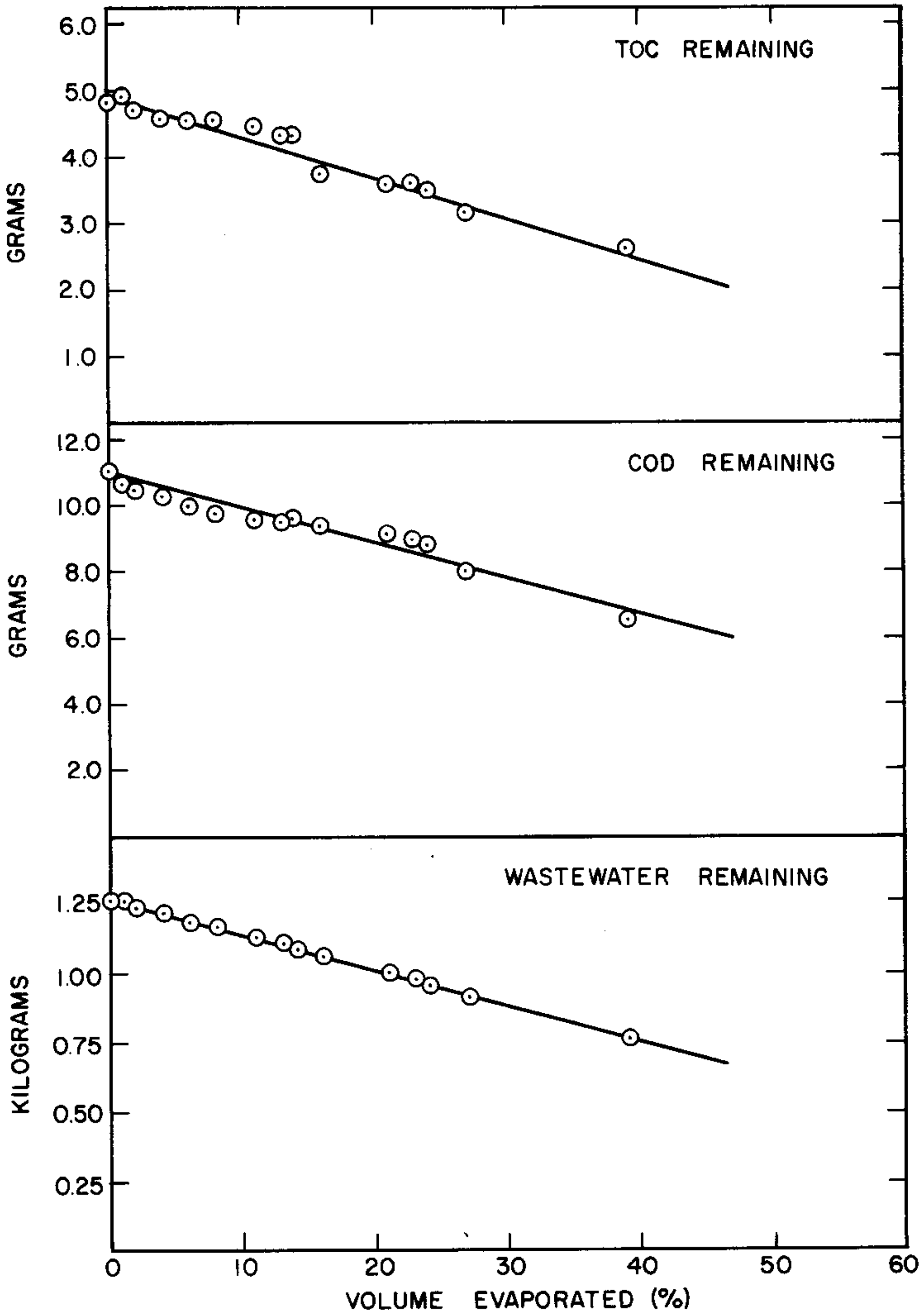


FIG. 31.- TOC and COD Remaining in Batch Evaporation of Plant IV-C Sample Coagulated with Ferric Chloride and Lime

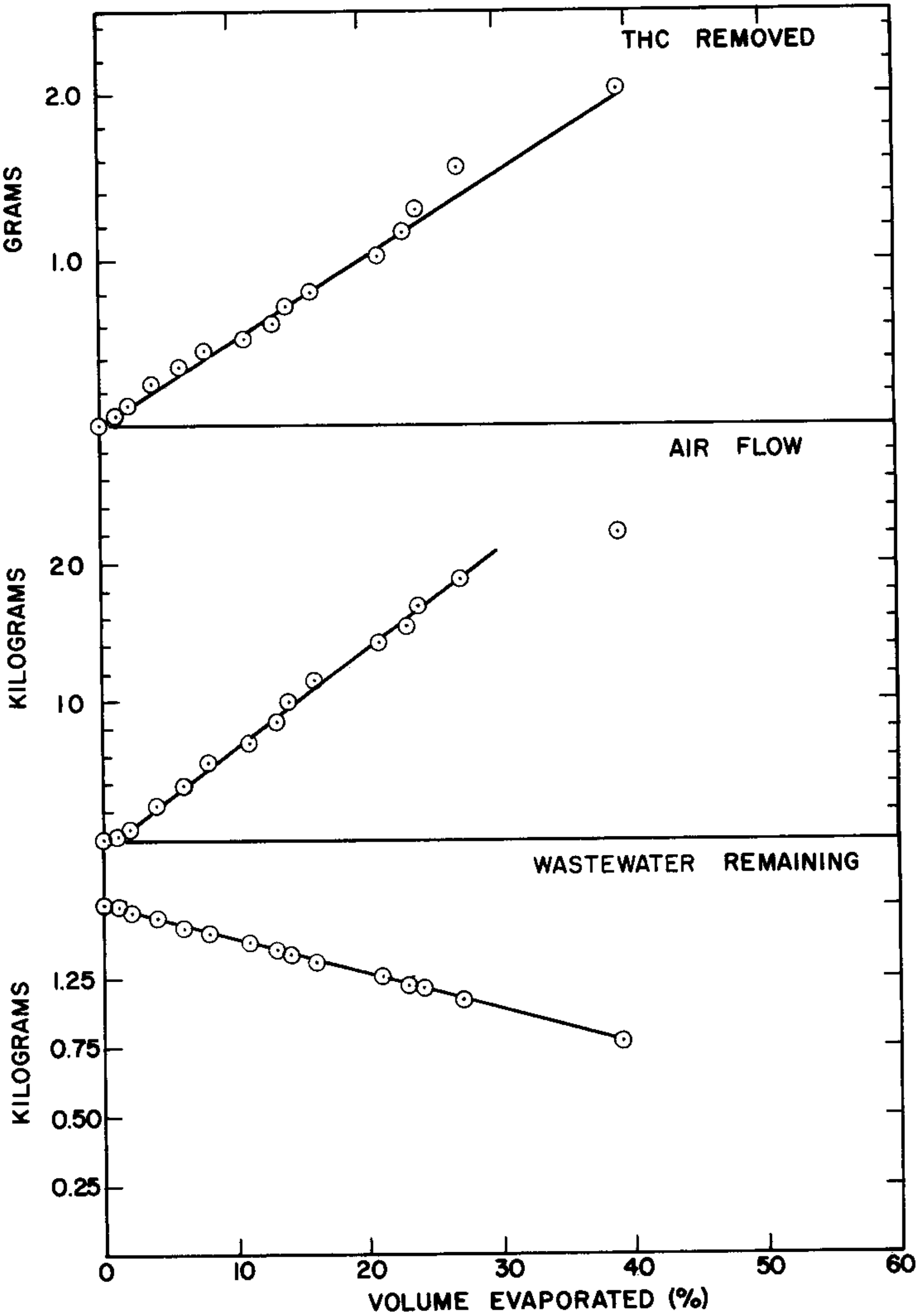


FIG. 32.- THC Removal and Air Flow in Batch Evaporation of Plant IV-C Sample Coagulated with Ferric Chloride and Lime

The hydrocarbon emmissions measured were somewhat erratic. In two tests the readings are obviously in error, but the remainder of the tests appear consistent enough to indicate emmission ratios. Once again, these ratios vary considerably from test to test.

Evaluation of Results

Spray chamber test results are consolidated in Table 9. The four tests can be grouped into two pairs of tests, one at a wastewater evaporation rate of about 0.5 kg/hr and the other at about 0.15 kg/hr. The higher rate tests had lower evaporation ratios than the 0.15 kg/hr tests. This indicates that the COD evaporation ratio varies inversely to the wastewater evaporation rate. All of the tests reached and maintained a constant COD evaporation ratio. In three of the four tests an initial period of higher COD evaporation was present indicating that a highly volatile fraction was removed soon after spraying commenced. The volatile component could likely be some light oils present in the wastewater emulsion; since no effort was made to remove the emulsion prior to spraying.

The results obtained from the diffused air evaporation of coagulated and settled wastewaters show that a straight line relationship exists between the amount of water evaporated and the loss of carbon compounds. This relationship is exhibited for TOC, COD, and total hydrocarbons (THC); however, the rates of removal were different in all of the tests as shown in Table 10. Notice that higher initial concentrations correspond to higher evaporation ratios. In

TABLE 9. - Summary of the Results from Spray Evaporation Tests

Test Run Number (1)	Hours Run (2)	Percent Waste Evaporated (3)	Percent COD Evaporated (4)	Evaporation Rate (kg H_2O/hr) (5)	Evaporation Ratio (g COD/g H_2O) (6)
I-A	89	53	49	0.417	0.00149
I-B	82	49	61	0.532	0.00361
I-C	76	23	52	0.166	0.01019
I-D	78	16	29	0.149	0.00869

TABLE 10. - Summary of Results from Diffused Air Evaporation Tests

Sample		Initial Concentration		Evaporation Ratio		
Plant (1)	Coagulant (2)	TOC (mg/l) (3)	COD (mg/l) (4)	TOC (g/g H_2O) (5)	COD (g/g H_2O) (6)	THC (g/g H_2O) (7)
I	Polymer	1,165	2,868	0.0010	0.0019	0.0022
II	$FeCl_3$	655	1,352	0.0006	0.0009	0.0004
IV-P	Polymer	2,880	6,552	0.0018	0.0039	0.0054
IV-P	$FeCl_3$	3,060	6,511	0.0024	0.0028	0.0024
IV-C	Polymer	4,185	9,247	0.0028	0.0047	0.0118
IV-C	$FeCl_3$	3,810	8,706	0.0028	0.0044[a]	0.0038

[a] A later ratio of 0.087 was measured.

fact, if the evaporation ratio is plotted as a function of the initial concentration a reasonably straight line results. Fig. 33 illustrates the data in this form in terms of TOC and COD. This is significant in verifying some of the assumptions necessary to validate the model's operation. It indicates that the vapor concentration is directly proportional to the initial concentration in the liquid phase.

In the diffused air evaporation tests coagulation was used to eliminate the emulsion and thereby reduce the emmission of organic compounds to the atmosphere. This is particularly important for pentachlorophenol wastewaters because the PCP has an affinity for the oil fraction of the emulsion and can be removed to a large degree by coagulation thereby reducing the hazard of volatilizing PCP into the atmosphere.

The results of the two bench scale tests are consistent because both produced a constant evaporation ratio, but the value of this ratio appears to be comparatively low for the spray evaporation tests. An explanation could be that the lighter oils present in the emulsion of the wastewater used for spray evaporation tests was not detected by the COD test because they were volatilized before the COD oxidation could begin. In the diffused air tests the wastewater was flocculated so the presence of remaining light oils would be insignificant.

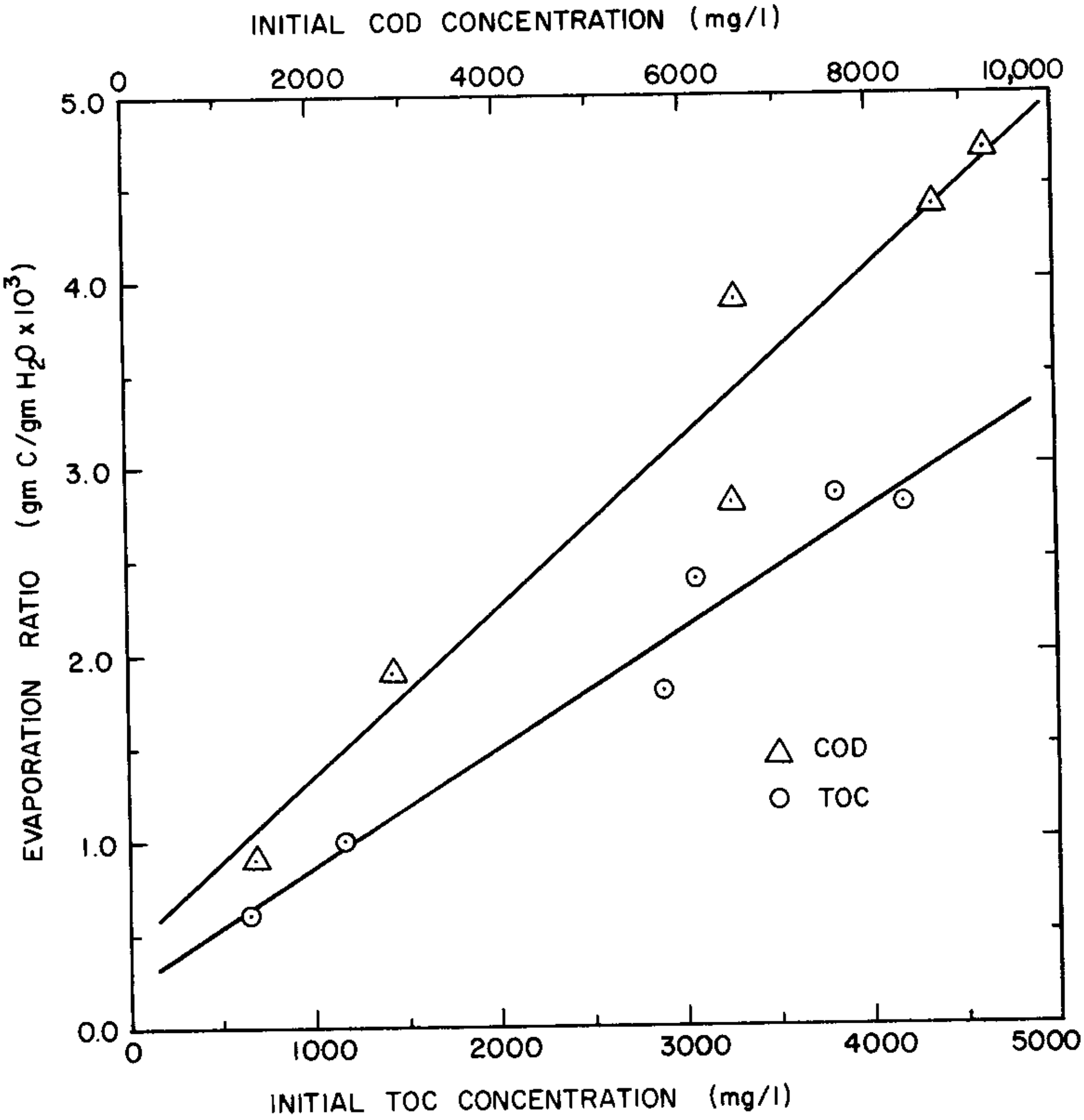


FIG. 33.- Relationship Between Evaporation Ratio and Initial Carbon Content in Batch Evaporation

CHAPTER V

SPRAY POND DESIGN

This chapter presents a procedure for designing atmospheric evaporation spray ponds and guidelines for its application. The procedure is based on an equation for spray pond evaporation which was developed for concentrating brine solutions. After the procedure is presented an example design is worked and some design considerations including air pollution are discussed. The chapter concludes with a suggested treatment scheme for applying atmospheric evaporation.

Theoretical Background

Since the theory of evaporation is not common knowledge among environmental engineers, a brief review of the basic concepts employed follows. Psychrometry is the study of the properties which exist in a gas-vapor mixture. Much of psychrometry is devoted to the air-water system. Some important definitions and relationships from psychrometry are as follows.

Absolute humidity (H) is the mass of water vapor contained in a unit mass of air. Usually ideal gas behavior is assumed and for the air-water system this gives,

$$H = \left(\frac{M_v}{M_a}\right)\left(\frac{P_v}{P_a - P_v}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

where H = the absolute humidity; M_v = the molecular weight of water vapor; M_a = the molecular weight of air; P_v = the partial pressure of water vapor; and P_a = the total atmospheric pressure.

Relative humidity (H_r) is the partial pressure of the water vapor in air divided by the vapor pressure of water at that air temperature, usually expressed as a percent. Therefore,

$$H_r = \frac{P_v\,(100)}{P_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

in which P_s = the vapor pressure of water at that temperature.

Wet bulb temperature (T_w) is the temperature reached by a water surface when it is in dynamic equilibrium with its surrounding. This occurs when the rate of heat transfer to the surface by convection equals the rate of heat transfer away from the surface due to evaporation.

In humidification, moisture is transferred to the air in immediate contact with the water by evaporation, and this moist air then diffuses into the drier atmosphere. Simultaneous transfer of heat and mass takes place according to the relationships of thermodynamics. The mass transfer is given by, (28)

$$E = k_g \left(\frac{(P_s - P_v)}{P_a}\right)\left(\frac{M_v}{M_a}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3$$

in which E = the rate of mass transfer in units of mass per hour; k_g = the mass transfer coefficient in units of mass per hour per unit humidity difference; P_s = the saturation vapor pressure;

P_v = the actual partial pressure of water vapor in the air; P_a = the atmospheric pressure; M_v = the molecular weight of the vapor; M_a = the molecular weight of air; and the heat transfer is given by,

$$Q = h_c (T - T_w) \quad \ldots\ldots\ldots\ldots \quad 4$$

where Q = the rate of heat transfer in units of heat per hour; h_c = the heat transfer coefficient in units of heat per hour per degree temperature difference; T = the atmospheric (dry-bulb) temperature; and T_w = the wet-bulb temperature.

The heat lost in evaporation is known as the latent heat of vaporization, and the loss of this heat causes the water temperature to decrease. For a falling drop of water, the water surface remains at the wet-bulb temperature, and it is the water within the drop that cools. Therefore, in Equation 3, P_s is the water vapor pressure at the wet-bulb temperature.

The evaporation of volatile components is approximated by an equation commonly used in distillation of organic compounds. It gives the composition of the vapor produced in terms of mole fractions and partial pressures of the substances being volatilized. At any time during the evaporation of a mixture of two substances the mole ratio of the vapor is,

$$\frac{n_A}{n_B} = \left(\frac{f_A}{f_B}\right)\left(\frac{p_A}{p_B}\right) \quad \ldots\ldots\ldots\ldots \quad 5$$

where n_A and n_B are the moles of each substance A and B in the vapor phase; f_A and f_B are the mole fractions of each substance in the liquid phase; and p_A and p_B are the vapor pressures of the two volatile components (33). Although this only applies to a two component system, it illustrates the principle involved.

Since the concentration of volatiles in the liquid phase is on the order of one-hundreth of a percent, their effect upon the vapor pressure of water will be assumed negligible for design purposes. The effects of non-volatile dissolved solids are given by the graph shown in Figure 34 (28). Although this graph is for solutions of sodium chloride, the vapor pressure depression of a 40,000 mg/l solution is only three percent. As long as the dissolved solids do not increase above six percent, their effect can generally be neglected.

Evaporation Equation for Spray Ponds

The evaporation equation to be used in design calculations comes from the basic mass transfer relationship, Equation 3; however, as the air passes over the pond its humidity increases. This increases the partial pressure of the water vapor in the air, and thus the driving force is reduced, as well as the rate of evaporation. Consequently, the last spray nozzle over which the air passes is evaporating at a lower rate than the first spray nozzle due to the increase in humidity over the pond. Lof, et al. (28) have developed an equation to account for this decrease in evaporation rate. The change

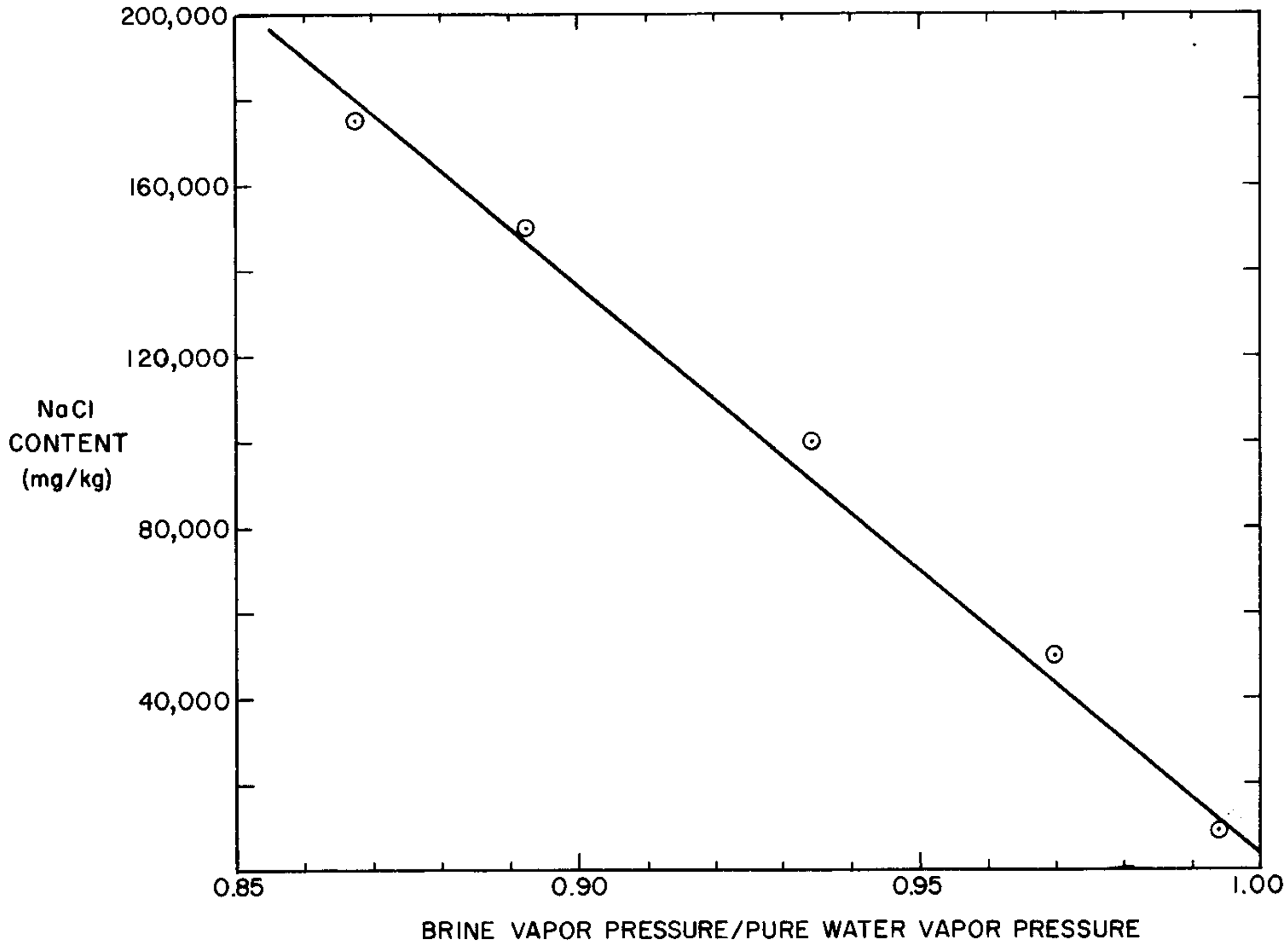


FIG. 34.- Vapor Pressure Depression Due to Salinity (28)

in evaporation along the path of the wind is given by an exponential decay function of the general form $y = k(1-e^{-x})$. The equation by Lof, et al. is,

$$E_u = 5280\ Wh\rho \left[1 - e^{-\left(\frac{k_y'L + C_w WL}{5280\ Wh\rho}\right)}\right] \left(\frac{P_s - P_v}{P_a}\right) \left(\frac{M_v}{M_a}\right) \quad . \ . \ . \ . \ . \ . \ . \ . \ 6$$

in which E_u = the evaporation in pounds per hour per foot of pond width; W = the wind speed in miles per hour; h = the height of the spray in feet; ρ = the density of air in pounds per cubic foot; k_y' = the nozzle mass transfer coefficient in (pounds)/(hr)(ft^2 surface area)(humidity difference); L = the length of the pond in the direction of wind in feet; C_w = the surface mass transfer coefficient in (pounds)/(hr)(mph wind speed)(ft^2 surface area)(unit humidity difference); P_s = the saturation vapor pressure of the air in atmospheres; P_a = the atmospheric pressure in atmospheres; M_v = the molecular weight of the vapor which for water is 18 pounds per pound mole; and M_a = the molecular weight of air which is 29 pounds per pound mole.

The variables in this equation can be divided into two groups: (1) design parameters and (2) meteorological conditions. The design parameters are the spray height, the mass transfer coefficients, and the length of the pond. The meteorological conditions are the wind speed, the partial pressure of water vapor in the air, the saturated vapor pressure of water for that temperature, and the air density. The resulting evaporation (E_u) in Equation 6 is in terms of pond width.

Equation 6 expresses the evaporation rate for a given set of meteorological conditions. However, applying it to a design procedure requires modification to take into account fluctuations in meteorological conditions and other design factors such as variations in pond depth, the pond width, etc.

To express the evaporation in cubic feet per month as a function of relative humidity, the driving force can be rewritten as,

$$\frac{P_s - P_v}{P_a} = \frac{(1 - H_r)\, P_s}{P_a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 7$$

where H_r is the relative humidity expressed as a fraction.

The ratio of the molecular weights, M_v and M_a, is,

$$\frac{M_v}{M_a} = \frac{18}{29}$$

Substituting these relationships in Eq. 6 and multiplying gives,

$$E_u = 3277\ Wh\rho \left[1 - e^{-\left(\frac{k'_y L + C_w WL}{5280\ Wh\rho}\right)}\right]\left(\frac{(1\text{-}Hr)\ P_s}{P_a}\right) \quad \ldots\ldots\ldots \; 8$$

The evaporation can be converted from pounds per hour per foot width to cubic feet per month (E) by multiplying the right side of Equation 8 by the number of hours in the month, the inverse of the unit weight of the water, and the pond width (RL). The width is given as a ratio (R) times the length (L); the number of hours in the month is 24 times the number of days (n); and the unit weight of water is 62.4 pounds per cubic foot. Incorporating these in Equation 8 gives,

$$E \;=\; 1260.5\ Wh\rho \left[1 - e^{-\left(\frac{k_y'L \,+\, C_w WL}{5280\ Wh\rho}\right)}\right] \left(\frac{(1\text{-}Hr)\ P_s}{P_a}\right) \ RLn \ .\ .\ .\ .\ .\ 9$$

in which E = the cubic feet per month of evaporation. In this form, the equation developed by Lof, et al. may be applied for design.

Design Procedure

The design procedure uses the evaporation equation, Equation 9, to predict the performance of an assumed pond configuration. The operating parameters such as nozzle height, spacing, discharge pressure, and size are initially selected. An appropriate length to width ratio and an initial trial length are chosen and the evaporation equation is solved for each month of the year. The total annual evaporation is entered into a water balance which includes precipitation and inflow. The water balance gives the change in pond depth that would be experienced using the assumed pond size. If the depth increases over a year, a larger pond is required. Conversely, if the depth decreases, a smaller pond will be adequate.

Several assumed lengths are used in the evaporation equation, Equation 9, to determine the length which results in a zero annual depth change. After several lengths have been tried, a plot of the change in depth versus length can be used to solve the equation. The detailed procedure is as follows:

Step 1. Determine the monthly plant flows to be used in the design of the spray pond.

Step 2. Obtain five or ten year averages of temperature, relative humidity, barometric pressure, precipitation, and pan evaporation for each month of the year. Also, data giving the magnitude and direction of winds and their frequency should be obtained from a nearby weather station.

Step 3. Select the wind speed for design purposes and determine the monthly values for the percent of the time the pond is operating.

Step 4. Select the operational parameters to be used in the first assumed design. These include nozzle size, discharge pressure, nozzle density (spacing), and height. From these parameters an appropriate mass transfer coefficient can be chosen from the tables in Appendix III.

Step 5. Calculate from the monthly weather data the air density for each month using the equation,

$$\rho = \frac{39.66\ P_a}{460 + T_a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 10$$

in which ρ = the air density in pounds per cubic foot, P_a = the atmospheric pressure in atmospheres, and T_a = the atmospheric temperature (dry bulb) in degrees Farenheit.

Step 6. Calculate the saturation vapor pressure, P_s, in atmospheres for each month. The vapor pressure of water in millimeters of mercury is available in tabular form for various values of temperature in degrees Centigrade (24). The vapor pressure in atmospheres is the value taken from the table divided by 760 millimeters per atmosphere.

Step 7. Select a constant width to length ratio, R, and an initial pond length, L.

Step 8. Solve the evaporation equation, Equation 9, for each month of the year. The following substeps give the procedure for tabular computations.

(a) Calculate the air mass flow rate per unit width of pond for each month. The equation for air flow, G, in pounds per hour per foot of pond width is,

$$G = 5280 Wh\rho \quad \text{. . . . . } 11$$

in which W = the wind speed in miles per hour; h = the height of the spray in feet; and ρ = air density in pounds per cubic foot.

(b) Calculate the mass transfer coefficient per foot of pond width, k_g, from the equation,

$$k_g = k_y' L + C_w WL \quad \text{. . . . . } 12$$

in which k_y' = the nozzle mass transfer coefficient in pounds of water evaporated per hour per square foot of pond surface; L is the pond length in feet; and C_w is the surface mass transfer coefficient in pounds of water evaporated per hour per square foot of pond surface per mile per hour wind speed.

(c) Calculate the exponential term in Equation 9 for each month from,

$$1 - e^{-\left(\frac{k'_y L + C_w WL}{5280\ Wh\rho}\right)} = 1 - e^{-k_g/G} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad 13$$

(d) Calculate the driving force, i.e., the humidity difference, for each month. The driving force is previously given in Equation 7.

(e) Multiply to obtain the product of G from Step 8(a), the value from Equation 13 in Step 8(c), the driving force from Step 8(d), and 1260.5/5280 or 0.238727. Then, multiply the resulting product times the width (RL) and times the number of days in the month (n). This gives the evaporation in cubic feet per month, E.

Step 9. Sum the monthly rainfall, evaporation, and plant flows to annual totals, then convert the annual rainfall to feet.

Step 10. Convert the volume of water evaporated into feet of pond depth by dividing the evaporation by the area of the pond in square feet.

Step 11. Convert plant flows to cubic feet, then convert to feet of pond depth by dividing by the area of the pond in square feet.

Step 12. Multiply the evaporation in feet by the average annual wind frequency.

Step 13. Calculate a water balance on an annual basis for the pond as given by the equation,

$$\Delta d = q + r - e \qquad 14$$

where Δd is the change in depth of the pond in feet; q is the inflow expressed in feet; r is the rainfall expressed in feet, and e is the evaporation expressed in feet.

Step 14. Repeat steps 7 through 13 using two or more different pond lengths. The same length to width ratio must be maintained in these computations.

Step 15. Plot the annual change in depth as a function of length and connect the points with a best fit curve.

Step 16. Select the length which indicates zero annual depth change. This is the computed length for the design assumed.

Step 17. Repeat Step 8 for the design length.

Step 18. Compute a water balance and a cumulative depth change ($\Sigma\Delta d$) for each month.

Step 19. Determine the depth variation over one year by taking the difference between the maximum and minimum cumulative depth changes. This may be done graphically by plotting cumulative depth change versus time and measuring the difference between the largest and smallest values.

Step 20. Add the desired freeboard and storage depth to the depth variation determined in Step 19 to give the design depth.

The design procedure may be repeated selecting different operating parameters to obtain several designs for economic optimization, if desired.

An Example Design

To illustrate the procedure, design computations will be made for a hypothetical wood preserving plant located at College Station, Texas. Actual weather data is used and the plant flow is assumed to be 15,000 gallons per day. This is typical of a large preserving plant using current technology.

Step 1 requires monthly plant flows, thus, the daily flow is multiplied by the number of days in each month. The monthly flows are tabulated in Line 1 of Table 11. For Step 2, the weather data is collected from the College Station, Texas weather station and recorded in Table 11. All values are recorded in the units reported and represent monthly averages of hourly records. The wind frequency data for Step 3 represents the percent of the time the wind is between one and twelve miles per hour which is when the pond is assumed to be operating. An average speed of five miles per hour is used in the calculations.

Step 4 requires the selection of the operating parameters. Table 12 presents some common ranges of values as guidelines. The parameters chosen were: nozzle size of one-half inch, discharge pressure of 5 pounds per square inch, nozzle density of 4.4 per thousand square feet, and nozzle height of 25 feet. Perry (34) recommends that one foot of spray height should be allowed for each pound per square inch discharge pressure. This gives a spray curtain height of 30 feet since the nozzles are 25 feet above the

TABLE 11. - Design Tabulations for a 15,000 GPD Plant at College Station, Texas

Line (1)	Variable (2)	January (3)	February (4)	March (5)	April (6)	May (7)	June (8)	July (9)	August (10)	September (11)	October (12)	November (13)	December (14)	Annual (15)
1	Q, 1000 gal	465	420	465	450	465	450	465	465	450	465	450	465	5,475
2	T_a, °F	49.8	53.1	58.7	68.5	75.0	81.2	84.4	84.4	79.0	69.3	58.9	52.0	65.2[a]
3	H_r, %	75	65	70	76	75	72	68	66	71	68	67	70	
4	P_a, in. Hg	29.21	29.30	29.32	29.29	29.22	29.31	29.33	29.33	29.35	29.31	29.40	29.41	
5	r, in.	2.37	3.42	2.03	4.77	4.04	3.59	2.48	2.11	4.83	3.25	1.21	3.33	37.43
6	f, %	72	66.5	69	72	72	75	86	85	78	81	75	70	75.1[a]
7	ρ, pcf	0.07595	0.07569	0.07493	0.07346	0.07240	0.07179	0.07141	0.07141	0.07218	0.07340	0.07510	0.07614	
8	P_s, in. Hg	0.3599	0.4070	0.4982	0.7025	0.8752	1.0735	1.1902	1.1902	0.9990	0.7220	0.5018	0.3905	
9	G, lb/hr-ft	60,152	59,946	59,345	58,180	57,340	56,858	56,557	56,557	57,167	58,133	59,479	60,303	
10	F	0.002878	0.004857	0.005097	0.005756	0.008364	0.010255	0.012986	0.013797	0.009871	0.007882	0.005632	0.003983	
11	L = 400 ft													
12	k_g = 5,372													
13	$1 - e^{-k_g/G}$	0.08544	0.08572	0.08655	0.08820	0.08943	0.09016	0.09061	0.09061	0.08969	0.08827	0.08636	0.08524	
14	E, ft^3	43,785	66,728	77,494	84,614	126,966	150,591	197,003	209,306	144,989	119,725	82,874	60,599	1,364,641
15	L = 450 ft													
16	k_g = 6,044													
17	$1 - e^{-k_g/G}$	0.09559	0.09590	0.09682	0.09866	0.1000	0.1008	0.1013	0.1013	0.1003	0.09874	0.09662	0.09536	
18	E, ft^3	55,071	83,989	97,533	106,484	159,769	189,489	247,881	263,361	182,444	150,668	104,306	76,277	1,717,272
19	L = 500 ft													
20	k_g = 6,715													
21	$1 - e^{-k_g/G}$	0.1056	0.1060	0.1070	0.1090	0.1105	0.1114	0.1120	0.1120	0.1108	0.1091	0.1068	0.1054	
22	E, ft^3	67,664	103,121	119,744	130,719	196,116	232,585	304,248	323,249	223,946	184,958	128,061	93,656	2,108,067
23	L = 550 ft													
24	k_g = 7,387													
25	$1 - e^{-k_g/G}$	0.1156	0.1159	0.1170	0.1192	0.1209	0.1218	0.1224	0.1224	0.1212	0.1193	0.1168	0.1153	
26	E, ft^3	81,426	124,093	144,089	157,278	235,943	279,805	366,006	388,864	269,420	222,537	154,099	112,706	2,536,266
27	L = 600 ft													
28	k_g = 8,058													
29	$1 - e^{-k_g/G}$	0.1254	0.1258	0.1270	0.1293	0.1311	0.1321	0.1328	0.1328	0.1315	0.1294	0.1267	0.1251	
30	E, ft^3	96,376	146,873	170,532	186,120	279,189	331,075	433,058	460,103	318,797	263,346	182,380	133,401	3,000,125

[a] Annual average

TABLE 12. - Spray Pond Design Recommendations from Perry (34)

Design Parameter (1)	Typical Range (2)	Minimum (3)	Maximum (4)
Nozzle capacity, gpm	35 - 50	10	60
Nozzles per 12-ft of pipe	5 - 6	4	8
Nozzle height above pond sides, ft	7 - 8	2	10
Nozzle pressure, psi	5 - 7	4	10
Size of nozzles and nozzle arms, in	2	1¼	2½
Distance between spray laterals, ft	25	13	38
Distance from nozzles to side of pond w/o fence, ft	25 - 35	20	50
Distance from nozzles to side of pond w/fence, ft	12 - 18	10	25
Height of louver fence, ft	12	6	18
Depth of pond basin, ft	4 - 5	2	7
Friction loss per 100 ft pipe, inches of water	1 - 3	-	6
Design wind velocity, mph	5	3	10

pond. The nozzle mass transfer coefficient is selected from Table 24 in Appendix III and is 2144 pounds per hour per unit humidity difference driving force. Multiplying by the nozzle density gives the spray mass transfer coefficient which equals 9.43 pounds per hour per unit humidity difference per square foot of pond area.

In Step 5, the air densities are calculated from Equation 10 and entered in Table 11. In Step 6, the saturation vapor pressures (24) are entered on Line 8 in the design tabulation. To simplify the design example, a square pond is assumed for Step 7; therefore, the ratio, R, is one. An initial pond length and width of 400 feet is assumed for the design.

In Step 8, the solution of Equation 9 is initiated. The calculations are arranged to provide a tabulation for the solution. To illustrate the procedure, the calculations for January are detailed below:

(a) The mass flow rate of air (G) is given by Equation 11, thus, inserting the appropriate values gives,

$G = 5280\ (5\text{ mph})(30\text{ ft})(0.07595\text{ pcf}) = 60{,}152$ pounds per foot width

(b) The mass transfer coefficient term is calculated from Equation 12 for January as follows,

$k_g = (9.43)(400) + (0.8)(5)(400) = 5373$

The value of k_g is the same for all months. A surface mass transfer coefficient of 0.8 is used in this calculation (28).

(c) The exponential term in Equation 13 is solved for January as follows,

$$1 - e^{-k_g/G} = 1 - e^{-\left(\frac{5372}{60,152}\right)} = 0.08544$$

and is listed in Line 13, Table 11.

(d) The driving force (F) from Equation 6 for January is,

$$F = \frac{(1 - 0.75)\ (0.3599 \text{ in Hg})}{(29.21 \text{ in Hg})} = 0.002878$$

which is shown in Line 10, Table 11.

(e) The evaporation for January is calculated by,

$$E = (0.238727)(60,152)(0.08544)(0.002878)(400)(31) = 43,785$$

and is entered in Line 14, Table 11. Step 8 is repeated for each month and the values are tabulated in Lines 9, 10, 13, and 14.

In Step 9, the monthly values for evaporation (E), rainfall (r), and plant flow (Q) are summed to give the annual totals in Column 14, Lines 1, 5, and 14. Also, the rainfall is expressed in feet as,

$$r = \frac{37.43 \text{ in}}{12 \text{ in/ft}} = 3.12 \text{ feet}$$

In Step 10, the evaporation is converted to feet of depth by dividing by the area to give,

$$e_t = \frac{1,364,461 \text{ ft}^3}{(400 \text{ ft})^2} = 8.53 \text{ feet.}$$

In Step 11, the wastewater flow is converted to depth by,

$$q = \frac{5.475 \times 10^6 \text{ gal}}{(7.48 \text{ gal/ft}^3)(400 \text{ ft})^2} = 4.57 \text{ feet}$$

In Step 12, the total evaporation is multiplied by the annual wind frequency factor,

$e = (8.53)(0.75) = 6.40$ feet

In Step 13, the water balance is,

$\Delta d = 4.57 + 3.12 - 6.40 = +1.29$ feet

Since the annual depth change (Δd) is positive, the assumed length of 400 feet is too small for the design conditions; so in Step 14 the computations are repeated for lengths of 450, 500, 550, and 600 feet and are tabulated in Table 11. The annual depth changes for these lengths are +0.36, -0.28, -0.77, and -1.11 feet, respectively. In Step 15, each annual depth change (Δd) is plotted as a function of length as shown in Figure 35. For Step 16, intercept the curve at zero depth change and project down to get 475 feet, the design length (i.e. the length for which no net accumulation or deficit in pond volume occurs over an average year for the operational parameters assumed).

In Step 17, the monthly evaporation for the design length of 475 feet is calculated as shown in Table 13. In Step 18, a monthly water balance and cumulative depth change ($\Sigma\Delta d$) are calculated and shown in Table 13. The cumulative depth change is plotted versus time in Step 19, and the difference between the largest and smallest depths is determined graphically as shown in Figure 36. The annual depth variation is 1.1 feet to which a freeboard of 3.0 feet and a four month storage volume of 2.1 feet is added to give the design depth of 6.2 feet. The storage volume can also be calculated by

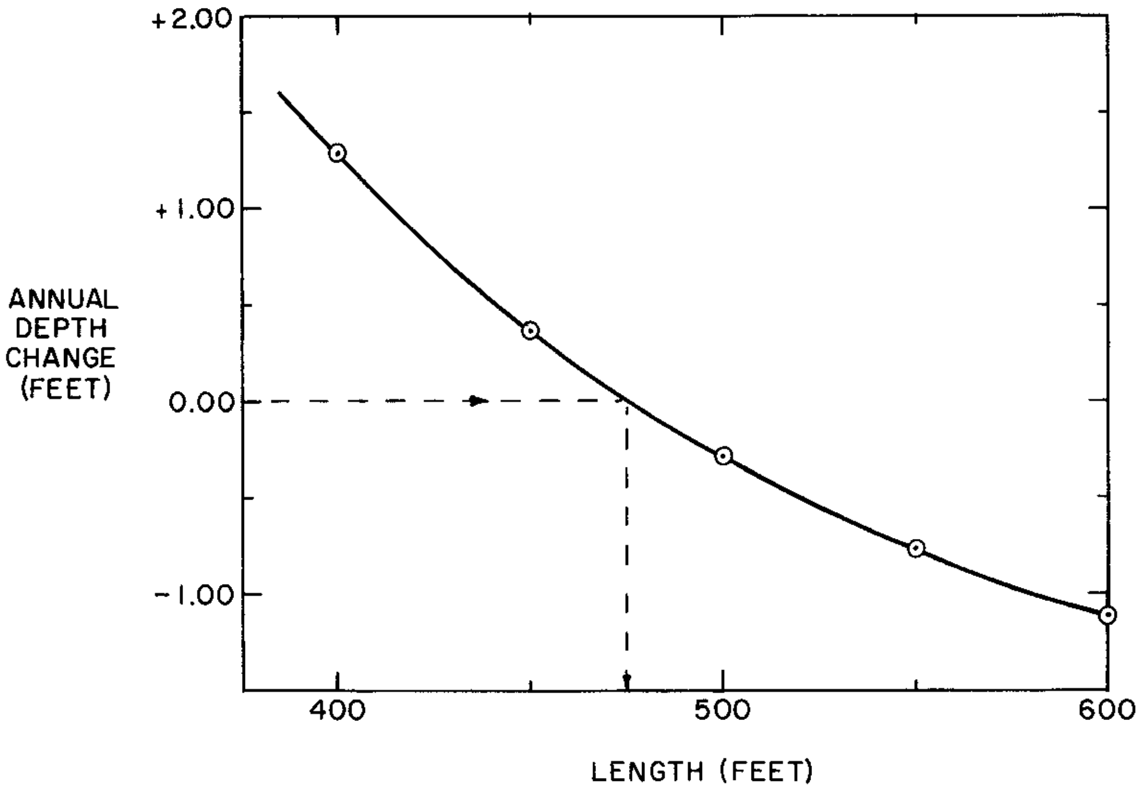


FIG. 35.—Design Length versus Depth Change for Example Design

TABLE 13. - Annual Water Balance for a Design Length of 475 Feet

Line (1)	I.D. (2)	January (3)	February (4)	March (5)	April (6)	May (7)	June (8)	July (9)	August (10)	September (11)	October (12)	November (13)	December (14)	Annual (15)
1	E, ft^3	61,234	93,323	108,370	118,308	117,503	210,517	275,384	292,583	202,694	167,399	115,896	84,756	1,907,967
2	e, ft	0.2714	0.4136	0.4803	0.5244	0.7867	0.9330	1.2205	1.2968	0.8984	0.7419	0.5137	0.3757	8.4564
3	(0.75)e, ft	0.2039	0.3107	0.3608	0.3939	0.5910	0.7009	0.9169	0.9742	0.6749	0.5574	0.3859	0.2822	-6.353
4	r, ft	0.1975	0.2850	0.1692	0.3975	0.3367	0.2992	0.2067	0.1758	0.4025	0.2708	0.1008	0.2775	+3.119
5	q, ft	0.2755	0.2489	0.2755	0.2666	0.2755	0.2666	0.2755	0.2755	0.2666	0.2755	0.2666	0.2755	+3.244
6	Δd, ft	+0.269	+0.223	+0.084	+0.270	+0.021	-0.135	-0.435	-0.523	-0.006	-0.011	-0.018	+0.271	+0.010
7	$\Sigma\Delta d$, ft	+0.269	+0.492	+0.576	+0.846	+0.867	+0.732	+0.298	-0.225	-0.231	-0.242	-0.260	+0.011	

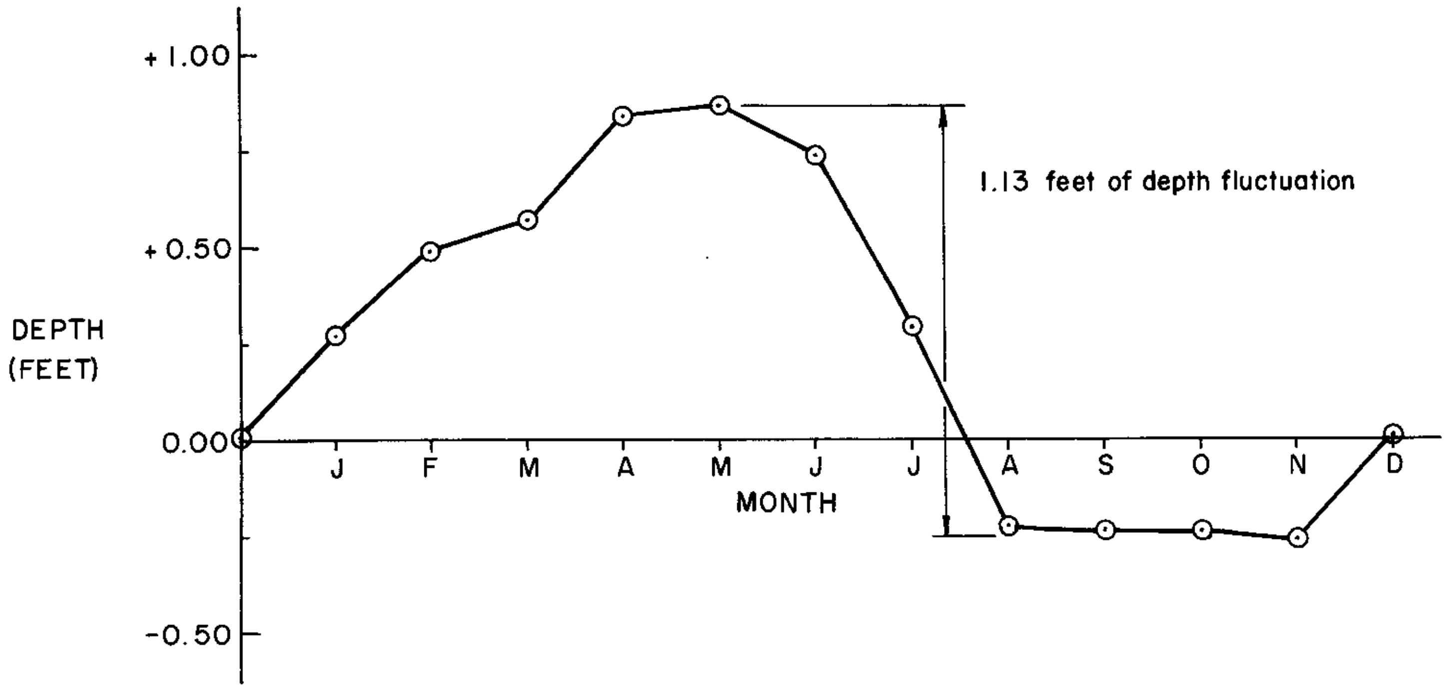


FIG. 36.—Annual Depth Fluctuation for a Design Length of 475 Feet

a water balance using the rainfall from a year of excessive precipitation.

Design Considerations

This design procedure should produce a conservative spray pond because the following assumptions are made: (1) a 5 mph wind is the average wind speed whenever the wind is between 1 and 12 mph (this may not be conservative at all locations), (2) no evaporation occurs during calm periods (however, at least pan evaporation occurs but is not included), (3) when the sprays are off (i.e. wind >12 mph) no evaporation occurs (however, surface evaporation is actually occurring), (4) all operating parameters are within common ranges, and (5) no drift loss occurs. Other important considerations in preparing a proper design are the input data, modifications to the design procedure, air pollution aspects, solids accumulation, and miscellaneous design considerations (drift losses, seepage, control of storm runoff, hydraulic design, and energy conservation).

Input Data

The projections of plant flows should be done with great care. In preparing the design flow, the plant's future production should be taken into account because of the appreciable fluctuations in the market shown in Figure 1. Some common ranges of operating parameters are presented in Table 12. The mass transfer coefficients are given in Tables 21, 22, 23, and 24 of Appendix III. They present the results of work by Lof, et al. (28) which show the effect of certain operational parameters upon the performance of the system. These tests were performed on hollow cone nozzles and additional information may be available from manufacturers.

Also, it may be desired to use a multiple pond system because of land restrictions. For this type design the input value for plant flow should be divided by the number of ponds desired, thereby solving for the design length of the smaller ponds.

Modifications to Procedure

If a more detailed design procedure is desired, several refinements can be made. By determining the evaporation which occurs under several different wind velocities, such as 0, 2, and 5 mph, a more detailed analysis results. The wind frequency data is usually divided into the following intervals: calm, 1 to 3 mph, 4 to 12 mph, and 12 to 24 mph. A rational approach is to use pan evaporation for calm conditions, to use the evaporation calculated for a 2 mph wind for wind conditions between 1 and 3 mph, and to use the evaporation calculated for a 5 mph wind for wind conditions between 4 and 12 mph. In the design procedure, Steps 1 through 9 should be completed for a wind speed (W) equal to 2 and again for 5. Then the total evaporation would be the sum of the pan evaporation, the 2 mph evaporation, and the 5 mph evaporation where each evaporation is multiplied by the appropriate frequency factor before adding. Mathematically, this may be written,

$$e_t = f_0 e_p + f_2 e_2 + f_5 e_5 \quad \ldots\ldots\ldots\ldots \quad 15$$

in which the wind frequency factors, f_0, f_2, f_5 are identified by subscripts, and the evaporations (e_t, e_p, e_2, and e_5) are the total evaporation, the pan evaporation, the 2 mph evaporation, and the 5 mph evaporation.

The use of this refinement is advisable or should be checked in a region where the calm and the 1 to 3 mph wind categories consistantly occur more than 25 or 30 percent of the time. Without any compensation in the design procedure, such conditions would produce an erroneously high evaporation resulting in an underdesigned spray pond.

Another modification which can be made is to use a computer program to average hourly weather data giving values for the average day of the month. This type of analysis would be possible by manual computation, but would require considerable time. The procedure would be to average the temperature, atmospheric pressure, and humidity at each hour during the day over an entire month. This hourly data would be entered into Equation 9 to determine the evaporation for each hour and the total of these hourly evaporations is the average daily evaporation for that month.

Finally, it might be desirable to optimize another design parameter besides length. Suppose the spray density is to be kept as high as possible to provide maximum transfer for the land area desired. Once the design length has been determined, the design procedure may be repeated changing the nozzle density and solving for a new length. A curve giving design length as a function of various nozzle densities may be developed to find the optimum density and length. Or, the length may be kept the same while density is varied and the optimum density for that length may be determined. These and similar refinements can be performed to develop a better design if the engineer deems it necessary.

Air Pollution Considerations

An air pollution problem may result from a spray pond since the waste being evaporated contains volatile organic compounds. These compounds evaporate with the waste and increase the equivalent hydrocarbon content of the air. In the laboratory phase of this project, the decrease in the carbon content of the waste was proportional to the amount of waste evaporated, and for a batch system, this is a constant proportionality. In a continuous-flow system, the same evaporation ratio applies, but since the wastewater is continually being added, little fluctuation in the total volume or carbon content occurs. The evaporation ratio of carbon compounds evaporated to waste evaporated can be used to estimate possible air pollution from a spray pond.

Preliminary calculations provide an estimate of the equivalent hydrocarbons in the exit air. The air flow is assumed to be that which passes through the spray filled volume above the pond. The equivalent hydrocarbons entering the air above the pond are equal to the experimental evaporation ratio times the mass of water evaporated in the spray. The estimated concentration of equivalent hydrocarbons is the mass of hydrocarbons evaporated divided by the volume of air passing through the spray.

In the design example, the pond to evaporate 15,000 gallons per day of wastewater was found to be 475 feet square with sprays 30 feet high. Assuming 5 miles per hour is the average annual wind speed, the daily air flow passing through the spray is 255 million cubic meters. The volume of water evaporated is 15,000 gallons or 125,000 pounds per day. The average of the experimental evaporation ratios is 0.0019, and multiplying by 1.333 converts this ratio to equivalent methane. The amount of hydrocarbons evaporated is the ratio times the mass of water evaporated. Performing this calculation gives the hydrocarbons evaporated as 317 pounds expressed as methane. Dividing this by the air flow and making the appropriate conversions gives an equivalent hydrocarbon concentration of 565 micrograms per cubic meter.

In Table 14 the estimated hydrocarbon emissions are shown for each experimental ratio determined. These estimates can be considered conservative because the following assumptions are made: (1) no diffusion, convection, or dispersion occurs, (2) a low average wind speed of 5 miles per hour was used, (3) the spray rises only 5 feet above the nozzles, and (4) the experimental conditions employing evaporation did not cause an increase in the evaporation ratio.

TABLE 14. - Estimated Hydrocarbon Emission from an Evaporation Pond For a 15,000 GPD Plant

Experimental Ratio gm TOC/gm H_2O	Concentration		Emmission Rate	
	$\mu gm/m^3$	ppm	lb/hr	kg/hr
0.0006	178	0.27	4.17	1.89
0.0010	297	0.45	6.95	3.16
0.0018	535	0.80	12.51	5.68
0.0024	714	1.07	16.67	7.58
0.0028	832	1.25	19.45	8.84
0.0019 (Avg)	565	0.85	13.20	6.00

Note: Hydrocarbons expressed as methane.

It is difficult to interpret or determine the significance of the emission estimates because the standards are ill-defined and obscure for this type of process. In fact, it would be very difficult to say what is an acceptable level because it depends upon how the regulatory agencies define acceptable levels. The difficult process of defining safe levels is the current topic of much research and decision making; however, some comparisons can be made.

The national primary and secondary ambient air standard is 160 micrograms per cubic meter or 0.24 parts per million (32). The average spray pond concentration in the example problem was three and a half times this value. In terms of automobiles the spray pond for a 15,000 gallons per day plant would equal about fifty-five 1975 automobiles. This comparison is based on the Environmental Protection Agency hydrocarbon emission factor for a car traveling at 35 miles per hour (41). The breathing loss from a fixed roof storage tank holding 1.5 million gallons of gasoline is about equal to the emissions from the spray pond, based on the same EPA data. These comparisons indicate the air pollution from a spray pond cannot be ignored, but insufficient regulatory information prohibits accurate judgement.

Another approach to assessing the air pollution impact is to determine how far away from the pond a person would have to be before the equivalent hydrocarbon concentration dispersed to the national ambient air quality standard. An estimate of this distance can be made using the "Atmospheric Dispersion Handbook" (47).

The handbook provides graphs of the dispersion downwind from a source based upon Sutton's equation for Gaussian distribution of a plume.

In Figure 37, a point source which is equivalent to the spray pond lies the virtual distance, x_v, upwind of the pond. Following a method outlined by Turner (47), the two sources are considered equivalent when their dispersion coefficients perpendicular to the wind direction, σ_y, are equal. The initial dispersion coefficient for a square source is given as,

$$\sigma_{y_o} = S/4.3 \quad \text{. . . . .} \quad 16$$

in which σ_{y_o} is the initial dispersion coefficient and S is the length of the side of the source in meters. For the 475 foot (145 meters) design length, Equation 16 gives

$$\sigma_{y_o} = 145/4.3 = 34 \text{ meters.}$$

The distance downwind to this dispersion coefficient for a point source will vary depending upon atmospheric conditions. The atmospheric conditions which describe each atmospheric stability category are given in Table 15. Category A is an unstable atmosphere (good vertical mixing) such as a clear summer day; Category F is a very stable atmosphere (little vertical mixing) such as a thermal inversion. In Table 6, Col. 2, the values of the virtual distance, x_v, are given for the various atmospheric stability categories.

The pollutant concentration is modified in the normalized form, $\chi U/Q$, where, χ is the concentration, U is the mean wind velocity,

TABLE 15. - Atmospheric Stability Categories

Surface Wind Speed (m/sec) (1)	Day Incoming Solar Radiation			Night	
	Strong (2)	Moderate (3)	Slight (4)	Thin Overcast or ≥ 1/2 Cover (5)	≤ 3/8 Cover (6)
<2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Note: Class D should be assumed for overcast conditions during day or night.

TABLE 16. - Computations for Estimate of Air Pollutant Dispersion to Ambient Levels

Stability Class (1)	Virtual Source (km) (2)	$\frac{X_o U}{Q}$ (3)	$\frac{X_{160} U}{Q}$ (4)	$x_v + x_{160}$ (km) (5)	x_{160}	
					(km) (6)	(ft) (7)
A	0.126	5.6×10^{-4}	1.6×10^{-4}	0.24	0.114	370
B	0.185	2.8×10^{-4}	7.8×10^{-5}	0.34	0.155	510
C	0.29	1.1×10^{-4}	3.0×10^{-5}	0.48	0.19	620
D	0.37	6.0×10^{-5}	1.7×10^{-5}	0.58	0.21	690
E	0.65	1.3×10^{-5}	3.5×10^{-6}	0.98	0.33	1,080
F	0.99	3.3×10^{-6}	9.3×10^{-7}	1.55	0.56	1,840

and Q is the emission rate. The values of normalized concentration for a distance, x_v, downwind from a point source are shown for each stability category in Table 16, Col. 3. Assuming the wind velocity and emission rate are constant, the normalized concentration for a point further downwind can be calculated using a direct proportionality; thus,

$$\frac{\chi U}{Q} = \frac{\chi_o U}{Q}\left(\frac{\chi}{\chi_o}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 17$$

in which χ_o is the concentration at the source and χ is the downwind concentration. Based upon a concentration of 565 μg/m^3 at the source and no upwind pollution, Column 4 in Table 16 shows the normalized concentrations for a downwind concentration of 160 μg/m^3 as calculated from Equation 17. In Col. 5 of Table 16, the distance to these normalized concentrations $(x_v + x_{160})$ is shown. Subtracting the virtual distance from these values gives the distance downwind from the pond to a concentration of 160 μg/m^3 as shown in Col. 6, Table 16. This means that the distance to the ambient air standard would be anywhere from 370 feet to 1840 feet downwind of the pond depending upon atmospheric stability.

There are some means to reduce emissions and keep concentrations low. Air pollution can be minimized by providing for good flocculation; since, in the experimental data, the well flocculated wastes produced lower emission ratios. Placing the spray pond in a location on the plant site where the property line is a maximum distance away is advantageous. It does not decrease emissions but the distance will provide a buffer zone for dispersion of evaporated organic compounds. Often boundary line concentrations are used to assess the impact of a facility on the environment.

Solids Accumulation

In an operating evaporation pond, dissolved solids will accumulate to some equilibrium concentration which will be dependent upon the amount of drift loss. In some instances additional blowdown may be necessary to keep the dissolved solids below the point where evaporation is seriously impaired. The blowdown could be used in the closed steaming process or diverted to a small brine evaporation pond.

A materials balance on a spray pond operating under steady-state conditions shows that the equilibrium concentration of dissolved solids, C_e, is equal to the influent concentration, C_o, divided by the blowdown expressed as a decimal fraction of the inflow, b ($b = Q_b/Q_i$ where Q_b is the blowdown flow and Q_i is the inflow to the pond). Mathematically this may be written as,

$$C_e = \frac{C_o}{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 18$$

For an influent concentration of 1000 mg/l dissolved solids, the blowdown required to maintain an equilibrium concentration of 5 percent is 2 percent of the influent flow. Two percent drift loss is not an unreasonable value, therefore, no intentional blowdown would be necessary.

Miscellaneous Design Considerations

If atmospheric evaporation is to be used effectively, and in an environmentally satisfactory way, other aspects of the spray evaporation system must be properly designed. Aspects needing attention are drift losses, seepage, control of plant storm runoff, hydraulic design of the spray system, and energy conservation.

Drift losses. The spray from a nozzle can be easily carried away from the perimeter of the pond by the wind. To a certain extent, this produces the same effect as spray irrigation of the wastewater. The easiest remedy or control for drift loss without impairing evaporative capacity appreciably is the use of drift fences. A drift fence is a vertical barrier fence made of inclined louvers which encircles the spray pond. The louvers are inclined so that the lower edge is to the inside. Water droplets which are blown into the fence strike the louvers and roll down to the inside edge where they drip back into the pond. The devices are quite common in industrial cooling operations and have been used with good results.

Other modifications to control drift losses are to decrease nozzle pressure, to decrease the nozzle height above the pond, and to increase the distance from the edge of the pond to the nearest upwind nozzles. All of these can affect the amount of evaporation achieved.

Seepage. The seepage of the pond contents into groundwater supplies must be prevented, and the best means is to provide an impervious liner in the pond. The choice of a site with impervious clay would be desirable but sometimes the pond must be located on sandy soils. Therefore, the use of a lining of impervious clay or a plastic membrane may be necessary to prevent seepage losses. The choice of lining material will depend upon the underlying stratum, the distance to groundwater, the materials readily available, and the cost.

Control of plant storm runoff. The plant drainage which enters the wastewater pond system must be kept to a minimum. The plant runoff should be segregated into two streams: one that carries runoff polluted enough to warrant treatment, and the other which is relatively clean. Testing will usually be necessary to categorize plant runoffs into the two streams, but generally the runoff from the treating area of the plant near the cylinders, the storage tanks, and the charge cooling area may require gravity separation followed by evaporation. A holding pond would be necessary to store this storm water until it could be treated. The other plant runoff, from the pole yard, building roofs, etc. can usually be discharged without treatment.

Hydraulic design. The pumps, distribution pipes, and spray nozzles must be designed efficiently to produce a design requiring the least energy cost. For a given flow per nozzle, hydraulic relationships can be developed into equations to give pipe, nozzle, and pump sizing. A variable speed pump or multiple pumps would be desirable for versatility. During high winds the wastewater flow must be reduced to operate without excessive drift loss. Also, it would be desirable to have valves arranged so one portion of the system can be isolated for unfavorable wind conditions and maintenance.

Energy conservation. Since added heat will increase the amount of evaporation the system can produce, any point where waste heat can be saved would increase the evaporation rate. Steel tank separators and metal piping carrying the waste can be insulated to minimize heat losses. Placing the pond a minimum distance from the preserving cylinder would also be good practice.

Proposed Treatment Scheme

The wastewater should be segregated into an oily stream, a dirty stream, and a clean stream. The oily stream would consist of oily condensates from the retort, condensed vapors from the condenser, door pit drainage, and oily runoff waters from the treating area. The dirty stream would consist of sapwater, contaminated plant runoff, equipment cleaning wastes, and other polluted but not oily wastewaters. The inclusion of sapwater in this wastewater stream would require valving the retort drain so that initial steaming condensate (containing oils from the previous preserving cycle) could be discharged to the oily stream. Then adjustment of the valves would send the remaining condensate to the dirty wastewater stream. The clean stream would contain relatively clean wastewaters such as cooling water, runoff from building roofs, and other uncontaminated runoff from the plant site.

The oily stream would go to pretreatment for removal and recovery of preserving solutions as shown in Figure 38. Gravity separation is the common practice and should be employed. Following gravity separation, the oily stream should be coagulated to remove emulsified oils. The inclusion of a coagulation process increases the complexity and cost of the treatment system, but it brings about significant benefits. Coagulation removes the highly organic emulsion which, in many cases, contains a major portion of the organic content and toxic substances. Most of the suspended solids are precipitated from the wastewater as sludge reducing the rate and severity of sedimentation in the evaporation ponds. Since suspended solids removals greater than 80 percent are common, pond life between cleanings may be increased by a factor of five over a system without coagulation. The sludge can be dewatered using typical sand drying beds with an underdrain system to collect and recycle to the coagulation tank the water which seeps to the bottom of the bed. After coagulation the oily stream would be discharged into the evaporation pond system. Two ponds are recommended for flexibility.

The dirty stream should be temporarily impounded in a dirty water holding lagoon to remove materials by separation. Skimming and bottom withdrawal should be provided for removing separated materials. The skimmings and bottom withdrawals from the dirty wastewater lagoon would be discharged to the batch coagulation tank during periods of low flow from the oily stream. The remaining dirty water should either go to the evaporation ponds or be discharged depending upon water quality.

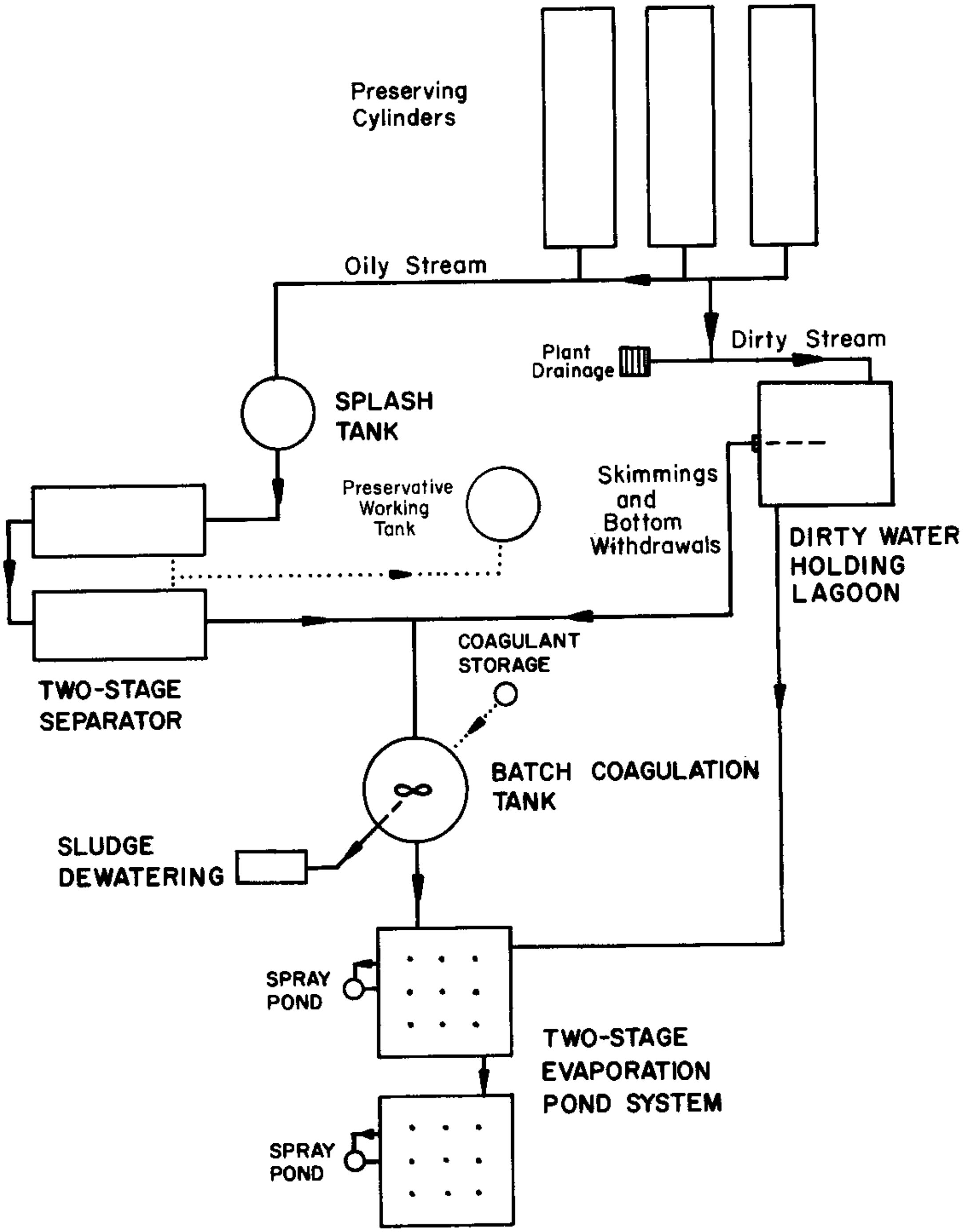


FIG. 38.-Treatment System Schematic

The clean stream can be released without treatment. However, a diversion box should be provided to direct clean stream flow into the dirty water holding lagoon in the event of a plant emergency such as a hazardous material spill.

In the previous design problem a nozzle size of 1/2 inch was used and in the Appendix the maximum nozzle size for which mass transfer coefficients are available is 3/4 inch. Much larger nozzles are available and can be used possibly resulting in a smaller number of total nozzles if mass transfer data are available.

Treatment System Costs

The proposed system presented in the example problem consists of two gravity separators, two batch coagulation and settling tanks, a single evaporation pond and all of the necessary piping, pumping and miscellaneous equipment. The capital cost, based on 1976 cost data, would be about $650,000. The operating costs (i.e., the pumping costs, the chemical costs, and the maintanence expenses) would be about $40/day. An activated sludge plant for the same organic loading would cost about $1,300,000 and its operating costs would be about $150/day. Thus, the proposed system is competitive costwise to a biological treatment system.

CHAPTER VI

CONCLUSIONS

Based upon the experimental and theoretical analyses presented in this report, the following conclusions are forwarded.

1. Atmospheric evaporation is a feasible treatment alternative for wood preserving wastewaters.

The situation for which this process is best suited is a moderately-sized rural plant because of land requirements, air pollution aspects, and the unavailability of a municipal wastewater treatment plant.

2. The rate of evaporation of equivalent hydrocarbons present in the waste is directly proportional to the rate of water evaporation.

Experimentally this ratio varied from 6.0×10^{-4} to 2.8×10^{-3} gram of total carbon as methane per gram water evaporated. This relationship was repeatedly demonstrated.

3. A spray pond can be rationally designed using the procedure presented in this report.

In an example design a large plant located at College Station, Texas and having a flow of 15,000 gallons per day would require an evaporation pond 475 feet square by 6.2 feet deep. This represents a conservative design.

4. At this time, the significance of air pollution from this process cannot be fully assessed.

Predictions of equivalent hydrocarbon content in the air downwind from the spray pond were made. A concentration of 565 micrograms per cubic meter was the average value at the downwind side of the spray pond. Assuming no upwind hydrocarbons are present, the concentration downwind will be above the national ambient air quality standard for a distance of 370 to 1,840 feet depending upon atmospheric conditions. This estimate is based upon a theoretical plume model.

5. The most feasible treatment scheme employing atmospheric evaporation consists of gravity separation, coagulation, settling, and spray evaporation. This provides for removal of oils and emulsions thereby lowering air emissions. The coagulated sludge would have to be dewatered and the sludge disposed in an acceptable manner.

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APPENDIX II - RESULTS OF COAGULATION STUDY

TABLE 17.- Results from the Coagulation of Plant I Wastewater (Creosote Waste)

Coagulant (1)	Dosage (mg/l) (2)	COD (mg/l) (3)	COD Removal (%) (4)	pH (5)	Turbidity (FTU) (6)	Sludge (mg/l) (7)
Ferric Chloride ($FeCl_3$)	100	-	-	-	T[a]	N[b]
	200	3680	35.4	-	T	40
	300	2950	48.2	-	LT	50
	400	3060	46.4	-	20	50
	500	2990	47.5	-	20	40
	600	3010	47.1	-	16	40
Ferric Chloride ($FeCl_3$) + Bentonite Clay	500 + 150	2826	50.4	-	18	30
	500 + 500	2711	52.4	-	20	50
Aluminum Sulfate ($Al_2(SO_4)_3$)	100 - 300	-	-	-	T	N
	400	-	-	-	T	25
	500	-	-	-	T	35
	600	3850	32.5	-	T	40
Polymer A	25	-	-	-	T	N
	50	3250	42.9	-	27	40
	75	3240	43.1	-	22	30
	100	3190	44.0	-	7.8	40
	200	-	-	-	4.0	30
	250	3230	43.3	-	4.0	40
	300	-	-	-	4.5	40
	350	-	-	-	3.8	30
	400	3770	33.8	-	4.1	45

TABLE 17. - (Continued.)

Coagulant (1)	Dosage (mg/l) (2)	COD (mg/l) (3)	COD Removal (%) (4)	pH (5)	Turbidity (FTU) (6)	Sludge (mg/l) (7)
Polymer B	25	-	-	-	T	N
	50	3330	41.5	-	25	40
	75	3240	43.0	5.0	9.2	50
	100	3290	42.3	-	8.0	50
	200	3255	42.9	-	4.4	40
	300	3310	41.9	-	12	50

Note: Raw wastewater COD, pH, and temperature were 5696 mg/l, 4.2, and 20.5° C, respectively.

[a] T indicates turbid supernatant; LT indicates low turbidity in supernatant.

[b] Volume of sludge produced is negligible.

TABLE 18. - Results from the Coagulation of Plant II Wastewater (Creosote + Penta Waste)

Coagulant (1)	Dosage (mg/l) (2)	COD (mg/l) (3)	COD Removal (%) (4)	pH (5)	Turbidity (FTU) (6)	Sludge (mg/l) (7)
Ferric Chloride ($FeCl_3$) + Lime ($Ca(OH)_2$)	100 + 700	-	-	11.2	4.6	40
	200 + 1400	-	-	11.5	2.6	60
	300 + 2100	1100	81.0	11.7	2.5	70
	500 + 3500	970	83.2	-	2.4	110
Polymer A	100	1380	76.1	6.7	10	30
	200	-	-	6.5	9.6	30

Note: Raw wastewater COD, pH, and temperature were 6860 mg/l, 6.6, and 21.5° C, respectively.

TABLE 19. - Results from the Coagulation of Plant IV-C Wastewater (Creosote Waste)

Coagulant (1)	Dosage (mg/l) (2)	COD (mg/l) (3)	COD Removal (%) (4)	pH (5)	Turbidity (FTU) (6)	Sludge (mg/l) (7)
Ferric Chloride ($FeCl_3$)	0 - 400	-	-	-	T[a]	N[b]
	500	6750	81.2	-	-	80
	600	6450	82.0	-	-	100
	800	6113	82.9	-	T	50
	1000	7280	79.7	-	T	90
Ferric Chloride ($FeCl_3$) + Bentonite Clay	800 + 150	6151	76.1	-	T	80
	1000 + 150	5486	79.0	-	T	100
Ferric Chloride ($FeCl_3$) + Calcium Hydroxide ($Ca(OH)_2$)	50 + 350	-	-	5.1	T	N
	75 + 525	-	-	6.3	T	N
	100 + 700	-	-	7.4	T	N
	250 + 1850	-	-	11.3	23	70
Aluminum Sulfate ($Al_2(SO_4)_3$)	100 - 450	-	-	-	T	N
	600	8565	76.1	-	T	<50
	1000	-	-	-	T	60
Polymer A	100	7520	79.0	-	T	50
	200	7107	80.2	4.1	LT	50
	300	7062	80.3	-	LT	50
	350	6674	81.4	-	LT	75
	400	7332	79.5	-	LT	60
Polymer A + Bentonite Clay	300 + 150	6751	81.1	-	T	70

TABLE 19. - (Continued.)

Coagulant (1)	Dosage (mg/l) (2)	COD (mg/l) (3)	COD Removal (%) (4)	pH (5)	Turbidity (FTU) (6)	Sludge (mg/l) (7)
Polymer B	100	7370	79.4	-	T	40
	200	7270	79.7	-	LT	65
	300	7245	79.8	-	LT	60
	400	7120	80.1	-	LT	50
	500	7120	80.1	-	LT	60
Polymer B + Bentonite Clay	450 + 150	6088	83.0	-	T	50

Note: Raw wastewater COD was 35,830 mg/l.

[a] T indicates turbid supernatant; LT indicates low turbidity in supernatant.

[b] Volume of sludge produced is negligible.

TABLE 20. - Results from the Coagulation of Plant IV-P Wastewater (Penta Waste)

Coagulant (1)	Dosage (mg/l) (2)	COD (mg/l) (3)	COD Removal (%) (4)	pH (5)	Turbidity (FTU) (6)	Sludge (mg/l) (7)
Ferric Chloride ($FeCl_3$)	100	14,035	6.2	-	-	-
	250	11,700	21.9	-	-	-
	400	5,760	61.5	-	-	-
	500	5,750	61.6	-	-	-
Ferric Chloride ($FeCl_3$) + Bentonite Clay	450 + 100	5,530	63.1	-	-	-
	450 + 1000	5,375	64.1	-	-	-
Ferric Chloride ($FeCl_3$) + Lime ($Ca(OH)_2$)	50 + 350	-	-	8.3	T[a]	N[b]
	75 + 525	-	-	9.7	T	40
	100 + 785	6,090	40.7	6.7	7.3	-
	100 + 1040	3,910	26.1	9.8	18	-
	300 + 2185	-	-	11.5	28	-
	300 + 2440	-	-	11.8	19	-
	500 + 3585	3,850	25.7	11.7	17	120
	500 + 3840	5,960	39.8	11.8	28	70
Aluminum Sulfate ($Al_2(SO_4)_3$)	100 - 800	-	-	-	T	N
Polymer A	150	16,640[c]	-11.2	4.4	-	-

TABLE 20. - (Continued.)

Coagulant (1)	Dosage (mg/l) (2)	COD (mg/l) (3)	COD Removal (%) (4)	pH (5)	Turbidity (FTU) (6)	Sludge (mg/l) (7)
Polymer A + Bentonite Clay	150 + 500	5,810	61.2	-	-	-
	150 + 1000	5,670	62.1	-	-	-

Note: Raw wastewater COD was 14,970 mg/l.

[a] T indicates turbid supernatant.

[b] Volume of sludge produced is negligible.

[c] Floc floated.

APPENDIX III - NOZZLE OPERATIONAL PARAMETERS

TABLE 21. - Hydraulic Characteristics of Nozzles (28)

Nozzle No. (1)	Pipe Conn. NPT (inches) (2)	Body Inlet Diam. (inches) (3)	Orifice Diam. (inches) (4)	Capacity (gpm) Operating Pressure (psi)						
				3 (5)	5 (6)	7 (7)	10 (8)	20 (9)	30 (10)	40 (11)
1/4A10	1/4	3/16	3/16	.55	.71	.84	1.0	1.4	1.7	2.0
3/8A15	3/8	15/64	7/32	.82	1.1	1.3	1.5	2.1	2.6	3.0
1/2A25	1/2	3/8	1/4	1.4	1.8	2.1	2.5	3.5	4.3	5.0
3/4A50	3/4	1/2	3/8	2.7	3.5	4.2	5.0	7.1	8.5	10.0
3/4A80	3/4	1/2	9/16	4.4	5.7	6.7	8.0	11.3	13.8	16.0
3/4A120	3/4	1/2	23/32	6.6	8.5	10.1	12.0	17.0	20.8	24.0
2C60	2	1 7/16	1 9/16	39	51	60	72	102	124	143

TABLE 22. - Effect of Nozzle Operating Pressure on Theoretical Mass Transfer Coefficient (28)

Pressure (psi) (1)	Nozzle 1/4 A10 (2)	3/8 A15 (3)	1/2 A25 (4)	3/4 A50 (5)	3/4 A80 (6)	3/4 A120 (7)
2.5	193	199	286	180	228	177
5.0	347	424	527	504	544	464
7.5	544	635	854	829	895	856
10.0	715	901	1115	1172	1210	1260
20.0	1442	1530	2253	2682	3060	3090
30.0	1980	2115	3153	3750	4450	5200
40.0	2750	2845	4290	5480	7130	8200

Note: Values based on zero nozzle elevation and zero wind.

TABLE 23. - Effect of Nozzle Height on Theoretical Mass Transfer Coefficient (28)

Elevation (ft) (1)	Nozzle 1/4 A10 (2)	3/8 A15 (3)	1/2 A25 (4)	3/4 A50 (5)	3/4 A80 (6)	3/4 A120 (7)
0.00	715	901	1115	1172	1210	1260
0.82	834	1000	1210	1257	1270	1315
1.64	937	1105	1305	1340	1322	1365
2.50	1038	1210	1395	1423	1378	1415
3.30	1142	1305	1487	1506	1430	1462
4.10	1246	1405	1578	1585	1481	1513
5.00	1346	1500	1670	1663	1533	1575

Note: Values based on 10 psi operating pressure and zero wind.

TABLE 24. - Effect of Nozzle Elevation and Wind Speed on Theoretical Mass Transfer Coefficient at a Nozzle Operating Pressure of 5 psi

Nozzle	1/4 A10			3/8 A15			1/2 A25				3/4 A50				3/4 A80			3/4 A120		
Pressure (psi)	5			5			5				5				5			5		
Wind (mph)	0	5	10	0	5	10	0	5	10	20	0	5	10	20	0	5	10	0	5	10
Elevation (ft) (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
0	347	363	384	424	437	463	527	543	573	628	504	517	552	647	545	552	567	464	468	488
5		713	763		739	784		880	938	959		785	832	972		747	771		613	636
10		1052	1094		1028	1094		1203	1275	1298		1021	1083	1257		918	947		752	766
15		1391	1497		1312	1400		1518	1614	1624		1255	1325	1530		1010	1115		872	891
20		1726	1863		1598	1702		1823	1935	1950		1481	1560	1800		1240	1280		990	1011
25		2072	2232		1879	1999		2144	2281	2277		1712	1800	2060		1396	1440		1100	1122

TABLE 25. - Effect of Nozzle Elevation and Wind Speed on Theoretical Mass Transfer Coefficient at a Nozzle Operating Pressure of 10 psi

Nozzle	1/4 A10			3/8 A15			1/2 A25				3/4 A50				3/4 A80			3/4 A120		
Pressure (psi)	10			10			10				10				10			10		
Wind (mph)	0	5	10	0	5	10	0	5	10	20	0	5	10	20	0	5	10	0	5	10
Elevation (ft) (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
0	731	768	811	901	944	993	1116	1161	1206	1378	1171	1185	1225	1380	1210	1210	1230	1258	1245	1258
5	1346	1461	1550	1500	1606	1702	1670	1734	1823	2256	1663	1664	1728	1955	1533	1513	1548	1575	1525	1546
10		2128	2289		2256	2409		2301	2433	3092		2120	2210	2500		1800	1840		1772	1810
15		2798	3019		2811	3100		2867	3043	3919		2555	2665	3020		2070	2228		2026	2062
20		3469	3758		3541	3806		3429	3638	5723		3020	3212	3540		2340	2420		2263	2620
25		4143	4481		4192	4497		3983	4224	5562		3595	3590	4060		2630	2672		2425	2540