Wastewater Treatment Systems

Upgrading Textile Operations to Reduce Pollution

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WASTEWATER-TREATMENT SYSTEMS

Upgrading Textile Operations to Reduce Pollution

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Chapter I

THE NEED FOR WASTEWATER TREATMENT

The human race is indeed part of a limited ecosystem. While the population continues to increase, the available natural resources are decreasing. Recent history has recorded periodic water shortages in many highly populated areas. Newspaper reports of fish kills, toxic and hazardous chemical spills, and even "rivers on fire" are not infrequent. Recognizing the need to reverse the trend toward further environmental degradation, recent and proposed legislation is focusing on cleaning up the water environment. Although any one wastewater effluent may not of itself seriously degrade the receiving stream, as one of the aggregates of wastes, it may be "the straw that breaks the camel's back."

Major point-source discharges encompass domestic wastewaters and industrial wastewaters. The textile industry is composed of over 7,000 plants, with approximately 680 using wet processes or discharging wastewater. This wastewater is treated by municipal treatment plants, treated on site, or discharged untreated. The major pollutional parameters in textile wastewaters are solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrogens and phosphate, temperature, toxic chemicals such as phenols, chromium and heavy metals, pH, alkalinity-acidity, oils and grease, sulfides, and coliform bacteria.

Solids are present in textile wastewaters from process wastewater generated from fibrous substrate and process chemicals, and as a result of biological wastewater treatment. The solids can affect the natural aquatic environment by hindering oxygen transfer and reducing light penetration. Solids that settle on the stream bottom can cover the flora and fauna and result in an anaerobic sludge layer.

The BOD, resulting from organic process chemicals, varies widely. Some chemicals, such as starch, are completely biodegradable, while others, such as refractory compounds in dyes, are essentially nonbiodegradable. Five-day BOD values of 50 mg/l to 3,000 mg/l are experienced in textile wastewaters. Effluents containing high concentrations of BOD could deplete the dissolved oxygen (DO) concentration in the receiving stream, resulting in fish kills and objectional water quality.

Phosphates are present in the detergents used by the textile industry. Together with nitrogen, a proper balance is necessary for good biological treatment. Excess concentrations of either appear in the effluent and reach the receiving stream. If nutrient concentrations in the receiving waters become high, algal blooms can occur.

The temperatures that biological wastewater-treatment systems can tolerate predicate acceptable effluent temperatures. Physical-chemical treatment could withstand higher temperatures, and these treated wastewaters may require temperature reduction before introduction into the receiving stream because the natural aquatic environment is a "living system" and could be damaged by high temperatures.

Heavy metals such as chromium, copper, zinc, and mercury can be found in many textile process waters, especially those of wool and synthetics finishing. These, along with other toxic chemicals, are detrimental to biological organisms and would harm the receiving stream. If biological treatment is practiced at the mill, prevention of biological upsets will insure discharge of nontoxic wastewaters.

In the textile industry, some processes require highly acid conditions while others are highly alkaline. Consequently, wastewater pH can vary greatly over a period of time, and some form of neutralization or equalization is necessary. The degree of neutralization-equalization will depend on the extreme of the pH and the alkalinity-acidity of the wastewaters. Biological wastewater treatment inherently provides an effluent with acceptable pH for discharge to the receiving stream.

Grease and oil are harmful to biological systems and esthetically damaging to the environment. Concentrations in the effluent should be limited. This parameter is especially important in wool-scouring processes.

Often sanitary waste is included in the industrial wastewaters, necessitating the control of coliform bacteria. Chlorination may be needed with fecal coliform limits based on sanitary-system guidelines.

The textile industry is dynamic with constantly changing manufacturing processes and resulting wastewaters. Protection of the environment through adequate wastewater treatment will be a continuing requirement for acceptable textile manufacturing.

Chapter II

SOURCES AND STRENGTHS OF TEXTILE WASTEWATERS

Textile-mill operations consist of weaving, dyeing, printing, and finishing. Many processes involve several operations, each contributing a particular type of waste. Examples of waste-producing operations are sizing of the fibers, kiering (alkaline cooking), desizing the woven cloth, bleaching, rinsing, mercerizing, dyeing, and printing.

Textile wastes are generally colored, high in BOD and suspended solids, highly alkaline, and high in temperature. The wastes are characterized by extreme variability and may contain toxic compounds. The sources of pollution are the natural impurities extracted from the fiber together with the processing chemicals, which are either directly discharged batchwise (as with kier liquor, for example) or leached out during rinsing operations and discharged as waste.

The basic factors that bear on wastewater quantity and quality are as follows:

- Type of fiber
- Unit operations constituting the overall textile-finishing process
- Process chemicals
- Recycle and conservation procedures in force

While the last three factors play important roles in determining wastewater quality, it is both informative and useful to "hold them constant" for the moment and attempt to characterize textile wastes on the basis of process fiber—namely, cotton, wool, or synthetic. It must be emphasized that the design of treatment facilities must be custom tailored to the individual mill, based on the results of a carefully conducted wastewater survey. In discussing general characteristics, the objective is to introduce the plant engineer to the sources and problems of water pollution.

Waste constituents that present pollutional problems are those that deplete oxygen in the receiving stream (i.e., exert an oxygen demand), those that encourage excessive aquatic growth (by introducing nutrients), those that are toxic to aquatic life, and those that damage the esthetic nature of receiving streams. Biochemical and chemical oxygen demand, nitrogen and phosphorus, temperature, pH, chrome, phenol, sulfide, and color are all parameters that define wastewater quality.

COTTON

Cotton processing consists of two basic processes—weaving and finishing. Each comprises several operations, some of which use water while others do not. In the sequence of weaving operations, most of the water pollution originates with slashing. In slashing, the warp thread is sized with

Table II-1.—*Pollutional loads contributed by various cotton-mill processes*[1]

Department	Process	Pounds BOD per 1,000 pounds cloth	Percent of total
Desizing[2]		53	35
Scouring	Pressure kier, 1st scour	53	16
	Either pressure kier, 2d scour,	8	1
	or continuous scour	42	15
	Subtotal (scouring)	47	16
Dyeing		.5-32	1.5-30
Printing	Color shop wastes	12	7
	Wash after print, with soap	17-30	17-30
	Wash after print, with detergent	7	7
	Subtotal (printing)	19-32	15-35
Bleaching	Hypochlorite bleach	8	3
	Peroxide bleach	3	1
Mercerizing		6	1
Total		125-250	

[1] Part of the loadings shown are only indirectly contributed by these operations and, in fact, directly result from rinsing operations. For example, a rinse after dyeing will remove a portion of the dyestuff. The resulting BOD_5 is here attributed to dyeing.

[2] For acid desizing. Enzyme desizing or solvent desizing will produce different BOD_5 loadings.

Source N. L. Nemerow, *Liquid Wastes of Industry, Theories, Practices, and Treatment*, Reading, Mass., Addison-Wesley, 1971.

starch or a substitute to give it the tensile strength and smoothness necessary for subsequent weaving. The sizing compounds used are natural starches, modified cellulose, and synthetics, which may exert either a short-term or long-term BOD. Conversion to synthetic sizing, such as carboxymethyl cellulose (CMC), has often made it appear that plants were reducing BOD. In fact, while CMC and other substitute sizes can have a very low BOD over a 5-day span (BOD_5, the common measure of BOD), they can exert a substantial BOD in the longer run, for example, over a 20-day period (BOD_{20}). In addition, a significant BOD_5 can result with an acclimated biological culture.

The weaving process produces fixed cloth or gray goods containing from 8 to 15 percent slashing compound. A pollutional loading occurs when the sizing is washed out during the finishing process that follows. In addition, desizing, kier boiling, bleaching, mercerizing, printing, dyeing, rinsing, resizing, and final finishing are all operations that may contribute waterborne waste. Table II-1 indicates typical pollution loads generated by these processes. A typical cotton-process flowsheet is shown in figure II-1, and table II-2 describes the overall characteristics of the mill wastewater.

The cotton-finishing mill using conventional process chemicals (no substitution for soap, starch, or acetic acid) discharges a composite waste that is decidedly alkaline, colored by the predominant dye, with a BOD_5 of approximately 300 mg/l and a volume of approximately 40,000 gallons per 1,000 pounds of finished cloth.

Recent data[1] indicate a trend toward lower water consumption, approximately 20,000 gallons per 1,000 pounds, with correspondingly higher concentrations. Substitution of synthetic sizing

Table II-2.—*Average character of composite waste, cotton finishing*

Constituent	Mill			
	1	2	3	4
Turbidity, ppm	–	125	Gray, colloidal	Gray, colloidal
Color	Variable, dark	Dyes	Dyes	Dyes
Total alkalinity, ppm	–	500	300-900	600
Hydroxide alkalinity, ppm	–	100	–	–
pH	10.5-11.9	9.0	8-11	10-11.5
Suspended solids, ppm	–	100	30-50	40
Settleable solids, percent	–	0.25	–	–
BOD_5, ppm	500-800	175	200-600	300
Total solids, ppm	–	–	1,000-1,600	1,300
Chromium, ppm	–	–	Up to 3.0	2.0
Volume, gal/1,000 lb	30,000-40,000	–	30,000-40,000	70,000

Sources: 1, Lockwood Greene Engineers, Inc.; 2, Bogren, "Treatment of Cotton Finishing Wastes at the Sayles Finishing Plant," *Sewage and Industrial Wastes.* 3, "An Industrial Waste Guide to the Cotton Textile Industry," USPH; 4, Joseph W. Masselli, Nicholas W. Masselli, and M. G. Burford, "A Simplification of Textile Waste Survey Treatment," N.E. Interstate Water Pollution Control Comm , 1959.

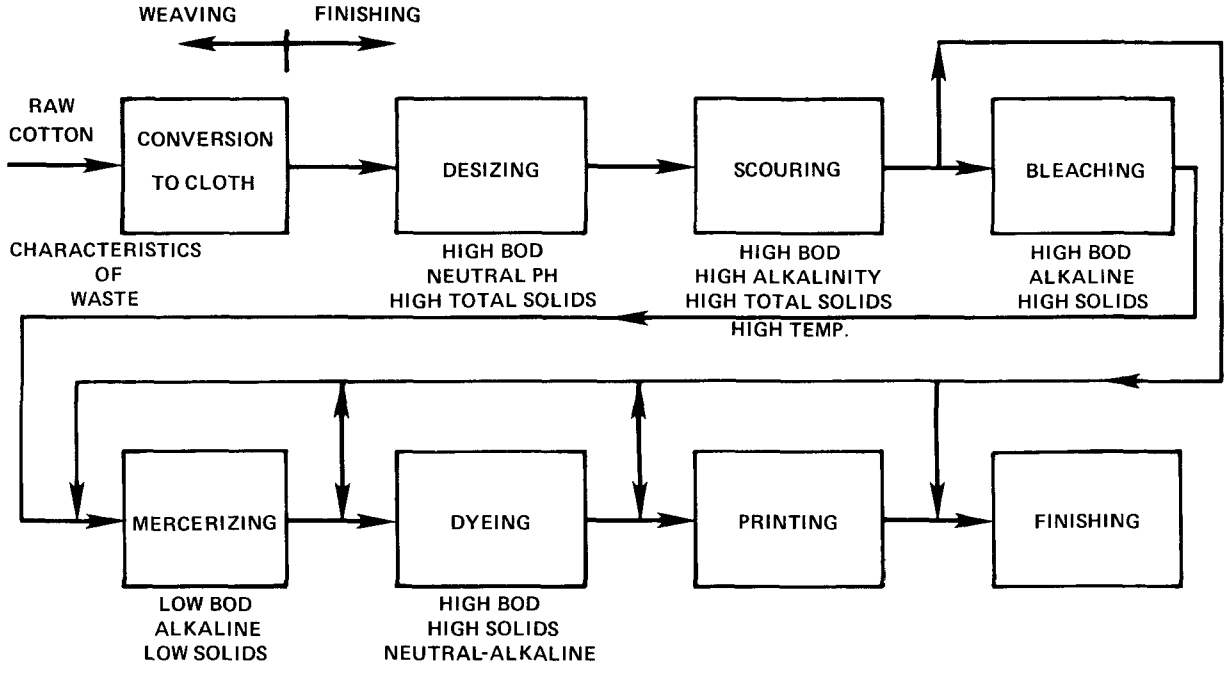


Figure II-1. Cotton-textile-finishing process flowsheet. (Rinsing operations not shown.)

for starch has appeared to reduce BOD_5 values as much as 50 percent. Researchers have shown, however, that activated-sludge populations can acclimate to the synthetic sizes, resulting in higher BOD_5.[2]

Within the cotton industry, as within the wool and synthetics industries, variation in processing, materials, styles, and finishes introduces substantial variability into wastewaters from mill to mill. For the average mill, however, starch waste will constitute about 16 percent of the total wastewater volume, 5.3 percent of the BOD, 36 percent of the total solids, and 6 percent of the alkalinity. Caustic waste constitutes some 19 percent of the volume, 37 percent of the BOD, 43 percent of total solids, and 60 percent of total alkalinity. Rinsing, bleaching, dyeing, and finishing generate the remaining portion of the composite.

Cotton-finishing wastes, although amenable to biological treatment methods, have peculiarities that may cause difficulties in biological processes. There may be toxic substances in the wastewater originating with the application of mildew depressants (fungicides), chromates (from dyes), and chloride or hydrogen peroxide (from bleaching). Occasionally, the waste will be deficient in nutrients (nitrogen and phosphorus). Because of the great variation in quantity and quality during the course of the day, owing to the batch operations involved in cotton finishing, equalization facilities may be required. Detergents may hinder settling of suspended solids and may also cause foaming problems in biological systems. Also, cationic detergents have been found to be bactericidal when present in concentrations as low as 1 ppm.

All cotton-finishing wastes contain fine fibers. Some are settleable and introduce problems in dewatering sludge. Suspended fibers can seal sand or carbon beds, clog equipment, and absorb certain chemicals leading to delayed pH changes. They also clog trickling filters, are unsightly in streams, and pose a long-term BOD.

High values of pH may necessitate neutralization before biological treatment. The low percentage of settleable solids usually makes primary sedimentation impractical. Fine screening is often necessary to protect mechanical equipment, such as pumps and mechanical aerators.

WOOL

Wool wastes originate from scouring, dyeing, rinsing, fulling, carbonizing, and washing operations. Practically all the natural and acquired impurities in wool are removed by scouring in a hot detergent-alkali solution producing a waste that is oily, alkaline, and high in solids and BOD. The actual wool-fiber content in "grease wool," as taken from the sheep's back, averages only 40 percent; the remaining 60 percent is composed of natural impurities such as sand, grease, suint (dried sheep perspiration), and burs. As a result, for every 1,000 pounds of scoured wool produced, 1,500 pounds of impurities are discharged, which corresponds to some 200 to 250 pounds of BOD_5 per 1,000 pounds of scoured wool.

Mills that both scour and finish wool produce a composite effluent with the following characteristics:

- pH, 9-10.5
- BOD_5, 900-3,000 ppm
- Total solids, 3,000 ppm
- Total alkalinity, 600 ppm
- Chromium, 4 ppm

- Suspended solids, 100 ppm
- Grease (for mill employing grease recovery), 100 ppm

Mills that only finish wool would be expected to produce a composite waste with much lower concentrations of BOD_5, suspended solids, and grease. The waste is likely to be brown in color, and the suspended solids are mainly colloidal. The major sources of BOD are the wool grease and suint removed in scouring and the soap used in fulling and washing. Approximately 7,500 and 13,800 gallons of water are required to scour and finish, respectively, each 1,000 pounds of wool.[1] Sedimentation, a common treatment to remove solids in domestic and some industrial wastes, is ineffectual in removing solids from wool wastes.

Many woolen mills in the United States are dyeing and finishing mills that purchase scoured wool. In these mills, 24 percent of the BOD_5 originates with dye operations, 75 percent with the wash that follows fulling, and 1 percent with neutralization that follows carbonizing.

Figure II-2 presents a wool process flowsheet, and table II-3 indicates pollutional loads of the untreated wastewaters.

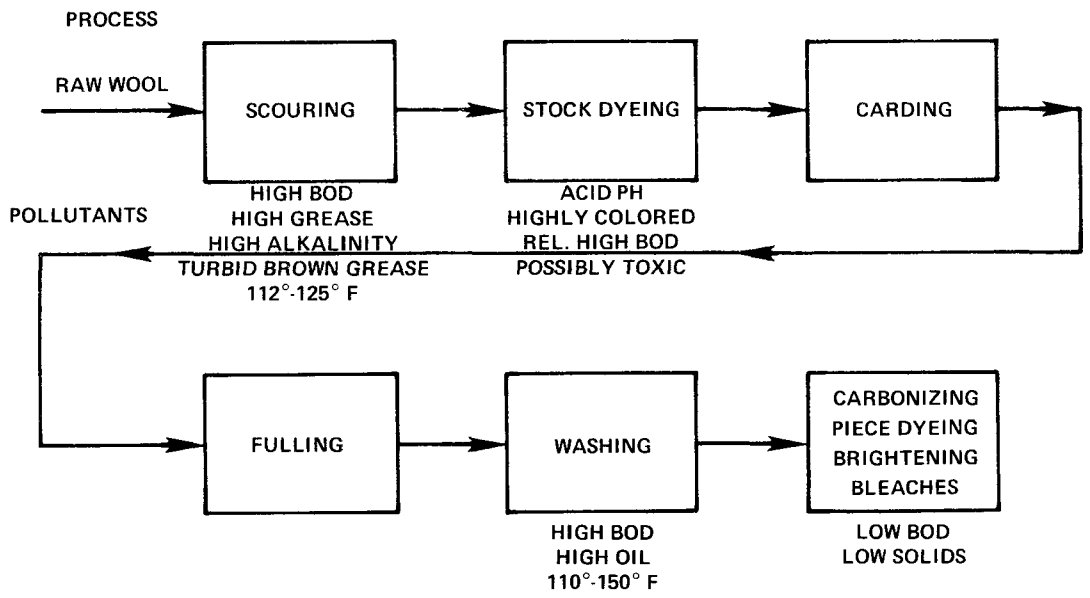


Figure II-2. Wool-process flowsheet. (Rinsing operations not shown.)

Table II-3.—*Pollution loads of wool, wet process*

Process	pH	BOD		Total solids, ppm	Volume, gal/1,000 lb
		ppm	lb/1,000 lb		
Scouring	9.0-10.4	30,000-40,000	104-221	1,129-64,448	5,500-12,000
Dyeing	4.8-8.0	380-2,200	9.0-34	3,855-8,365	1,900-2,670
Washing	7.3-10.3	4,000-11,455	31-94	4,830-19,267	40,000-100,000
Neutralization	1.9-9.0	28	1.7-2.1	1,246-4,830	12,500-15,700
Bleaching	6.0	390	1.4	908	300-2,680

Note.—Loads contributed from rinses are assigned to operation preceding rinse in each case.

Wool grease is a source of lanolin, which may be recovered and sold. Suint is a source of potassium salts. The combination of in-plant measures and wastewater treatment are generally designed to treat the following waste characteristics: variability, total flow, oil and grease, pH, color, temperature, BOD, chromium, and suspended solids. The presence of phenols, sulfides, and long-term BOD must be considered in surveys and studies. Nutrients, toxic compounds, and foam-causing detergents are all factors that must be dealt with before designing treatment facilities.

SYNTHETICS

Synthetic fibers are polymers derived from pure chemical compounds and have essentially no natural impurities. For this reason, no desizing is needed, and relatively light scouring and bleaching are all that is necessary to prepare the cloth for dyeing. The fibers and cloth are readily processed on the conventional machinery used for cotton and wool.

At present, the major synthetic fibers are rayon, acetate, nylon, Orlon, and Dacron. Scouring, dyeing, and finishing chemicals are the sources of waste in the synthetic textile industry. These fibers can all be considered as either cellulosic or noncellulosic. When such a distinction is made, it is possible to present process flowsheets representative of each of the two categories. Figures II-3 and II-4 illustrate the two processes. The noncellulosic fibers assume the greater portion of the textile market at present.

Tables II-4 and II-5 describe pollutional loads of synthetic fiber processes, and table II-6 presents qualitatively an analysis of waste associated with each of the major synthetic fibers.

Unlike wool and cotton, synthetic fibers of the same type can have different physical and chemical properties. The producers of synthetic textiles are frequently and continually changing their products, varying fiber blends, and investigating new finishes to keep abreast of changing market conditions. As a result, the wastewaters generated by the synthetic fiber industry are highly variable, and a general characterization of these wastes is useful only as an approximate indication of their composition.

GENERAL

Special finishing techniques can contribute from 5 to 15 percent of the total BOD_5 in any of the three fiber groups. Techniques vary greatly from mill to mill. There is little information on the toxicity of special finishing chemicals. Their purposes range from mildew proofing to imparting wash-and-wear properties.

Throughout the textile industry, the wastewaters are highly variable in quantity and composition. The sources of these wastes are, first, the natural impurities present in the fibers and, second, the process chemicals. Cotton and wool wastes are highly concentrated and primarily originate with natural impurities in the fibers.

Process chemicals constitute most of the wasteload from synthetic-textile processing. Industrywide, a great variety of process chemicals are used. Carriers used in synthetic dyeing present special problems. Chromium and derivatives of phenol and sulfur are often present. Color has become increasingly difficult to remove from wastewaters, since the market has demanded dyes that are increasingly more resistant to degradation. The substitution of synthetic sizing compounds often has resulted in merely shifting BOD from the short-term, 5-day BOD to a longer term oxygen demand. While in-plant pollution control measures can be quite effective

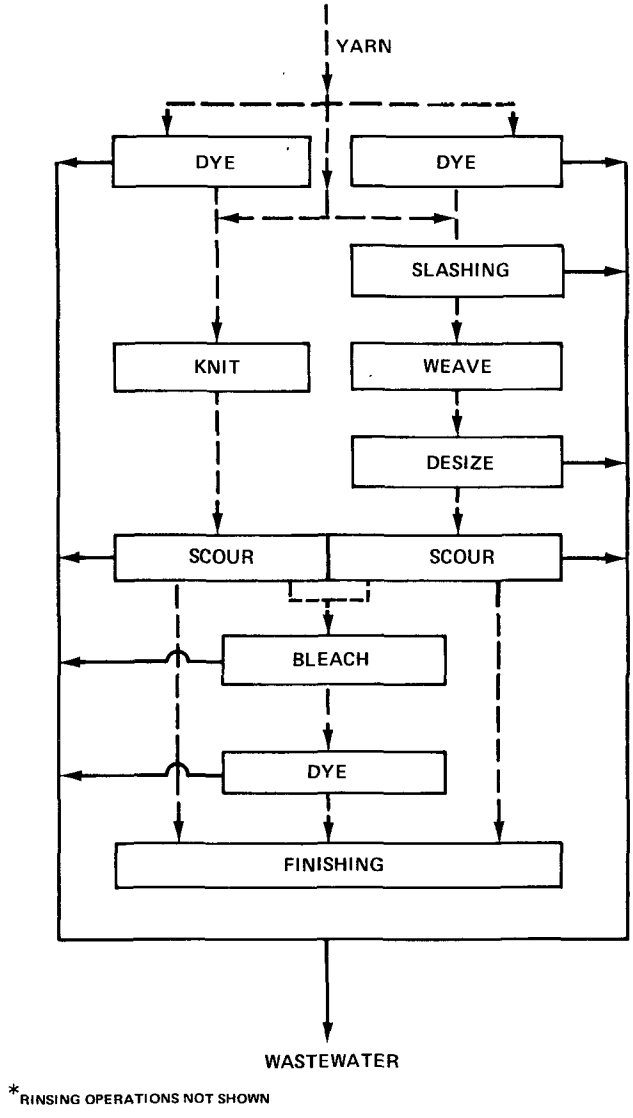


Figure II-3. Noncellulosic synthetic-textile-finishing process flowsheet. (Rinsing operations not shown.)

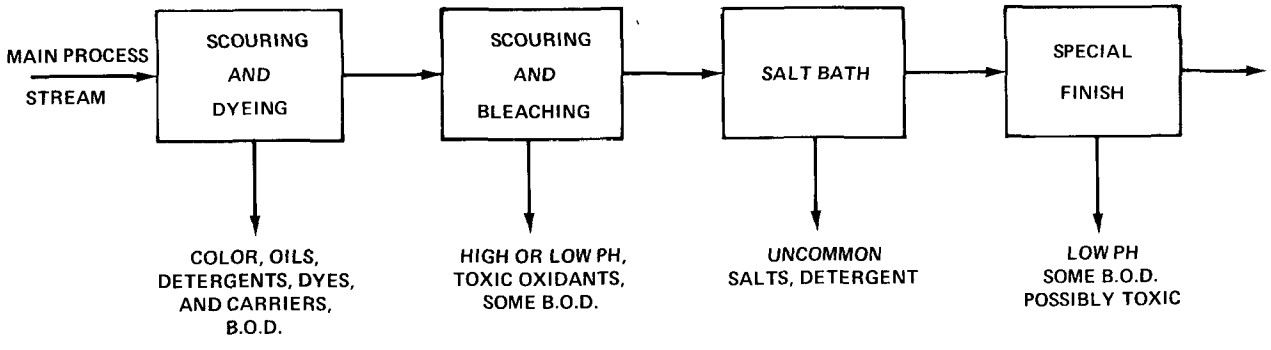


Figure II-4. Cellulosic synthetic-textile-finishing process flowsheet. (Rinsing operations not shown.)

Table II-4.—*Pollutional load of synthetic wet fiber processes*

Process[1]	Fiber	pH	BOD_5		Total solids		Suspended solids, lb/1,000 lb	Volume, gal/1,000 lb
			ppm	lb/1,000 lb	ppm	lb/1,000 lb		
Scour	Nylon	10.4	1,360	30-40	1,882	30-50	20-40	6,000-8,000
	Acrylic/ modacrylic	9.7	2,190	45-90	1,874	12-20	25-50	6,000-8,000
	Polyester	–	500-800	15-25	–	25-35	5-15	3,000-5,000
Scour and dye	Rayon	8.5	25-32	50-70	3,334	25-39	0-4	2,000-4,000
	Acetate	9.3	2,000	40-60	1,778	–	1-20	4,000-6,000
Dye	Nylon	8.4	368	5-20	641	20-34	2-42	2,000-4,000
	Acrylic/ modacrylic	1.5-3.7	175-2,000	2-40	833-1,968	6-9	5-20	2,000-4,000
	Polyester	–	480-27,000	15-800	–	30-200	–	2,000-4,000
Salt bath	Rayon	6.8	58	0-3	4,890	20-200	2-6	500-1,500
Final scour	Acrylic/ modacrylic	7.1	668	10-25	1,191	4-12	3-7	8,000-10,000
	Polyester	–	650	15-25	–	10-50	3-50	2,000-4,000
Special finishing	Rayon	–	–	20	–	3-100	3-50	500-1,500
	Acetate	–	–	40	–	3-100	3-50	3,000-5,000
	Nylon	–	–	10	–	3-100	3-50	4,000-6,000
	Acrylic/ modacrylic	–	–	60	–	3-100	3-50	5,000-7,000
	Polyester	–	–	2-80	–	3-100	3-50	1,500-3,000

[1] Waste load due to rinsing attributed to operation preceding rinse.
Source: F. H. Lund, *Industrial Pollution Control Handbook,* New York, McGraw-Hill, 1971

Table II-5.—*Pollution loads*[a] *from textile processes with various fibers*

Fiber	Natural impurities	Sizes, oils, antistats	Scouring[1]	Dyes,[1] emulsifiers, carriers, etc.	Special finishes	Total
Cotton	3-5	0.5-10	0.5-6	0.2-8	0.2-8	4.4-37
Greasy wool[2]	20-30	0.2-9	[3] 1.5-15	0.5-10	0.2-8	[2] 21.9-72
Scoured wool	1-2	0.2-9	[3] 1.0-15	0.5-10	0.2-8	2.9-44
Rayon	0	0.5-6	.5-5	0.2-5	0.2-8	1.4-24
Acetate	0	0.5-6	.5-5	0.2-5	0.2-8	1.4-24
Orlon	0	0.5-6	.5-5	0.5-10	0.2-8	1.7-29
Nylon	0	0.5-6	.5-5	0.2-5	0.2-8	1.4-24
Dacron	0	0.5-6	.5-5	0.3-60	0.2-8	4.2-78

[a] Percent of fabric weight.
[1] Partial contribution from subsequent rinse operation.
[2] Reduced by 98 percent with solvent extraction.
[3] High values include soap (fulling).
Source. N. L. Nemerow, *Liquid Wastes of Industry, Theories, Practices, and Treatment,* Reading, Mass., Addison-Wesley, 1971.

Table II-6.—*Significant pollutants in synthetic fiber, wet processing*

Fiber	Process	Liquid waste pollutant
Rayon	Scour and dye	Oil, dye, synthetic detergent, and antistatic lubricants
	Scour and bleach	Synthetic detergent and hydrogen peroxide
	Salt bath	Synthetic detergent, chloride, or sulfate
Acetate	Scour and dye	Antistatic lubricants, dye, sulfonated oils, synthetic detergent, esters, and softeners
	Scour and bleach	Synthetic detergent, hydrogen peroxide, or chlorine
Nylon	Scour	Antistatic lubricants, soap, tetra-sodium pyrophosphate, soda, and fatty esters
	Developed dispersed dye	Dye, $NaNO_2$, hydrochloric acid, developer, and sulfonated oils
	Bleach	Peracetic acid
Acrylic/modacrylic	Dye	Dye, formic acid, wetting agents, aromatic amines, retarding agent, and sulfates
	Thermosol dyeing	Acid
	Bleach	Chlorite
	Scour	Synthetic detergent and pine oil
Acrylic/modacrylic	Dyeing with	Chlorobenzenes, hot water, and dye; or phenylmethyl carbinol, dye, and hot water; or orthophenylphenol and dye
	Scour	Antistatic lubricants, chlorite or hypochlorite, and nonionic synthetic detergent
	High temperature and pressure dyeing	Dye and hot water
	Bleach	Chlorite, $NaNO_2$, acetic acid, oxalic acid, nitric acid, bisulfite, proprietary bleaches

Note.—A source of potential toxicity and odor is dye carriers used with some of the synthetics (particularly polyesters). Examples are orthophenylphenol, phenylmethyl carbinol, and monochlorobenzene. Sodium dichromate, used in dyeing, will contribute toxic chrome to the wastes, but substitutes are available. Much of the pollutants contributed by these operations actually enter the waste stream through rinses that follow the operations.

Source. H. F. Lund, *Industrial Pollution Control Handbook,* New York, McGraw-Hill, 1971.

in their immediate objectives, the environmental effect in terms of long-term oxygen demand and toxicity must be considered.

For individual mills, there is no substitute for a wastewater survey. General characteristics are helpful in defining the nature of problems formed by an industrial process; however, the solution of the problems encountered in any one mill is achieved only after careful analysis of the mill wastewaters, together with determination of effluent limitations and laboratory and pilot-plant studies of treatability. This survey must be combined with carefully considered in-plant measures of waste reduction. Determining the most economical method of pollution control is only possible if complete and accurate wastewater analysis has been undertaken. Pollution-control measures, once installed, must be continually evaluated via ongoing wastewater monitoring programs. Existing wastewater-treatment facilities and effluent quality standards must be considered before making substantial process changes or chemical substitutions. The wastewater-treatment process should, in actuality, be considered a part of the overall manufacturing process, which begins with the raw product arriving at the plant and the finished product and resulting wastewater leaving the plant.

Chapter III

BIOLOGICAL WASTEWATER TREATMENT

OVERVIEW

Before any decision can be made regarding the type of treatment to be used, all the basic facts must be available for evaluation. These facts fall into two general categories, namely,

- The characteristics of the wastewater that is to be treated
- The effluent requirements of the treated wastewater

The missing link is the "black box" between the input (characteristic wastewater) and the output (effluent characteristics).

A good approach to putting all the pieces in perspective for critical evaluation is the preparation of a preliminary design report, which is the best means of insuring that all of the relevant facts have been collected, placed in proper perspective, and critically examined. Since many of the failures or malfunctions of wastewater-treatment plants are related to poor design resulting from negligence in obtaining adequate design information, this report serves as an intermediate checkpoint in an effective wastewater-pollution-abatement program. It should be reviewed not only by the company, but by the proper regulatory agencies.

Adequate characterization of the industrial wastewater could include the following parameters:

- Flow, variation
- Temperature, variation
- Character of wastes, variation
  - pH
  - Alkalinity or acidity
  - BOD: raw and settled
  - COD: raw and settled
  - Phosphorus: inorganic and total
  - Nitrogen: ammonia and organic
  - Metals: particularly toxic
  - Anions: chlorides and sulfates; toxic

— Phenol and other organics of concern

— Oils and grease

— Solids: total with volatile; suspended with volatile (raw and settled); settleable

— Color

— Chlorine

Additions or exceptions to this list should be based on knowledge of the manufacturing process and chemical use.

To obtain this information, a carefully planned and executed wastewater survey is required. The survey should identify the sources, strength, and variation of the various process streams and should be related to stockroom and production records as well as to the ongoing process flowsheet. This information will be of value later for a continuous monitoring program. It should be noted that a good in-plant survey will not only provide the necessary wastewater-treatment-plant design information, but will also identify many in-plant measures of pollution control, such as water conservation, reduction in chemical use, process modifications, and chemical substitution. These measures have been highly successful in the past in reducing textile waste loads. BOD loads have been reduced as much as 75 percent in cotton processing, by 30-70 percent in wool processing, and up to 40 percent in synthetic processing by implementation of in-plant measures. Needless to say, these in-plant remedial measures can have significant economic impact on the wastewater-treatment-plant requirement.

Having characterized the input to the "black box" or the character of the wastewater that must be treated, it is now necessary to consider the effluent standard that must be met. It could be that effluent concentrations are governed by the EPA industrial effluent guidelines, but with projected increase in plant production in the near future, the State stream water quality standards may become the controlling criteria. Since the proposed wastewater-treatment plant will be designed to treat future loads as well as present ones, this must be a consideration in choosing the mode of treatment.

Some other considerations in choosing the best method of treatment may be flexibility, since the wastewater characteristics can change from day to day as well as over the years, and space availability, since some methods of treatment may be precluded merely because insufficient space is available.

The significance of the wastewater-characterization parameters as related to treatment-plant design should be discussed briefly before considering treatment alternatives.

Flow: Measurement of flow, in particular flow variations, is highly important. Greatest variations will occur when weekend and vacation period shutdowns are practiced. Daily variations will be great with one- and two-shift operations or when batch operations occur. In all situations in which significant flow variations occur, some provision must be made for equalization, either through providing storage or by using long-detention treatment systems. Obtaining good flow data when multiple sewer discharges occur offers a real challenge.

Temperature: The temperature of wastewaters is an important consideration in selection of biological treatment systems. High-temperature wastes in excess of 100° F are not amenable to short-detention systems such as conventional activated sludge or even trickling filters. Low-temperature wastes are not amenable to treatment in aerated lagoon systems in cold climates where temperatures drop below freezing. Wastes that vary widely in temperature because of batch operations require equalization or long-detention treatment systems.

Character of wastes: It is not necessary to analyze wastewaters for all the items previously given. Some judgment should be used based on the industrial process involved, compounds used in processing, and final disposition of the wastewater.

Variation in wastewater quality is of major concern, and judgment must be used in establishing a sampling program. When space limitations force employment of short-term, high-rate systems, or other reasons dictate, collection of 8-hour or shift composites is indicated. When long-term treatment systems are employed, 24-hour composited samples are adequate. In any event, a sufficient number of samples, usually at least 10, spaced to measure product variation, should be collected.

pH: In addition to determining the pH of composited samples, a continuous record of pH should be obtained when it is known to vary widely, as with many textile wastes.

Alkalinity or acidity: Both of these items are related to pH in a qualitative manner, but their measurement is required in making assessments of whether neutralizing chemicals are needed. In situations in which equalization is impossible, hour-to-hour measurement is needed.

BOD: Measurement of BOD_5 is usually necessary for determining the size of treatment units and aeration devices. Determination should be made on both raw and settled waste to ascertain need for primary clarification. The ultimate BOD (BOD_U, BOD_L, or BOD_{20}) is sometimes required by regulatory authorities.

COD: The COD, as determined by dichromate, measures the total oxygen demand, including biologically refractory materials. COD data cannot be used in design unless they can be interpreted in terms of BOD. When laboratory or pilot-scale studies are conducted,

$$\frac{COD}{Inf} - \frac{COD}{Eff} = BOD$$

To obtain reliable results, the final effluent samples should be filtered to remove biological flocs before determining COD.

Phosphorus (P) and nitrogen (N): Both of these elements are important in the nutrition of activated sludge, micro-organisms, and other biological growths employed in wastewater treatment. The amount required is related to the BOD_5 and the method of treatment. The following ratios are recommended:

	BOD	N	P
High rate-high synthesis	100	5	1
Medium rate-medium synthesis	100	3	0.5
Low rate-low synthesis	100	2	0.3

Phosphorus and nitrogen in excess of the foregoing requirements will appear in the final effluent and may cause a pollution problem in the receiving waters.

Metals: Of particular concern are the so-called toxic metals, or any whose discharge to receiving waters is limited. In general, most metals do not have serious effect in biological waste-treatment systems, provided the pH is maintained in the range of 8 or above. Under such conditions, the metals are precipitated as the hydroxides become incorporated in the sludge, and the amount of metal that can exist in the ionic form is negligible. The presence of the precipitated hydroxides,

however, constitutes a serious threat. If the pH should fall, large amounts of the metals in ionic form could be released and cause great harm to the treatment plant and stream biota.

Mercury is an exception and should be recognized. It should be removed at the source by isolation and separate treatment.

Chromates are normally considered along with the metals. Chromates are not precipitated at high-pH levels. Being soluble, they pass out in the effluent. Limits on the discharge of chromates (Cr^{+6}) are quite strict. At pH values of 6.5 or below, they become quite toxic and could be detrimental to wastewater treatment.

Anions: Chlorides and sulfates are normally of little concern in biological waste treatment unless the concentration becomes high or variable. They are also of concern in receiving waters, particularly those used for public water supply.

The cyanide ion is noted for its toxicity to fish. Essentially, complete destruction or conversion to cyanate is recommended. Arsenic in the form of arsenites and arsenates are both soluble and toxic. Rather strict regulations govern discharge to natural waters.

Phenol and other organics: Phenol is biologically degradable with an acclimated biota. Certain derivatives of phenol (e.g., orthophenylphenol as used in the textile industry for dye carrier) and other organic compounds are quite resistant to biological oxidation. Treatability studies are required if such compounds occur. Physical removal by adsorption may be required.

Oils and grease: Oils and grease are a serious problem in many industrial wastewaters, such as wool-scouring wastewaters in the textile industry. When present in significant amounts they should be removed by pretreatment, as they tend to be a nuisance in biological treatment systems and may even hinder purification. If oils and grease are present, final clarifiers should always be provided with skimming devices.

Solids: Total solids analyses, including volatiles, should be run on 24-hour composited samples.

Suspended solids analyses, with volatiles, should be run on both raw and settled wastes for the purpose of determining benefits to be derived from primary clarification.

The settleable solids test gives a crude measure of the volume of primary sludge to be expected. It can be interpreted in quantitative terms when it is related to suspended solids removed by settling.

Color: The color of wastes is becoming more and more important as restrictions on discharge become tighter. Of great importance is the residual color following treatment. Color considerations may force the use of physical-chemical methods of treatment or biological treatment with physical-chemical polishing.

Chlorine: Chlorine is an oxidant and, as such, a biological disinfectant. Strong doses of chlorine can be harmful to biological systems.

If the input to a treatment system, the significance of the input parameters on various systems, and the performance requirements of a system are known, feasible alternative treatment systems can be chosen, based on the following criteria:

- Experience—the engineer must have enough experience with the manufacturing processes and resulting wastewaters to reliably choose workable alternative systems

- Data available on similar situations—other similar plants may have workable wastewater-treatment systems for comparable wastewaters

- Laboratory study—it may be necessary to screen several possible methods to determine the acceptable alternatives

- Pilot-plant study—certain significant questions may be left unanswered after a laboratory study or unpredictable scale-up effects may need to be investigated before workable systems can be chosen

The choice of treatment could follow the following paths:

- Joint treatment with a municipal or regional plant

- Pretreatment at the plant site followed by joint treatment

- Treatment at the plant site

Joint treatment would involve contracts, surcharges, shared capital costs, and possibly partial onsite treatment. If it is decided that onsite treatment of the wastewater is preferred, the additional alternatives are

- Physical-chemical

- Biological

- Combination of physical-chemical and biological

A qualified engineer can usually select a preferred treatment system from the feasible alternatives based on the accumulated data, experience, and logic. Occasionally, two systems will appear so nearly comparable that it is difficult to make a decision. Cost estimates will usually resolve the problem. Capital, operating, and annual cost estimates should be compared. Often a preference for capital costs versus operating costs is the deciding factor. The following discussion is concerned with biological treatment—treating industrial wastewater by a living system.

Biological treatment of an industrial wastewater involves contacting the wastewater with a mixed culture of micro-organisms (bacteria being the most important species) under a favorable environment. The micro-organisms metabolize the wastewater components for energy and synthesis of cells. In the process, the micro-organisms use DO, produce carbon dioxide, and synthesize new cells. These reactions are continually occurring in nature, but the rate is usually limited owing to one or more controlling parameters, such as DO, available nutrients, and microbial concentrations. In biological wastewater treatment, the rate is greatly accelerated by providing high concentrations of micro-organisms to feed on the wastewater, substantial mixing, adequate DO, and good agitation for frequent contact between the "food" and the micro-organisms.

Methods of biological treatment are either aerobic or anaerobic. In the first case, degradation of organic matter takes place in the presence of and through combination with oxygen. The oxidation of glucose is an example.

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Bacteria}} 6CO_2 + 6H_2O$$

Since textile wastes are generally alkaline (high pH), the release of carbon dioxide in the aerobic biological process serves to reduce alkalinity and lower the pH. It has been demonstrated that when

wastewater contains sufficient BOD_5, enough carbon dioxide is generated to convert all phenolphthalein alkalinity to bicarbonate.

$$2OH^- + CO_2 \longrightarrow CO_3^= + H_2O$$

$$CO_3^= \ddagger CO_2 + H_2O \longrightarrow 2HCO_3^-$$

High-pH wastewater is rapidly neutralized within the treatment system, at no cost, to a pH in the range of 8.5–9.0, which is highly satisfactory for biological treatment.

Oxidation of organic matter (food) supplies energy to the microbial population. These micro-organisms also need to synthesize new cells. They do this by again drawing upon the organic portion of the waste in combination with nutrients, including nitrogen and phosphorus. Cell synthesis may be represented simplistically as follows:

$$\underset{\text{organics}}{C_6H_{12}O_6} + O_2 + \underset{\text{nutrients}}{NH_3} \longrightarrow \underset{\text{new cells}}{C_5H_7NO_2} + CO_2 + H_2O \text{ (unbalanced)}$$

Both synthesis and oxidation are ongoing metabolic processes within the biological reactor. In any reactor, a complex mixture of micro-organisms specifically adapted to the conditions of their environment (food supply, nutrient level, oxygen level, pH, temperature, etc.) will exist. Those that are aerobic will be found in aerobic reactors where biochemical reactions similar to the preceding reactions will occur. Anaerobic micro-organisms exist where there is little or no oxygen. (A third type, facultative micro-organism, can adapt to either condition.) A simple reaction that may typify anaerobic processes is as follows:

$$C_6H_{12}O_6 \xrightarrow{\text{Bacteria}} 3CH_4 + 3CO_2$$

Depending on the DO level, one can expect a certain type or mixture of micro-organisms to be present. The same can be said of temperature, since there are temperature ranges within which certain micro-organisms thrive and others do not. Bacteria may be psychrophilic (4°-10° C), mesophilic (20°-40° C), or thermophilic (50°-55° C), for instance. For the population of any biological reactor to perform well, it must be well adapted to its environment. These populations can be "upset" by rapid or sudden changes in temperature, organic level, pH, or other factors, and the bioreactor will suffer reduced performance. Thus, with highly variable wastes, flow equalization or a large biological reactor may be required to treat the waste satisfactorily.

On a steady-state basis, aerobic systems suffer temperature limitations based on oxygen solubility and micro-organism adaptability. Anaerobic systems perform better at higher temperatures. A continuous supply of nutrients must be present in the wastes in either case. The adequacy of available nutrients must be determined during the effluent survey.

Biological treatment has often been referred to as "secondary" treatment. It is usually preceded by "primary" treatment, typically sedimentation. Pretreatment of textile wastes before biological treatment could include any or all of the following: screening, sedimentation, equalization, neutralization, chrome reduction (and precipitation), coagulation, or any of the other physical-chemical treatments. Additional sedimentation is required following the biological reactor to remove the suspended micro-organisms that settle as a sludge. The amount of sludge produced will depend on the type of biological treatment, the organic loading, the temperature, and the efficiency of sedimentation. Sludge handling is a basic consideration in biological treatment.

Phenols and sulfides can be successfully oxidized by aerobic biological treatment. The activated-sludge process has been known to remove as much as 98 percent of the phenol present in refinery waste.[3]

Hexavalent chrome (Cr^{+6}) may be toxic, even at low levels, to the micro-organisms of biological treatment. While toxicity of hexavalent chrome will be dependent on pH and temperature, reported Cr^{+6} limits for biological treatment vary from 0.05 to 5 mg l, with an average of 1 mg/1.[4] It is advisable to remove hexavalent chrome or reduce it to the trivalent form before biological treatment. Since biological treatment has typically produced only moderate color removals with textile wastes, a process such as carbon adsorption, which has been shown to remove both color and chromium, may be particularly advantageous as a pretreatment or posttreatment to biological oxidation. Ion exchange, chemical coagulation, or other physical-chemical treatments might also be considered.

In summary, biological treatment encompasses basically aerobic treatment and anaerobic treatment. Aerobic processes require input of DO and temperatures below 100° F and are characterized by nearly complete metabolism and high growth rates, while anaerobic processes are reductive in nature, use no free DO, and can tolerate high temperature, but exhibit lower growth rates and incomplete metabolism with resulting higher energy and products.

The biological treatment methods applicable to textile wastewater follow and are listed in order of increasing detention time:

- Trickling filters
- Activated sludge
- Rotating biological disks
- Extended aeration
- Lagoons

TREATMENT METHODS

Trickling Filters

Trickling filters are the oldest form of biological wastewater treatment. They simulate in a manmade system the same natural purification process that occurs in shallow streams where pollutants are removed by attached biological slimes on rocks and stream bottom as the water flows by. Trickling filters are employed in two capacities, as roughing filters before activated-sludge treatment or as the major biological treatment system. The flow diagrams for these two are shown in figure III-1.

In the early days, filters used sand as a media. These filters produced a high-quality, well-nitrified effluent, but were plagued with clogging problems and high maintenance costs, and required great areas of land. They are seldom used today except as "polishing" filters.

At the turn of the century (1900), rock filters became a favorite method of biological treatment. These filters produced reasonably high degrees of purification and had the ability to shed biological slimes, thus avoiding clogging problems. Clarifiers were required following the filters to capture the sloughed biological solids. Shallow (3-4 feet) and deep (5-8 feet) filters, single and two stage, with and without recirculation were widely used.

Today, synthetic materials are used widely as filter media. These filters are constructed of Saran or polyvinylchloride (PVC) sheets arranged in "bundles." Being lightweight, they can be stacked to great heights (as much as 40 feet) with intermediate supports, are capable of accommodating high hydraulic loadings, and are, therefore, extremely conservative of space. Recirculation is

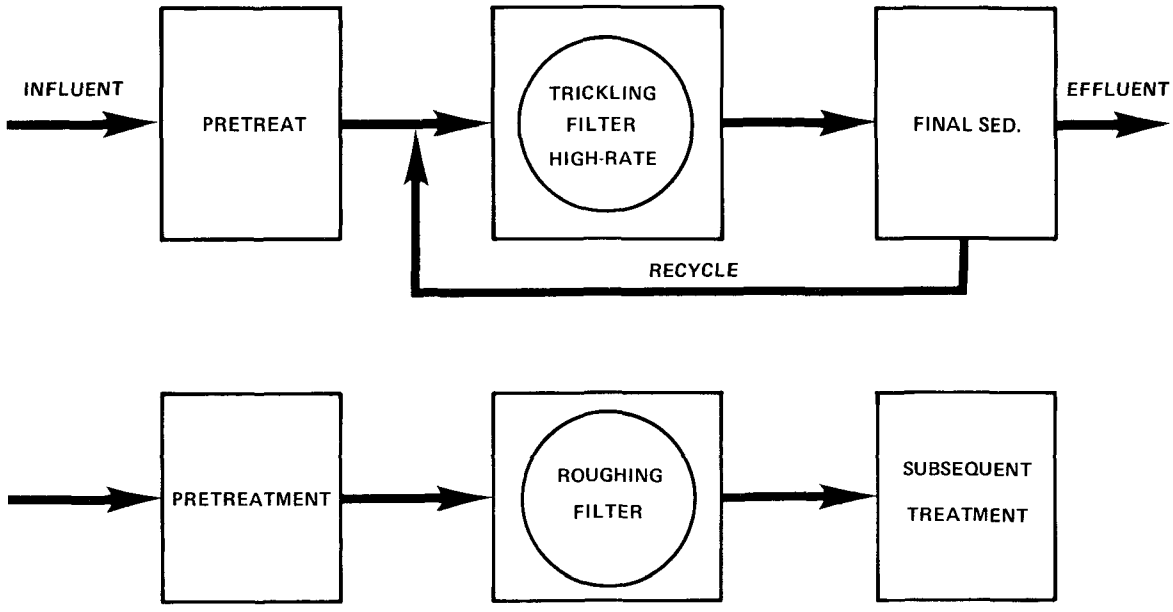


Figure III-1. Trickling filters.

usually desirable and is a necessity for variable pH wastewater or if toxic organics, such as phenol, are present. Their capability to remove BOD_5 varies with organic loading and with the character of the wastewater.

Trickling filters exhibit variable behavior, and this is their greatest shortcoming. Whenever trickling filters are proposed as the major biological system, a safe design should be based on pilot-plant studies at the site or, alternatively, on operating data from a plant treating similar wastewaters.

Activated Sludge

The activated-sludge process was developed by Ardern and Lockett in England during 1912-14. It was named for the activated sludge produced. The process involves aeration of a suspended growth culture in the wastewater as a means of purification. During the aeration, aerobic bacteria and other organisms grow and produce a biological floc, which, if conserved and fed back (return activated sludge) to fresh wastewater, results in rapid rates of purification. Many modifications of the original (conventional) activated-sludge process have been proposed since its inception. For textile wastewaters, some form of a completely mixed activated-sludge system is usually preferred.

Detention times for a conventional system usually are 6-12 hours; however, the BOD_5 loading actually defines a conventional system. The loading is best expressed as food to micro-organism (F/M) ratio. For diffused and mechanical aeration systems, the F/M ratio should be restricted to the range of 0.2-0.5. Because of limitations on the amount of micro-organisms (mixed liquor suspended solids (MLSS) or preferably mixed liquor volatile suspended solids (MLVSS) that can be carried in a system, volumetric BOD loadings normally range from 25 to 75 pounds per 1,000 ft^3/day. Removals of BOD_5 in excess of 90 percent are expected from this system. Waste solids are produced at the rate of 0.35-0.55 pound per pound of BOD_5 removed.

Turbine aeration systems employing compressed air with mechanical dispersion and systems employing oxygen can operate at higher BOD_5 loadings, namely, F/M ratios from 1 to 5. The effluent produced, however, is high in suspended solids, and BOD_5 removals are normally in the range of 95 percent unless filtration of the effluent is incorporated. Oxygen requirements for this high-rate modification of the conventional system are about double those of normal conventional

systems. Approximately 10 percent of the sludge produced must be wasted compared to 5 percent for the normal conventional system.

Having a small volume to dissipate a surge, shock loads do have an adverse effect on the system. Therefore, the application of the activated-sludge process to textile wastewater results in the need for pretreatment facilities such as equalization basins and neutralization equipment. Color removal is usually less than 50 percent. High sludge production in the conventional activated-sludge system may require substantial sludge-handling equipment, and disposal of sludge may be a costly process.

Rotating Biological Disks

Rotating biological disks are a relatively new type of biological treatment. Originally developed in Europe, there are now some 1,000 such installations for treating domestic sewage in West Germany, France, and Switzerland. Development has continued in the United States, where both domestic and industrial wastes have been successfully treated.

The rotating-biological-disk system consists of large-diameter, lightweight plastic disks, which are closely packed and mounted on a horizontal shaft located in a semicircular tank. A series of these units treats the waste, which flows from one tank to another. The micro-organisms present in the wastewater adhere to the plastic surfaces as they rotate through the tank. The wastewater is picked up on the surface of the disk and the portion that is not submerged absorbs oxygen from the atmosphere. The micro-organisms then aerobically degrade organic matter present in the waste. As they multiply, excess micro-organisms are sloughed off the disks into the wastewater. Mixing action provided by the disks keeps solids suspended. After treatment through a series of rotating biological disks, a final clarifier receives suspended solids.

Biological rotating disks have been found to be flexible with respect to varying organic and hydraulic loads, but the short detention times of each unit make them vulnerable to toxic shock loads. Reduction in waste temperature would be slight, and high influent temperatures would adversely affect treatment. This treatment method offers the advantage of low space requirements and, in some instances, may be economically competitive with other methods. Four-stage treatment by biological rotating disks has demonstrated BOD removals from 60 to 95 percent for domestic wastewaters. The final effluent is well oxygenated. Oxidation of ammonia, sulfides, and phenols would likely take place. Pilot installations are presently treating textile wastes in North Carolina. In one instance, biological disks are used to further reduce the BOD of activated-sludge effluent from an existing plant.

Extended Aeration

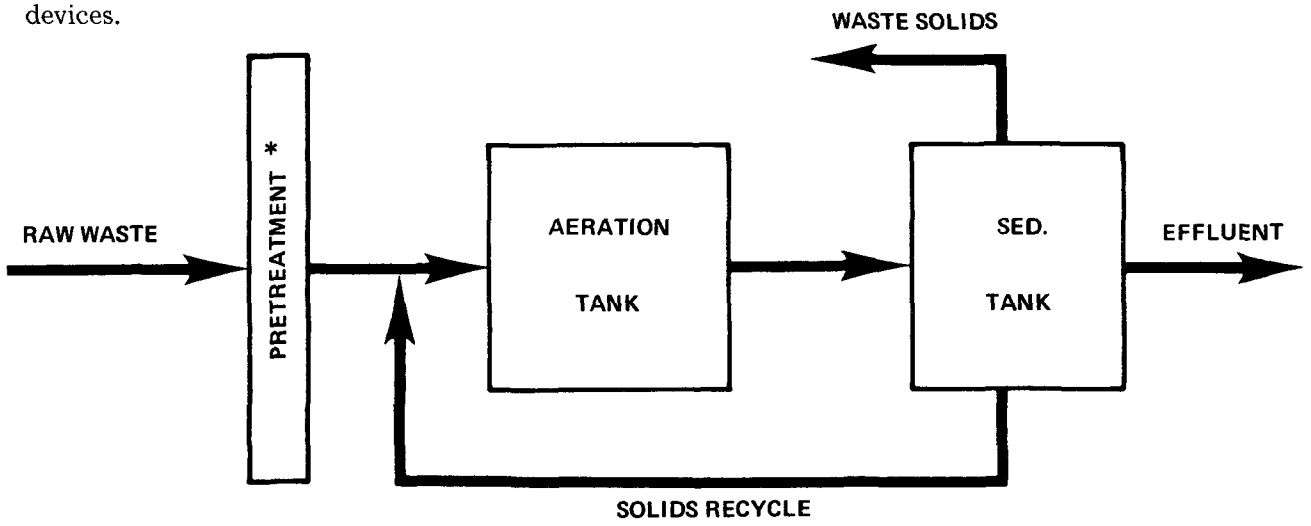
Another modification of the conventional activated-sludge process is extended aeration. This process was developed primarily to serve situations in which short-term variations in BOD_5 loadings are great, such as batch operations, and, secondarily, to minimize the production of sludge, namely, to only 0.1-0.2 pound per pound of BOD_5 removed.

Although the original concept was to provide 24 hours' detention time, modern concepts define an extended-aeration system as one in which BOD_5 loadings are kept in the range of 10-15 pounds per 1,000 ft^3/day of aeration tank capacity or F/M ratios of 0.04 to 0.06. A sludge-recirculation ratio of 100 percent is common practice.

With domestic wastewater, the F/M ratio is usually satisfied with a 24-hour detention period. For wastewaters of higher strength, such as textile waste, aeration periods of 36, 48, 60, 72, 96, or over 120 hours may be required.

A highly purified effluent is possible with BOD_5 removals of 90 to 95 percent. Also, due to the longer detention time and consequently larger volumes, the process is more resistant to upsets from shock loads.

The clarifiers used in extended-aeration systems should be at least 12 feet deep and have detention times of at least 4 hours. Surface overflow rates equal to or less than 300 gal/ft^2/day are commonly used with textile wastewaters. The clarifiers must also have mechanical sludge removal devices.



*SCREENING, EQUALIZATION, NEUTRALIZATION, CHROME REMOVAL

Figure III-2. Activated-sludge flowsheet.

Figure III-2 represents the flowsheet for both the conventional activated-sludge system and the modified-system extended-aeration activated sludge. It is the extended-aeration form of activated sludge that is very common to wastewater treatment of textile wastewater.

Lagoons

Lagoons may be classified as aerobic, anaerobic, or combination aerobic-anaerobic. One type of aerobic lagoon relies on natural processes such as wave action and photosynthesis by algae. Such lagoons are called oxidation ponds. They are very shallow and cover a large land area. Waste-detention times are as great as several months. The BOD_5 loading must be light to avoid anaerobic conditions and the generation of odors. While means of controlling water level are usually necessary (variable weirs, etc.), the equipment cost for such lagoons is minimal. The major portion of this cost is for acquiring land.

Aeration basins are mechanically aerated lagoons. They require only 3-5 percent of the land needed for oxidation ponds. They are 8-15 feet deep and have waste-detention times of 2-10 days, although 5 days is usually appropriate if the heat loss is great. Oxygen may be supplied by air diffusers or turbine aerators. The design of these lagoons must insure that the wastewater is well aerated throughout. The mixing required for thorough aeration makes it unfeasible to separate solids within the lagoon. As a result, clarifiers are required to treat the lagoon effluent. BOD_5 removal in aerated lagoons is greater than in oxidation ponds. Removals of 85-95 percent BOD are typically experienced with textile wastes. Resistance to shock loads and ability to efficiently treat variable wastes are advantages offered by these two treatment methods. Detergents may

cause excessive foaming problems when mechanical aerators are applied. Aerated lagoons and particularly oxidation ponds suffer reduced performance during winter, and ice may hamper operations.

Anaerobic lagoons are deeper than their aerobic counterparts, with depths up to 20 feet. Wastes are stabilized by a combination of precipitation and the anaerobic conversion of organic matter to CO_2, CH_4, H_2S, other gaseous end products, organic acids, and bacterial cells. Detention times are somewhat longer than those of mechanically aerated lagoons, 10 days being a typical value.

Tables III-1, III-2, and III-3 list treatment efficiencies observed for several methods of treatment when applied to textile wastes. Typical construction costs for the three most common methods of biological treatment are presented in table III-4. Chapter IV presents case studies illustrating the application of biological treatment to textile wastewaters.

Table III-1.—*Treatment process removal efficiencies for cotton and synthetic finishing*

Removal method	Removal efficiency, percent		
	BOD	Suspended solids	Total dissolved solids
Screening	0-5	5-20	0
Plain sedimentation	5-15	15-60	0
Chemical precipitation	25-60	30-90	0-50
Trickling filter	40-85	80-90	0-30
Activated sludge	70-95	85-95	0-40
Oxidation pond	30-80	30-80	0-40
Aerated lagoon	50-95	50-95	0-40

Source J Porter, "State of the Art of Textile Waste Treatment," study conducted for the WQO, EPA, Clemson University, Clemson, S C., Feb 1971

Table III-2.—*Treatment process removal efficiencies for wool scouring and finishing*

Treatment method	Normal reduction, percent				
	BOD	Grease	Color	Alkalinity	Suspended solids
Grease recovery					
Acid cracking	20-30	40-50	0	0	0-50
Centrifuge	20-30	24-45	0	0	40-50
Evaporation	95	95	0	0	–
Screening	0-10	0	0	0	20
Sedimentation	30-50	80-90	10-50	10-20	50-65
Flotation	30-50	95-98	10-20	10-20	50-65
Chemical coagulation:					
$CaCl_2$	40-70	–	–	–	80-95
Lime + $CaCl_2$	60	97	–	–	80-95
CO_2-$CaCl_2$	15-25	–	–	–	–
Copperas	20	–	–	–	–
H_2SO_4 + Alum	21-83	–	–	–	–
Urea+Alum	32-65	–	–	–	–
H_2SO_4 + $FeCl_2$	59-84	–	–	–	–
$FeSO_4$	50-80	–	–	–	–
Alum	20-56	–	75	–	–
Activated sludge	85-90	0-15	10-30	10-30	90-95
Trickling filtration	80-85	0-10	10-30	10-30	90-95
Lagoons	0-85	0-10	10-30	10-20	30-70

Source J Porter, "State of the Art of Textile Waste Treatment," study conducted for the WQO, EPA, Clemson University, Clemson, S.C., Feb. 1971

Table III-3.—*Treatment of textile wastes*

Mill	Type of treatment	Scale	pH		BOD, mg/l		Suspended solids, mg/l		Temperature, °F		Color removal, percent	Phenol alkalinity	Nutrient addition
			Initial	Final	Initial	Final	Initial	Final	Initial	Final			
Lees Carpets, Glasgow, Va. (wool scouring and dyeing)	Chemical coagulation, aerated lagoon	Existing plant, lab		7.8		990 45		510 50		100-110 80-90		560	No
Dominion Textile, Magoe, Quebec	None	Existing	12.0		420		64					1,450	
Kendall Co., Bethune, S.C.	Aerated lagoon	Lab	11.4-11.8	9	1,000-1,500	100-150							Yes
Kendall Co., Griswoldville, Mass. (cotton)	Equalization/ extended aeration,[1]	Pilot	11.5	<9	440	35	70	68	40-150			615	No
	extended aeration plus coagulation[2]	Pilot	11.5	<9	440	22	70	54					
Liberty, S.C., Cotton Finishing (1970 WWE)	Activated sludge, x-aeration	Full scale	10.9	5.3	213	4	48	12			Good	378 198	No
Union Underwear Co., Campbellsville, Ky.	Aerated lagoons—problems with Cl_2 and other oxidants	Pilot	9-11	8.4-8.6	400	24-30	60-150	[3] 185	110-125	79-95		<400	No

[1] Sludge bulking required addition of alum before final clarification.
[2] Produced highly variable effluent.
[3] No final clarifier.

Table III-4. *Construction costs: three common biotreatment methods*

Method	Cost, million dollars				
	@ 3.0 mgd	@ 3.0 mgd	@ 3.0 mgd	@ 1.0 mgd	@ 5.0 mgd
BOD, amounts in ppm	300	450	700	450	450
Trickling filter, cost	.90	1.15	1.50	.60	1.50
Activated sludge, cost	1.05	1.30	1.70	.65	1.85
Aerated lagoon, cost	.17	.185	.190	.080	.290

Note.—Each method employs 3-day equalization lagoons and final sedimentation and sludge lagoons. Land costs are not included.

Source: J. Porter, "State of the Art of Textile Waste Treatment," study conducted for WQO, EPA, Clemson University, Clemson, S.C., Feb. 1971.

Chapter IV

CASE HISTORIES OF BIOLOGICAL WASTEWATER TREATMENT

DAN RIVER MILLS, DANVILLE, VA.

Dan River Mills is one of the largest industries in Danville, Va. The first phase of their approach to stream pollution abatement was to undertake studies of the Dan River and of the wastewaters from the mills while concurrent studies of in-plant measures to reduce wastes were underway. The second phase included a detailed study of treatment methods; the third and final stage consisted of implementing the recommendations of the first two stages.

Early stream studies indicated that the requirements of the State water-pollution-control bill could be met by a reduction in alkalinity to meet pH requirements, together with a 50-percent BOD_5 reduction to meet DO requirements.

A moderate reduction in alkalinity was achieved by installing caustic recovery equipment with the mercerization process, reducing caustic requirements by approximately 50 percent. The wastewater survey had indicated that desizing operations contributed the major share of organic loading. When synthetic sizing (CMC) was substituted for starch, BOD_5 of the composite waste was reduced by 45 percent. This conversion from starch to CMC, however, took 2½ years to complete. During this period, polyester-cotton blends were replacing 100 percent cotton, further reducing waste load. Still other in-plant changes produced further reductions.

At the completion of phase 1, a series of events took place altering the nature of the local watershed. The Dan River became a spawning area for striped bass and other game fish. As a result, the second phase recognized that greater reductions in BOD_5 and alkalinity would be required, and the need for external treatment soon became obvious.

Laboratory-scale treatability studies were conducted on composite wastewater samples. These studies concluded that supplemental nutrients were not required for biological treatment and indicated 90 percent BOD_5 removal would be possible. Neutralization before biological treatment was judged to be unnecessary.

Pilot studies were initiated to compare six treatment methods and develop design criteria for full-scale operation. The six types of treatment were as follows:

- Biological:
  - Aerobic lagoon
  - Aerobic-anaerobic lagoon
  - Conventional activated sludge
  - Extended-aeration activated sludge
  - Synthetic media filter

- Physical-chemical: Lime precipitation

An 18-acre site was available for construction of the full-scale treatment plant. Due to the location of this site, odors and noise would have to be minimal. Other considerations of the pilot study would be cost and reliability.

The aerobic lagoon was operated at 3-, 4-, and 5-day detention times without sludge recycle. Consistant removal of BOD_5 (90 percent) and reduction in pH (to 9.0-9.5) were observed. Later operation with a 1-day detention time and sludge recycle was equally successful. The only operational problem during these studies was entrainment of leaves in the impeller of the surface aerator.

The aerobic-anaerobic lagoon, operated at 4- and 5-day detention time, achieved BOD_5 and pH reductions equal to the aerobic lagoon. Initial operation was characterized by excessive mixing and, consequently, very little anaerobic action. Baffles, placed along the periphery of the lagoon, corrected this situation.

At conventional detention times, the activated-sludge unit performed unsatisfactorily, so operation was converted to extended aeration. At a detention time of 24 hours, BOD_5 removal was 90 percent and effluent pH between 9.0 and 9.5. During later trials at a 16-hour detention time, temperatures above 95° F and high alkalinities caused unstable operation and large variations in BOD_5 removal.

The synthetic media filter at two loading levels reduced BOD_5 by 78 percent and 75 percent at the low (51.4 pounds BOD_5 /1,000 ft^3/day) and high (92.5 pounds BOD_5 /1,000 ft^3/day) rates, respectively. In both instances, the filters were operated at recirculation rates of 2:1. Effluent pH in the former case was 9.8 to 10.0 and in the latter case, 10.0 to 10.5. Later operations used the synthetic media filter as a cooling tower for wastes sent to the activated-sludge unit.

The results of chemical precipitation were erratic. BOD_5 removal ranged from 10 to 60 percent. Color removal was also erratic. Some of the variability was due to the design of the pilot unit. Variation in wastewater characteristics created additional difficulties.

Reductions of color and temperature were major parameters considered, as were foaming and solids handling. Initial conclusions and results with the two of the more promising treatment methods are summarized below:

- The activated-sludge (extended aeration) unit would minimize land area requirements, but indications were that it would cost more to operate than the other two most promising treatment methods.

- The aerobic-anaerobic lagoon offered much promise as a low-cost treatment method.

- Since present processes and effluent requirements in the industry are changing, the design of wastewater-treatment facilities must be flexible. Pilot systems allow the testing of new processes before adoption.

- Performance of aerobic and aerobic-anaerobic lagoons are shown in table IV-1.

THE KENDALL COMPANY, GRISWOLDVILLE, MASS.

The Kendall Company, Fibre Products Division, operated a cotton-finishing mill in Griswoldville, Mass. This plant processes cotton and gauze hospital and sanitary products. Wastes are produced primarily from caustic kiering, hypochlorite bleaching, and washing operations. Sizes

Table IV-1.—*Performance of aerobic and aerobic-anaerobic lagoons*

Item	pH	Temperature, °F	BOD_5, mg/l	Suspended solids, mg/l
Raw waste	11-12	60-115	[1] 150-225	–
Effluent, aerobic lagoon	9-10	50-92	20-40	25-65
Effluent, aerobic-anaerobic lagoon	[2] 9-10	48-92	20-40	20-70

[1] Occasionally over 300 mg/l.
[2] Often exceeds 10 during winter.

and dyes may be found in the wastes on occasion. All operations are done batchwise and produce a highly variable wasteload. The mill does not operate on Sundays. Something in excess of 2 percent of the total flow is domestic waste. Water is supplied by the North River, a class C stream. Wastes are discharged to this river also.

Continuous flow measurement and composite sampling were begun in 1967. Average daily flow varies from 600 to 800 gpm, with a mean of 716 gpm or 1.03 mgd. Table IV-2 summarizes the results of composite sampling.

Table IV-2.—*Analyses of 24-hour composite samples*

Item	pH	Total alkalinity, mg/l as $CaCO_3$	Ammonia nitrogen, mg/l as nitrogen	Organic nitrogen, mg/l as nitrogen	BOD_5, mg/l	Suspended solids, mg/l
Minimum	11.2	520	1.4	3.2	290	40
Mean	11.5	615	2.2	9.9	440	70
Maximum	12.3	890	4.8	13.2	720	180

The concentration of inorganic phosphorus ranged from 8.6 to 9.4 mg/l, more than adequate for biological requirements. Supplemental nitrogen in the form of ammonia would be required to meet the nitrogen requirement of approximately 22 mg/l. On an instantaneous basis, waste characteristics were highly variable: pH was observed to fall as low as 3.5 and rise as high as 13, and temperatures between 40° F and 150° F were observed. The cold Massachusetts winters were expected to affect treatment-plant performance.

Limited land area directed the pilot study toward biological treatment, employment of short-to-moderate detention time, and a high food-to-micro-organism ratio. A detention time of 5 hours was found sufficient for equalization prior to biological treatment. Since shock loads of chlorine and other oxidants had been released on past occasions, the equalization facility would also reduce the possibility of upset from such chance occurrences.

Pilot studies investigated three forms of extended aeration and activated-sludge treatment systems that differed only in their flow patterns. BOD_5 removals of 88, 89, and 90 percent were observed with these 36 liters per day pilot units. Suspended solids removals of 3, 23, and 9 percent were achieved. MLSS concentrations were highly variable in each system, and generally lower than desired. Equipment problems and winter temperatures hampered studies. It was felt that the 36-hour completely mixed activated-sludge process would be most capable of treating these wastes. Subsequent studies were aimed at improving this process. It was found that the addition of alum prior to clarification improved BOD_5 and suspended solids removal to a slight

extent, but more importantly, such addition greatly improved sludge stability. Without alum, sludge bulking and suspended solids carryover were often observed. Efficient solids separation was required in order to raise MLSS to adequate levels. Intermittent alum addition at a rate of 50-100 mg/l was sufficient to provide efficient solids separation. The addition of polyelectrolyte seemed to offer little benefit, however.

The full-scale treatment plant was designed to treat 1.1 mgd. Based on pilot studies, it was felt that MLSS concentrations of 2,500-3,500 mg/l could be maintained, resulting in a BOD loading of 0.09-0.12 pound BOD_5 per pound MLSS per day. Intermittent application of alum would be required to obtain a sludge possessing good settling characteristics.

Sludge handling is a key element in the design and operation of any treatment plant. Pilot studies indicated that odor problems would be associated with the sludge should it become septic. Alum containing sludges was somewhat better in this respect. Aerobic sludge digestion was planned, thereby stabilizing the sludge prior to dewatering and disposal. It was found that centrifugation was superior to vacuum filtration for sludge thickening. A full-scale plant employing equalization, fine screening, extended-aeration activated sludge, clarification, aerobic digestion of sludge, centrifugation of sludge, and final sludge lagooning with supporting equipment could be expected to cost $1,054,000 to construct and $57,000 to operate, given the characteristics of the Griswoldville wastes.

The Kendall Company, after studying their processing procedures, felt that a reduction in flow of 350,000 gpd was feasible. This made it possible to choose a more economical treatment scheme with no expected reduction in efficiency. The new design eliminated equalization and aerobic sludge digestion. Sludge centrifuging was considered as a future alternative, as was the aerated sludge lagoon. Provision for sludge recycle made it possible to operate the plant as either an aerated lagoon (no recycle) or as an extended-aeration activated-sludge process. The plant flow diagram and cost breakdown are presented in figure IV-1 and table IV-3, respectively.

Table IV-3.—*Treatment-plant capital costs*[1]

Item	Cost
Screen building and equipment	$176,000
Aeration lagoon and equipment	158,000
Final clarifier	70,000
Sludge pumping station	85,000
Instrumentation and electrical work	90,000
Pumping and site work	70,000
Sludge lagoons (without land costs)	63,000
Landfill site work	40,000
Subtotal	752,000
Contingency (10 percent)	75,000
Total construction	827,000
Engineering and testing	103,000
Total project (exclusive of land, legal, and administrative costs)	930,000

[1] Estimated at ENR Construction Index of 1250.

The construction contract was awarded to the low bidder at $798,000 in early 1971. The plant was completed late in December 1971 and was operating by midspring of 1972. During the last 8 months of 1972, removal of BOD_5 averaged 96 percent. Foaming in the aeration basin, variable MLSS, and pumping problems were encountered. Facilities were added to provide for

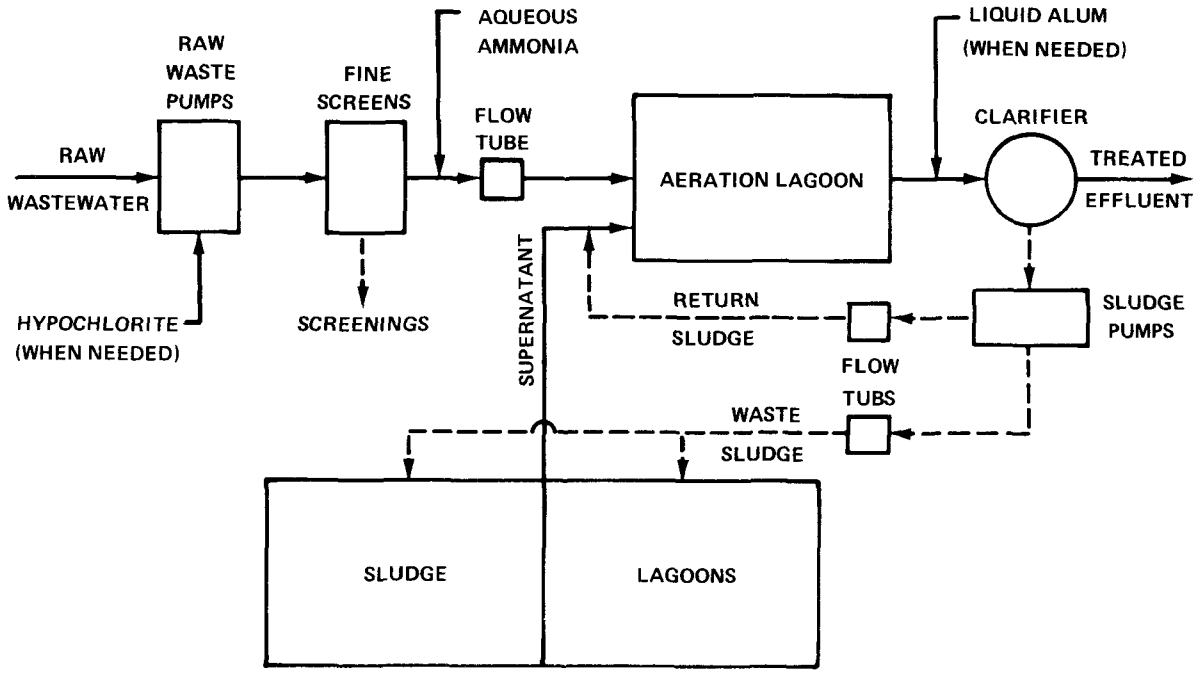


Figure IV-1. Simplified-process flow diagram, Kendall Company, Griswoldville, Mass.

neutralization with sulfuric acid. The plant is presently an extended-aeration activated-sludge system, with 3½ days' detention and 40 percent sludge recycle. Other parameters describing plant operation are listed in table IV-4.

Table IV-4.—*Treatment-plant parameters*

Parameter	Average	Range[1]
Flow, mgd	0.80	58-1.04
BOD_5, influent, mg/l	437	250-558
BOD_5, effluent, mg/l	16.6	3-53
MLSS, mg/l	1,739	482-3,696
F/M ratio	0.085	.036-.312
Settleability, ml/l		190-990
Sludge volume index		107-919

[1] Weekly averages.

Experience at Griswoldville has indicated that superior color removal and less foaming in the aeration basin are observed when wastes are neutralized prior to biological treatment. A continuous alum dosage (40 mg/l) is applied at present. Color removal is variable but generally greater than 50 percent. Most recently, the plant has experienced problems with rising sludge after a 1-week mill vacation. The sludge lagoons have proven to be an odor problem of late. Improved sludge handling and neutralization facilities are planned.

BRW TEXTILES, BANGOR, PA.

BRW Textiles operates a knit-dyeing and finishing mill in Bangor, Pa. Wastewater from the mill is cooled via heat exchanger, equalized, and then treated, first, biologically and second, chemically. The raw wastes enter the treatment plant at an average rate of 0.72 mgd.

Ammonia supplementation is provided when necessary, and the wastes are equalized in a 1-million-gallon basin. No aeration is provided, but hydrogen peroxide is added in the mill to help maintain an adequate dissolved oxygen level. The activated-sludge process is used for biological treatment. Twelve hours' aeration with an MLSS concentration of 2,500-3,500 mg/l results in 95 percent BOD_5 removal.

Raw waste is unusually high in color and high in temperature. Heat exchangers remove 20° F, and holding for equalization results in additional cooling. The temperature in the aeration basin averages 80° F, while raw-waste temperature averages 123° F. The biological process produces little color removal. As a result, alum is applied at 300 mg/l with 5 mg/l of anionic polymer. After rapid mixing, flocculation, and settling, the final effluent is colored to the extent of 300-400 color units (platinum-cobalt standard). This represents 75 percent color removal with respect to the raw waste, but State law requires additional removal to yield an effluent with 50-75 APHA color units. Earlier tests with lime indicated that this coagulant was ineffective. The State also limits aluminum and other phosphates. The former, contributed by alum, must be efficiently removed in the final clarifier, and the latter, present at high levels in the raw wastes, has not been removed as efficiently by alum addition as was hoped. Consequently, plans to construct a two-stage (2-pH level) process, which may improve both color and phosphate removal, are in the works.

Chemical antifoaming agents have had to be added to alleviate foaming problems in the aeration basin. Presently, solids are centrifuged and disposed of via landfill. Figure IV-2 presents the flow diagram for wastewater treatment at BRW Textiles in Bangor.

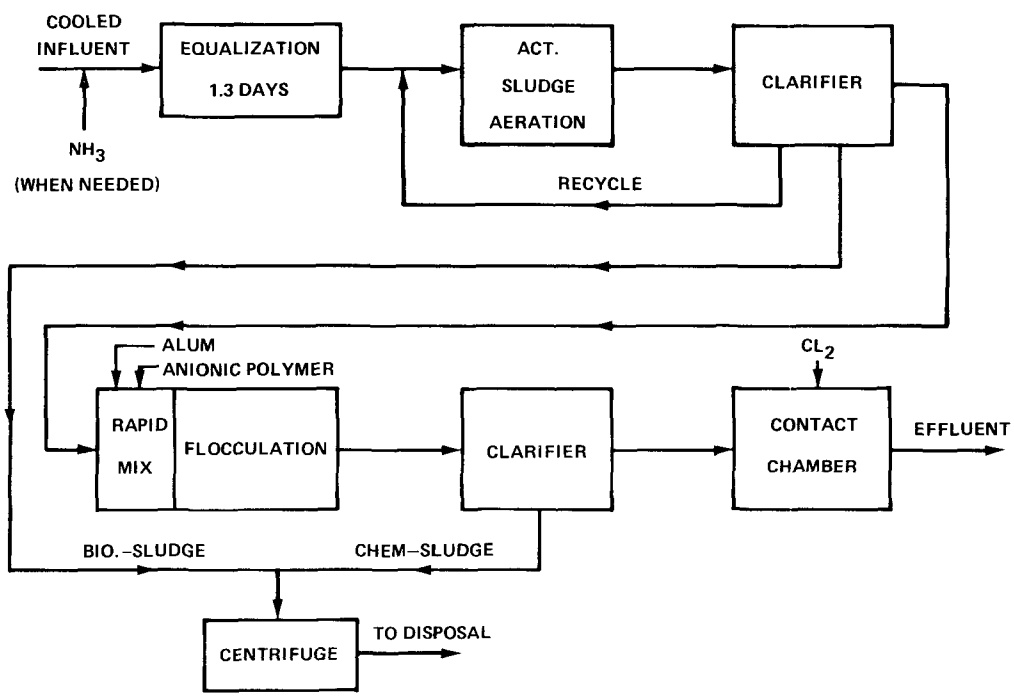


Figure IV-2. Flow diagram, BRW Textile, Bangor, Pa.

UNITED PIECE DYE WORKS, BLUEFIELD, VA.[1]

The wastewater-treatment facility at the Bluefield United Piece Dye Works (UPDW) plant originally was designed to treat 1 mgd of waste from the dyeing and finishing of woven goods.

[1] Abstracted from American Dyestuff report "Treating Finishing Waste Chemically and Biologically," Randall and King, pp. 63-66, June 1973.

Treatment then consisted of partial equalization followed by neutralization. Over 2 years ago, the plant installed process units for handling knit goods, and for the past 1½ years, has been processing equal amounts of knit and woven goods. As a result, the volume of wastes has decreased from 1 mgd to about 0.7 mgd, and the organic strength of the wastes has decreased as well. The characteristics of the wastewaters resulting from the processing of equal amounts of knit and woven goods are presented in table IV-5. The data represent wastewater that has been neutralized and partially equalized and are a summary of 73 routine samples taken over 1 year's time. The color of this waste is quite variable and may change from green to red to blue to yellow over a period of a few hours.

Table IV-5.—*Wastewater characteristics: Bluefield UPDW plant*

Parameter	Concentration		Sample 1[1]	Sample 2[1]
	Average	Range		
pH	6.8	–	6.4	10.3
Suspended solids, mg/l	61	28-120	96	125
Total solids, mg/l	1,705	1,138-2,584	–	–
Total volatile solids, mg/l			279	308
Settleable solids, ml/ml	0.02	0.01-0.04	–	–
BOD_5, mg/l	258	109-463	292	264
COD, mg/l			634	750
Total carbon, mg/l			228	252
Total organic carbon			200	205
Hue			Yellow	Greenish-yellow
Dominant wavelength, mm			578	568
Luminance, percent			63.3	54.8
Purity, percent			13	9
Zeta potential, mμ			-22.6	-26.2

[1] Typical grab samples.

Present treatment of the industrial wastes from the UPDW Bluefield plant may be visualized as a two-stage process. The first stage is a physical-chemical system. Equalization and neutralization are pretreatment steps. The chemical treatment that follows consists of coagulation and flocculation, using large quantities of lime (800 mg/l) as the primary coagulant. A high degree of color removal occurs at this point. Following flocculation, a high molecular weight anionic polymer is added (0.40 mg/l) to insure rapid settling of the floc in a sedimentation basin. The settled wastewater is then neutralized by the addition of strong acid. A small portion of the lime sludge is recycled to the influent end of the flocculation basin for particle nucleation, and the remainder is discharged to a sludge lagoon where it is mixed with fly ash, allowed to settle, and later disposed of as landfill.

The second stage is a biological system. The neutralized wastewater passes through four aerated lagoons operated in series. In these units, a high degree of biological treatment is accomplished. Oxygen is provided principally through the use of seven 20-horsepower aerators. No difficulty has been experienced in maintaining adequate DO levels in each lagoon. A flow diagram for the treatment plant is shown on figure IV-3.

Treatment Plant Performance

Color was measured on a comparative scale developed for the Bluefield installation. Color removal was always greater than 90 percent, both before and after the process change (from woven to 50 percent woven and 50 percent knit raw materials). BOD_5 removals were better than 85 percent

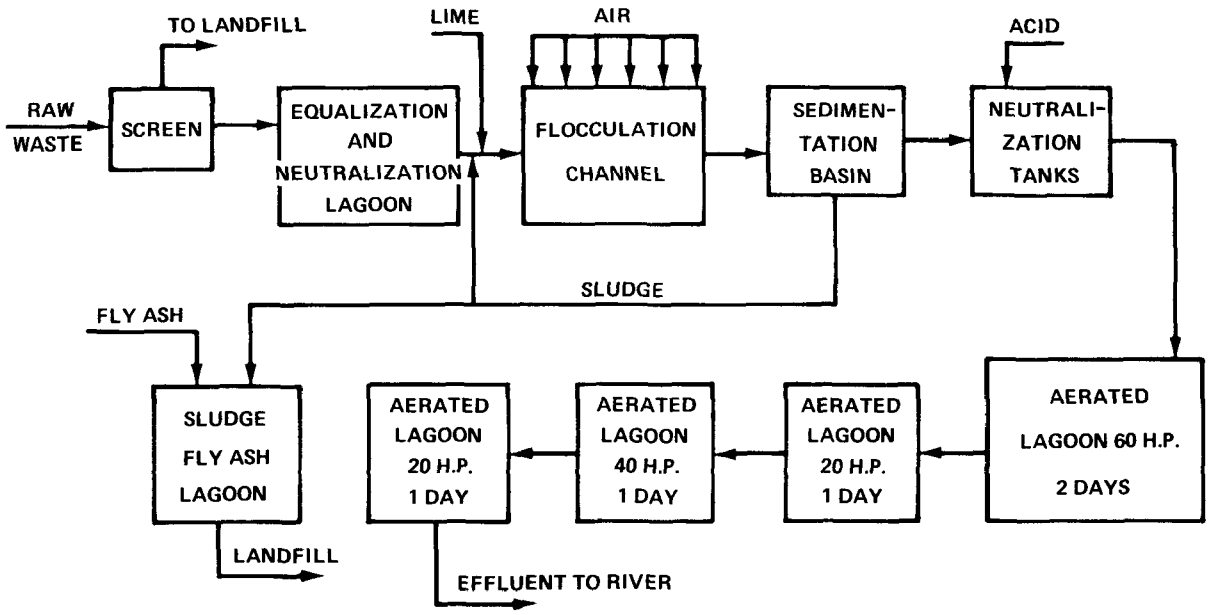


Figure IV-3. Flow diagram, Bluefield UPDW treatment facilities.

during the summer months, but a combination of an upset in the neutralization facilities and cool temperatures reduced BOD_5 removal to a low of 75 percent during the winter. BOD_5 was rarely 50 mg/l and was usually nearer 30 mg/l. An average reduction in suspended solids of 75 percent was observed during the 2-year period. Effluent concentrations generally fell within the range of 20-35 mg/l.

Most of the suspended solids were removed in the physical-chemical portion of the treatment plant. Removal of organic matter averaged some 20 percent in the physical-chemical portion of the plant, but substantially all the color removal occurred here. During the period of study, target pH for neutralization was raised from 7.5 to 9.6 and had no apparent effect on effluent pH. Biological production of CO_2 picked up the slack in reducing the pH of this alkaline waste.

Chapter V

EXPERIENCE WITH GRANULAR ACTIVATED CARBON IN TREATMENT OF TEXTILE INDUSTRY WASTEWATERS

INTRODUCTION

Although many textile plants have similar operations, experience to date indicates that the concentration and type of contaminant vary from plant to plant. Such variables would include suspended material, lint, organic dyes, dispersed dyes, sizing agents, and carriers. It is difficult, therefore, to design a waste-treatment process that would handle all types of textile-plant wastewaters.

In many cases, more than one unit process will be necessary to satisfy water-quality standards for discharge or reuse. Typical treatment systems may include such processes as screening, chemical clarification, settling lagoons, pH adjustment, filtration, activated sludge, trickling filters, adsorption, and ion exchange.

When examining the available alternatives, consideration must be given to capital and operating costs of a process, land requirements, flexibility for expansion, and the ability of the process to produce an effluent of consistent quality, regardless of changing conditions in the wastewater (i.e., temperature, volume, concentration). In addition, future wastewater-treatment requirements indicate that attention should be given to water-reuse possibilities.

Although there are no cure-alls for wastewater-treatment problems, one process—adsorption using granular activated carbon—has emerged as a practical and economical process for the removal of dissolved organics from textile wastewaters.

ADSORPTION

Webster defines "adsorption" as "the adhesion in an extremely thin layer of molecules (as of gases, solutes, or liquids) to the surface of solid bodies or liquids with which they are in contact." The phenomenon of adsorption dates back to 1550 B.C. when the Egyptians used carbon to "purify" medicines. Later, other civilizations used coconut char, bone char, and lignite char, to name just a few materials, for processes such as odor control, decolorization, and chemical purification.

In the early 1900's, a powdered form of activated carbon found utility in the removal of taste- and odor-causing constituents from drinking water supplies. Later, during World War II, a granular activated-carbon product was developed for use in gas masks. Since that time, activated carbon has been applied in almost every industry in which chemical processing plays a role. And, in addition, it has and continues to aid in the improvement of man's environment, both on this planet and in space.

The many uses of activated carbon are well documented in the literature; however, the employment of granular carbon for the treatment of textile wastes is relatively new and will be the subject of the following discussion.

GRANULAR ACTIVATED CARBON

Granular activated carbon can be manufactured using a number of source materials, including bituminous coal, coconut shells, and pulp mill black ash. The activated product is essentially inert. The hardness and density varies based on the raw material employed. During the manufacturing process, the carbon granules are permeated with a network of submicroscopic channels or pores, and it is this network that provides the vast surface area on which adsorption can occur. The surface area of a pound of granular carbon is equal to 125 acres, thus illustrating the magnitude of the porosity involved.

Carbon pores may be classified two ways: macropores and micropores. The macropores are the large pores in the carbon granule having diameters in excess of 1,000 angstrom units. These openings are large enough to admit complex, long-chain organic molecules. The micropores have diameters less than 1,000 angstrom units and provide most of the total surface area within the granule.

When a wastewater containing organic chemicals passes through a bed of carbon, the chemical molecules come in contact with the surface of the carbon and are held there by weak physical forces called Van de Waals forces. The water continues through the bed, free or organic contaminants.

It is important to note that when there is a mixture of organic molecules present, adsorption selectivity becomes a prime factor in the efficiency of the unit process. That is, carbon will preferentially adsorb some organic molecules over others. This selectivity is governed by three properties of the molecules: molecular structure, molecular weight, and polarity of the molecule. For example, if a wastewater contains a combination of an organic dye and a solvent, the dye, being a larger compound with a higher molecular weight than the solvent, would be more readily adsorbed by the carbon.

ADSORPTION FEASIBILITY

Adsorption Isotherm

An adsorption isotherm is usually run on representative samples of wastewater to determine the feasibility of using granular carbon to remove the organics. The test consists of contacting a fixed quantity of wastewater with varying amounts of carbon for a fixed length of time. The amount of organic removal at varying dosages then gives an indication of the amount of carbon required to treat this particular wastewater. This test is a very useful tool in determining the feasibility of carbon treatment. The dosages obtained from an isotherm may be very conservative, since they do not include the effects of biological degradation of organics during treatment.

Results of an adsorption isotherm are usually expressed in terms of the carbon's capacity for a given adsorbate at a specified equilibrium concentration. In most cases, the Freundlich equation is used to express the mathematical relationship between the quantity of substance adsorbed and the quantity that is left unadsorbed (figure V-1). The unadsorbed concentration left in solution (expressed by the symbol C) is measured directly. The adsorbed concentration on the carbon is indicated by the symbol x/m, where x is the total quantity of substance, and m is the carbon dosage used. Therefore, x/m is the quantity adsorbed by each unit weight of carbon.

With logarithmic plotting of data, the isotherm usually approximates a straight line when dealing with a single organic component. Since most, if not all, waste streams are mixtures, the plotting of the data results in a series of straight lines, each representing one of the components in the mixture. The equation is usually written:

$$x/m = kC^{1/n}$$

in which $1/n$ represents the slope of the isotherm.

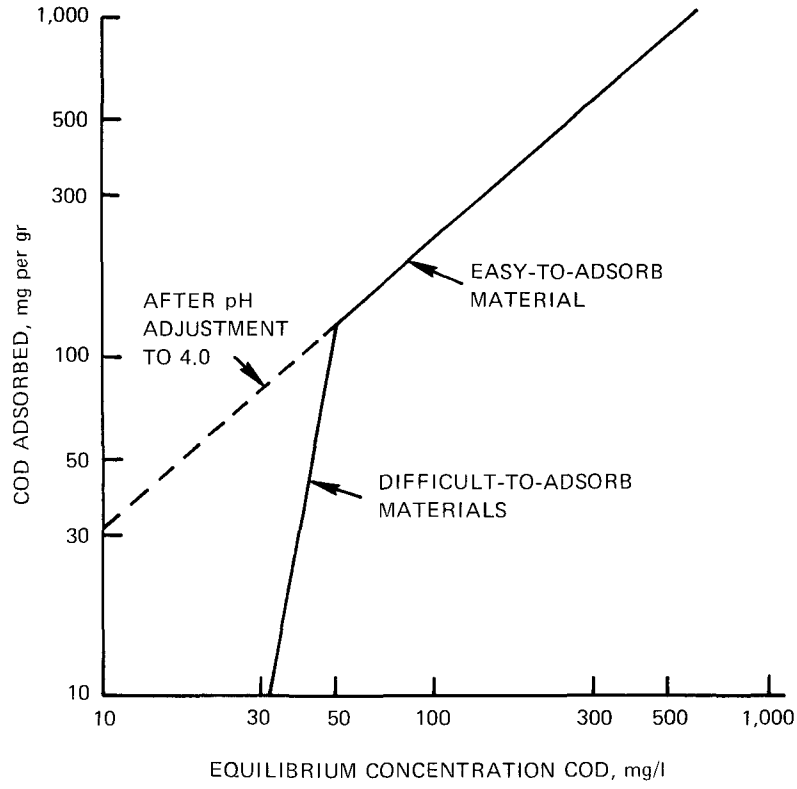


Figure V-1. Adsorption isotherm plot.

In review, an adsorption isotherm will provide the following useful information:

- Adsorbability
- Weight pickup
- Degree of removal
- Sensitivity to contaminant concentration
- Effect of variables such as pH, temperature, etc.

Pilot Carbon-Column Tests

The purpose of a pilot test is to obtain operating and design information. The test, which should be carried out in conjunction with pretreatment studies, involves passing a side stream to four columns filled with granular carbon and connected in series. The data obtained from the pilot column study tests indicate:

- The effect of biological activity
- Performance under dynamic conditions
- Filtration characteristics
- Contact time necessary to accomplish objectives

PRETREATMENT REQUIREMENTS

It sometimes becomes necessary to treat wastewaters prior to adsorption. Suspended solids content above 50 mg/l, for instance, would collect in the carbon bed and create excessive head loss across the bed. Lint can also cause premature pressure drop and problems by clogging pumps and valves. General practices employed for suspended solids or lint removal are screening devices, sand filters, diatomaceous earth filters, or conventional clarifiers. Adjustments in pH might also be necessary to destabilize colloidal materials or optimize the adsorption process.

ADSORPTION DESIGN PARAMETERS

Materials of Construction Consideration

Granular activated-carbon adsorption systems can be divided into four specific functional components:

- Granular activated carbon
- Adsorbers
- Reactivation package
- Hydraulic transport system

Granular activated carbon has been discussed in a previous section; therefore, only its effect on the other three components will be considered here.

One item that must be considered from an engineering standpoint common to all components is the extremely corrosive nature of the wet granular activated carbon. Wet carbon in contact with the metal surface will set up a galvanic cell, causing severe corrosion problems. Conversely, as long as carbon is kept moving through transport piping, corrosion is negligible.

Because of the corrosive nature of carbon in static conditions, engineering considerations should be given to the materials of construction employed in the entire adsorption system. Specifically, attention should be given to the following items from a corrosive standpoint:

- If pressure vessels are employed to house the carbon, then the mild steel vessels should be lined. Satisfactory linings used for this purpose are epoxy and coal tar resins.
- In downflow adsorbers that are employed not only for the removal of dissolved organics, but also for the removal of suspended solids, a surface wash or air scour system is usually installed. Since the carbon comes in contact with these systems, the material of construction should be resistant to galvanic corrosion.
- When carbon becomes exhausted, it must be removed through a hydraulic transport system. This removal can take place directly through the bottom or sides of an adsorber. Water is usually employed as the motive force. Since the moving carbon really does not present a corrosion problem, mild steel piping has been successfully employed as the transport system. To assure that no carbon remains in the pipelines, flush ports are usually installed for the removal of carbon granules that may settle out.
- Materials of construction are also very important in the thermal reactivation unit, which is either a multiple-hearth furnace or rotary kiln. Normally, the carbon is educted to a dewatering screw from which it is sent to the thermal reactivation unit. The dewatering

screw should be manufactured of stainless steel. In addition, the quench tank, into which the reactivated carbon is quenched, should be of stainless steel. Manufacturers of the thermal reactivation units are capable of recommending the materials of construction employed in the units themselves. Considerations to the type of brick will be dependent on the type and concentration of organics on the activated carbon, as well as the temperatures employed for reactivating carbon.

Adsorbers

Either pressure vessels or common wall concrete containers may be employed to house the carbon. The choice of adsorber types will be based on economics, land availability, and the amount of suspended solids present in the influent to the adsorption system.

These adsorbers are similar in design to rapid sand filters found in potable water plants. Water may be percolated through these adsorbers either upflow or downflow at surface loading rates anywhere up to 10-12 gpm/ft^2. A key consideration in all adsorbers is the type of underdrain system employed. Experience indicates that Leopold Block, Wagner, Wheeler, and even a pipe lateral system may be employed for the underdrain. The objective is to obtain uniform distribution. Most underdrain systems will work effectively as long as there is about a 1-psi pressure drop through it.

Adsorption systems configurations fall into four basic categories:

- Moving beds
- Fixed beds in series
- Fixed beds in parallel
- Expanded beds

The key feature of all adsorption design configurations is that they attempt to make maximum utilization of the carbon. Moving bed adsorbers operate on a countercurrent basis. Water flows upward through the bed and out the top. Once the treatment objective in the effluent has been exceeded, exhausted carbon is removed from the bottom of the adsorber and fresh carbon added to the top. This removal of carbon is countercurrent to the flow of water. Although this type configuration makes maximum utilization of the carbon, it has one major drawback—it can only handle a modest amount of suspended solids.

Fixed beds in series also attempt to make maximum utilization of the carbon. This is accomplished by valving the adsorption system so that any adsorbers can be placed in the lead position. When the objective is exceeded in the effluent from the last adsorber in the series, the exhausted carbon from the first adsorber is removed and replaced with fresh carbon. This first adsorber is then placed in the final, or polishing, position. This type of adsorber configuration does have the capability of handling suspended solids. However, one can immediately see that the capital investment is somewhat greater than using any one of the other designs.

Fixed beds in parallel are often employed since this design configuration has the capability of removing suspended solids in addition to the dissolved organics. Innate in this configuration is the ability to blend the effluent from all of the adsorbers to reach a treatment objective. Staggering the reactivation of each of the adsorbers permits one to blend the effluent to the degree required to reach the treatment objective desired.

Upflow expanded beds may be employed to overcome the possibility of premature plugging due to suspended solids in the influent. The carbon bed is normally expanded approximately 10 percent, and the solids are permitted to pass.

The choice of adsorber design configuration, therefore, will be made not only on the economics, but also on the concentration of contaminants in the influent to the system and the effluent objective desired.

Carbon Usage and Thermal Reactivation

When the activated carbon has become exhausted, three available alternatives may be considered:

- Throw the exhausted carbon away
- Thermally reactivate the carbon to its virgin quality and reuse it
- Have another company pick up the exhausted carbon and reactivate it for you (custom reactivation)

The method chosen is usually a matter of economics. Naturally, the most expensive method would be to employ the carbon on a throwaway basis. This method is usually reserved for the very small adsorption systems, or systems in which the carbon exhaustion rate is extremely low.

If the choice is made to reactivate the carbon, then thermal regeneration equipment must be designed and installed, based on the carbon exhaustion rate. Normally, 30-50 percent extra capacity is designed into the thermal-reactivation unit, since the increase in economics is not significantly greater than a unit sized to handle the specific exhaustion rate that was determined through testing.

Both multiple-hearth furnaces and rotary kilns have been employed for thermal regeneration of the carbon. Temperatures in the 1,600-1,800° F range are employed, with steam usually added to the fired hearths. Approximately 6,000 Btu's are required to reactivate a pound of carbon. During the reactivation process, the carbon is heated under controlled oxygen and temperature conditions to effect volatilization and selective oxidation of the adsorbed contaminants. The oxygen in the furnace is normally controlled at less than 1 percent. Carbon losses occur during this reactivation process and are due to abrasion and burning of some of the carbon. These losses have ranged from as low as 2 percent to as high as 10 percent. A 5-percent carbon loss is generally an accepted standard on which economics may be based.

Since thermal reactivation equipment is a significant portion of the capital investment, individuals may consider having someone else thermally reactivate their carbon. This approach to reactivation is usually chosen by those persons who do not want to reactivate the carbon themselves or to expend the capital required to purchase a thermal-reactivation unit.

CARBON-HANDLING SYSTEMS

The recommended method of carbon transport is the use of a water slurry. The ratio of carbon to water is 1-3 pounds of carbon per gallon of water. The minimum linear velocity necessary to prevent carbon settling is 3 feet per second. To minimize carbon attrition and pipe erosion, the hydraulic transport system should be constructed employing long sweep bends rather than 90° elbows.

Carbon slurries can be transported by using water or air pressure. Eductors, centrifugal pumps, or other pumps, such as diaphragm or Moyno, may be employed. A blowcase may be employed,

which uses air or water pressure applied in a pressure vessel. Carbon and water are slurried in a feed tank located above the pressure vessel. The slurry falls into the vessel, the valve is closed, and air or water pressure is supplied as the motive force. Water-jet eductors have been successfully employed in situations where other types of mechanisms are not practical or available. They are easy to operate and require little maintenance.

Either open or closed impeller pumps are suitable for carbon slurries, if the minimum clearance for granule passage is maintained. The speed of the pump should be in the range of 800-900 rpm to minimize degradation of the granules, and a rubber- or ceramic-lined impeller is recommended for pump resistance to abrasion.

ADSORPTION EXPERIENCE WITH TEXTILE-INDUSTRY WASTEWATERS

Survey

In a recent survey conducted by Calgon Corporation, 222 wastewater samples from 68 different manufacturing operations were examined to determine the applicability of granular carbon treatment for removal of dissolved organics. Of these, 34 samples were taken from 13 different types of textile manufacturers with specific four-digit Standard Industrial Classification (SIC) designations, as shown in table V-1.

Table V-1.—*Textile manufacturing categories from which wastewater samples were taken*

SIC number	Type of textile manufacturing
2211	Broad-woven fabric mills, cotton
2221	Broad-woven fabric mills, manmade fibers and silk
2231	Broad-woven fabric mills, wool
2241	Narrow fabrics and other smallware mills
2251	Full-fashioned hosiery mills
2252	Seamless hosiery mills
2254	Knit underwear mills
2266	Finishers of broad-woven fabrics of cotton
2269	Dyeing and finishing textiles
2272	Tufted carpets and rugs
2281	Yarn-spinning mills, manmade fibers and silks
2282	Yarn, throwing, twisting, and winding mills
2283	Yarn mills, wool, including carpet and rug yarn

Each sample was collected by plant operating personnel from the wastewater stream of concern. In some instances, a grab sample was used; in others, a composite sample was collected. The waste streams, in some cases, were point-of-origin wastewaters, while other samples represented combined wastewaters from a number of processes.

Each sample was tested for pH, suspended solids, total organic carbon (TOC), and adsorption as received, and selective removal of color was evaluated on 29 samples. The TOC test was used on the studies because it is a better measure of adsorption performance than either COD or BOD. Industrial wastes often contain inorganic contaminants that are chemically oxidized and, therefore, lead to COD values that are not associated with organic contaminants. Similarly, toxic substances adversely affect the BOD tests, which can also lead to incorrect conclusions.

Each sample was millipore filtered prior to adsorption isotherm testing to remove suspended material, which otherwise could be incorrectly associated with adsorption treatment. The type and concentration of suspended material removed in this step provide preliminary indications regarding

the desirability of pretreatment. A summary of raw-wastewater characteristics and treated water, both filtered and adsorbed, is shown in table V-2.

Table V-2.—*Textile-industry wastewater survey summary of adsorption isotherm results*

Item	Untreated wastewater		Following filtration		Following adsorption		Organic reduction, percent	
	Range	Median	Range	Median	Range	Median	Range	Median
TOC	9-4670	290	9-3335	183	1-440	16	75-99	94
Color	[1] 0.02-5.40	0.56	0.02-1.64	0.29	0.005-0.09	0.01	78-100	98
	[2] 50-7000	450	0.3-3500	410	0-15	0	98-100	100

[1] OD.
[2] Color units (platinum-cobalt standard).

This survey indicates that textile wastewaters contain color and other organics that are almost universally responsive to removal by adsorption. This result is consistent with data being collected from the installations presently treating textile wastewaters. It is apparent that pretreatment in the form of pH control and suspended solids removal will, in many cases, allow direct application of proven granular carbon technology to this industry, and the carbon-treated effluent will have direct reuse capability.

CASE HISTORIES

Velvet Textile Company

Velvet Textile Company, located in Blackstone, Va., manufactures velvet cloth used in clothing, draperies, and upholstery. Originally, the firm wove the cloth at Blackstone and then shipped it to Glastonbury, Conn., for dyeing. Early in 1970, however, Velvet Textile decided to combine its dyeing and weaving operations at Blackstone.

Although the physical transfer of the dyeing equipment did not present a major problem, one drawback that did emerge was that of wastewater disposal. Under an agreement with the U.S. Government, the city of Blackstone's domestic sewage is accepted by a treatment plant located a few miles away at Camp Pickett. Industrial wastewaters, however, are not accepted under any conditions. Thus, the textile firm began to examine various methods of treating its wastewater for reuse. After examining several wastewater-treatment methods, the firm decided to install a treatment system employing a combination of filtration and adsorption to remove suspended solids and color.

Velvet Textile uses a wide variety of soluble organic direct dyes to produce the desired colors and tones. Among these are phenamines and chloramines. The technique used to dye the fabric involves processing the velvet through three different steps: (1) scouring the material with a detergent, (2) dyeing the material, and (3) rinsing the excess dye from the fabric before drying. Wastewaters from these operations are discharged to a 225,000-gallon concrete equalization basin located below the building. Other plant wastes, such as this final rinse effluent, are also sewered to the basin.

The wastewater is pumped from the basin at approximately 160 gallons per minute to a diatomaceous-earth slurry mixing tank. Acid is also added to the tank to lower the pH to approximately 4.0 to help destabilize the colloidal particles. From here, the slurry is pumped to a diatomaceous-earth filter that has a filtering capacity of 10,000 gallons per hour. Samples of the

wastewater are visually examined before and after filtration to monitor the efficiency of the operation. Analysis has shown these samples to contain about 90 mg/l suspended solids and 175 mg/l TOC.

The clarified effluent is then pumped upflow through a moving bed carbon adsorber. The adsorber is 22 feet high and 9.5 feet in diameter and contains approximately 40,000 pounds of Filtrasorb 300 granular activated carbon. As the carbon becomes exhausted, a measured amount is removed from the bottom and an equal quantity of fresh carbon is added at the top. The exhausted carbon is shipped to Calgon Corporation's reactivation facility in Pittsburgh where the organic dyes are oxidized. The reclaimed carbon is then returned to the plant for reuse.

Effluent from the carbon column flows to an 800-gallon tank, where pH is readjusted to about 7.0. From there, it is discharged to a 100,000-gallon clear-water sump and held for reuse. Velvet Textile presently treats about 60,000 gallons of wastewater daily and is planning to increase this to 150,000 gallons soon.

The capital cost for the total system was approximately $100,000. The adsorber, tanks, and piping are of fiberglass construction, due to the corrosive nature of the wastewater. Operating costs have been estimated at 70 cents per 1,000 gal. In addition, reuse of the treated water has produced a 20-percent reduction in salt use and has eliminated both fresh-water and sewage bills.

Stephen-Leedom Carpet Company

Granular activated carbon is also being used to reclaim wastewater for reuse at a carpet manufacturing plant in Southampton, Pa. The management of Hollytex Carpet Mills, Inc., was faced with a serious problem when it began to plan an east coast operation. Water usage and discharge was estimated at 500,000 gpd at the onset, with expansion planned for 1 million gpd. Existing sewer capacity could not handle this volume of water. As a result, the municipality would have had to install new sewer lines, and the carpet firm would have had to pay for the installation in the form of a surcharge.

In addition, the water supply was not adequate to meet plant requirements. Costs for fresh water and sewer charges were prohibitive. Hollytex, therefore, began to examine water-reuse possibilities. After discussions with water-treatment specialists, it was decided to use a granular carbon system.

Pilot studies were conducted to establish the applicability and design parameters for an adsorption process. Subsequently, a plant was designed and constructed, and began operating in 1969.

Under an agreement with the local municipality, the carpet company would reclaim 80 percent of its water and discharge the remaining 20 percent to the sewer. Since the municipal treatment plant was able to handle the deep blue and red dye wastes, the carbon only treated rinse water and pastel dye solutions. This allowed the plant to operate at a carbon-exhaustion rate of 0.55 pound per 1,000 gallons of wastewater treated.

Wastewater from the dye becks flows into sumps through vibrating screens used to remove lint. From the sumps, the water is pumped upflow through a moving bed carbon column containing 50,000 pounds of Calgon's Filtrasorb 400 (12 $\times$ 40 sieve size). The treated water, free of all color and other organic materials, is then pumped through a cooling tower and stored for reuse.

Periodically, the carbon becomes exhausted and is withdrawn from the bottom of the column. It is then hydraulically transferred to a storage tank and, subsequently, to a multiple-hearth, gas-fired reactivation furnace. Here, the organics are oxidized and the carbon is restored to near-virgin activity.

This plant, now owned by the Stephen-Leedom Carpet Company, has been operating successfully since 1969.

ADSORPTION ECONOMICS

The capital and operating costs for custom-designed adsorption systems have been developed. The capital costs were determined for an adsorption system having an overall superficial contact time of 70 minutes. The system includes a two-stage adsorption system, a reactivation package, including dewatering screw and quench tank, and the carbon slurry handling system.

The reactivation package also includes an air scrubber and afterburner to prevent any air-pollution problems. In addition, it includes the initial carbon fill and a building to house the entire system. The capital costs for a 200,000- and an 800,000-gpd plant having an exhaustion rate of 1,500 pounds per day are $550,000 and $1 million, respectively. The capital costs for the same plants having an exhaustion rate of 10,000 pounds per day are $720,000 and $1,250,000, respectively.

The operating costs include the following:

- Amortization, using 7 percent interest on money over a 10-year period.
- Maintenance, insurance, and taxes at 5 percent of the capital.
- Labor costs based on one-half man per shift for a burn rate of 1,500 pounds per day and one man per shift for the higher burn rate. The labor rate was assumed to be $7 per hour.
- Utility costs were assumed at $1 per 1,000 pounds of steam, $1 per 1 million Btu's, and 1 cent per kilowatt-hours.
- Makeup carbon costs were determined assuming 7½ percent carbon loss and delivery price of virgin makeup carbon at 35 cents per pound.

SUMMARY

Granular carbon is presently being employed to treat textile wastewaters. Two case histories have been discussed; water reuse was an integral part of both.

A broad screening of adsorption applied to various types of wastewaters was shown and indicated that textile wastewaters are almost universally responsive to treatment via granular activated carbon.

Costs were shown and clearly indicate that the use of adsorption as a unit operation for treatment of textile wastewaters is quite economical.

REFERENCES

1. "Recommendations and Comments for the Establishment of Best Practicable Waste Water Control Technology Currently Available for the Textile Industry," report for the American Textile Manufacturers Institute, Inc., Charlotte, N.C., and the Carpet and Rug Institute, Dalton, Ga. Institute of Textile Technology and Hydroscience, Inc., 1973.

2. Baines, Frederic C., "Biodegradation of Polyvinyl Alcohol," A.A.T.C.C. symposium, *The Textile Industry and the Environment*, A.A.T.C.C., Washington, D.C., April 1973.

3. Eckenfelder, W. W., *Industrial Water Pollution Control*, New York, McGraw-Hill Book Co., 1966.

4. Nemerow, N. L., *Liquid Wastes of Industry, Theories, Practices, and Treatment*, Reading, Mass., Addison-Wesley, 1971.

METRIC CONVERSION TABLES

Recommended Units

Description	Unit	Symbol	Comments	Customary Equivalents
Length	metre	m	*Basic SI unit*	39 37 in =3.28 ft= 1.09 yd
	kilometre	km		0.62 mi
	millimetre	mm		0.03937 in.
	micrometre	μm.		3.937 X 10^{-3}=10^{3}A
Area	square metre	m^2		10.764 sq ft = 1.196 sq yd
	square kilometre	km^2		6.384 sq mi = 247 acres
	square millimetre	mm^2		0.00155 sq in.
	hectare	ha	The hectare (10 000 m^2) is a recognized multiple unit and will remain in international use.	2.471 acres
Volume	cubic metre	m^3		35.314 cu ft = 1.3079 cu yd
	litre	l	The litre is now recognized as the special name for the cubic decimetre.	1.057 qt = 0.264 gal = 0.81 X 10^{-4} acre-ft
Mass	kilogram	kg	*Basic SI unit*	2.205 lb
	gram	g		0 035 oz = 15.43 gr
	milligram	mg		0.01543 gr
	tonne or	t	1 tonne = 1 000 kg	0.984 ton (long) =
	megagram	Mg	1 Mg = 1 000 kg	1.1023 ton (short)
Time	second	s	*Basic SI unit*	
	day	d	Neither the day nor the year is an SI unit but both are important.	
	year	year		
Force	newton	N	The newton is that force that produces *an acceleration of* 1 m/s^2 in a mass of 1 kg.	0.22481 lb (weight) = 7.233 poundals
Moment or torque	newton metre	N-m	The metre is measured perpendicular to the line of action of the force N. Not a joule.	0 7375 ft-lbf
Stress	pascal	Pa		0.02089 lbf/sq ft
	kilopascal	kPa		0.14465 lbf/sq in

Recommended Units

Description	Unit	Symbol	Comments	Customary Equivalents
Velocity				
linear	metre per second	m/s		3.28 fps
	millimetre per second	mm/s		0.00328 fps
	kilometres per second	km/s		2.230 mph
angular	radians per second	rad/s		
Flow (volumetric)	cubic metre per second	m^3/s	Commonly called the cumec	15,850 gpm = 2.120 cfm
	litre per second	l/s		15.85 gpm
Viscosity	pascal second	Pa-s		0.00672 poundals/sq ft
Pressure	newton per *square metre* or pascal	N/m^2 Pa		0.000145 lb/sq in
	kilometre per square metre or kilopascal	kN/m^2 kPa		0.145 lb/sq in.
	bar	bar		14.5 b/sq in.
Temperature	Kelvin	K	*Basic SI unit*	5F
	degree Celsius	C	The Kelvin and Celsius degrees are identical. The use of the Celsius scale is recommended as it is the former centigrade scale.	$\frac{5F}{9}$ – 17.77
Work, energy, *quantity of heat*	joule	J	1 joule = 1 N-m *where metres are* measured along the line of action of force N.	2.778 X 10^{-7} kw hr = 3.725 X 10^{-7} hp-hr = 0.73756 ft-lb = 9.48 X 10^{-4} Btu
	kilojoule	kJ		2.778 kw-hr
Power	watt	W	1 watt = 1 J/s	
	kilowatt	kW		
	joule per second	J/s		

Application of Units

Description	Unit	Symbol	Comments	Customary Equivalents
Precipitation, run-off, evaporation	millimetre	mm	For meteorological purposes it may be convenient to measure precipitation in terms of mass/unit area (kg/m^3). 1 mm of rain = 1 kg/m^2	
River flow	cubic metre per second	m^3/s	Commonly called the cumec	35.314 cfs
Flow in pipes, conduits, channels, over weirs, pumping	*cubic metre per* second	m^3/s		
	litre per second	l/s		15.85 gpm
Discharges or abstractions, yields	cubic metre per day	m^3/d	1 l/s = 86.4 m^3/d	1.83 X 10^{-3} gpm
	cubic metre per year	m^3/year		
Usage of water	litre per person per day	l/person day		0.264 gcpd
Density	kilogram per cubic metre	kg/m^3	The density of water under standard conditions is 1 000 kg/m^3 or 1 000 g/l or 1 g/ml.	0.0624 lb/cu ft

Application of Units

Description	Unit	Symbol	Comments	Customary Equivalents
Concentration	milligram per litre	mg/t		1 ppm
BOD loading	kilogram per cubic metre per day	kg/m^3d		0.0624 lb/cu-ft day
Hydraulic load per unit area, e.g. filtration rates	cubic metre per square metre per day	m^3/m^2d	If this is converted to a velocity, it should be expressed in mm/s (1 mm/s = 86.4 m^3/m^2 day).	3.28 cu ft/sq ft
Hydraulic load per unit volume; e.g., biological filters, lagoons	cubic metre per cubic metre per day	m^3/m^3d		
Air supply	cubic metre or litre of free air per second	m^3/s l/s		
Pipes				
diameter	millimetre	mm		0.03937 in.
length	metre	m		39.37 in. = 3.28 ft
Optical units	lumen per square metre	lumen/m^2		0.092 ft candle/sq ft

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