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DEVELOPMENT DOCUMENT FOR EFFLUENT LIMITATIONS GUIDELINES AND STANDARDS OF PERFORMANCE

TEXTILE INDUSTRY

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

NOTICE

The attached document is a DRAFT REPORT. It includes technical information and recommendations prepared by the Effluent Guidelines Division of the United States Environmental Protection Agency ("EPA") regarding the subject industry. It is being distributed for review and comment only. The report is not an official EPA pulication and it has not been finally reviewed by the Agency.

The report, including the recommendations, will be undergoing extensive review by EPA, Federal and State agencies, public interest organizations and other interested groups and persons during the coming weeks. The report and in particular the recommended effluent limitations guidelines and standards of performance is subject to change in any and all respects.

The regulations to be published by EPA under Sections 304(b) and 306 of the Federal Water Pollution Control Act, as amended, will be based to a large extent on the report and the comments received on it. However, pursuant to Sections 304(b) and 306 of the Act, EPA will also consider additional pertinent technical and economic information which is developed in the course of review of this report by the public and within EPA. EPA is currently performing an economic impact analysis regarding the subject industry, which will be taken into account as part of the review of the report. Upon completion of the review process, and prior to final promulgation of regulations, an EPA report will be issued setting forth EPA's conclusions concerning the subject industry and effluent limitations guidelines and standards of performance applicable to such industry. Judgments necessary to promulgation of regulations under Sections 304(b) and 306 of the Act, of course, remain the responsibility of EPA. Subject to these limitations, EPA is making this draft report available in order to encourage the widest possible participation of interested persons in the decision making process at the earliest possible time.

The report shall have standing in any EPA proceeding or court proceeding only to the extent that it represents the views of the individuals who studied the subject industry and prepared the information and recommendations. It cannot be cited, referenced, or represented in any respect in any such proceedings as a statement of EPA's views regarding the subject industry.

U. S. Environmental Protection Agency
Office of Air and Water Programs
Effluent Guidelines Division
Washington, D. C. 20460

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ABSTRACT

The 1967 Census of Manufacturers lists approximately 7,000 plants in the textile industry (SIC 22) for which 1972 production was estimated at 10 billion linear meters (11 billion linear yards) of fabric. The total process water consumption of the industry in 1972 is about 473 billion liters (125 billion gallons) per year. However, it appears that more than 95 percent of this water consumption was accounted for by only some 680 plants.

In 1968, only about 28 percent of the total wastewater received secondary treatment, with a further 27 percent going to municipal sewage plants. Installation of new or improved waste treatment plants has proceeded rapidly over the last few years and roughly 45 percent of the waste effluent presently receives secondary treatment and that another 35 percent goes to municipal plants. This treatment removes about 70 percent of the BOD raw waste load from the effluent.

Many textile plants are 'dry' in that they have effectively no water use and the 'wet' processing plants are not adequately defined by the sub-categories of SIC 22. For waste treatment purposes, the water using portion of the industry has been divided into seven categories: (1) wool scouring; (2) wool finishing; (3) greige goods mills; (4) woven fabric finishing; (5) knit fabric finishing; (6) carpet mills; and (7) stock and yarn dyeing and finishing.

Wool processing was kept as a separate category because of the high raw waste loads associated with the processing of this fiber. Greige goods mills are essentially dry plants and therefore have minimal waste loads. Many knitting mills and yarn and thread mills which do not carry out dyeing or finishing operations also fall into this category.

Finishing plants (categories, 4, 5, and 7), together with carpet mills (category 6), constitute the major portion of the 'wet' processing industry.

Synthetic fibers used alone or in blends with other fibers are used in all sections of the industry. In fact this tendency to increasing use of fiber blends blurs the distinction between categories, but for the present there are sufficient unique differences to maintain the seven categories.

In all categories there are plants that show greater than 90 percent BOD removal by conventional secondary biological treatment. This degree of treatment is the basis for Level I effluent guidelines to be achieved by the industry in 1977.

For Level II guidelines, to be achieved by 1983

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zero discharge is recommended as being technically achievable by present techno reverse osmosis or evaporation, followed by incineration of effluent. However, it appears to be associated with a relatively high cost.

New source performance standards (i.e., Level III) should be set at the same Level II guidelines, although the technical risk associated with installing this technology now is somewhat greater.

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SECTION I

Conclusions

1. The textile industry has over 7,000 plants, but many of these carry out only dry operations and many more are connected to municipal treatment systems. About 680 wet process plants account for 95 percent of the total water used 473 billion liters per year or (125 billion gallons per year). Only about 20 percent of this water is discharged untreated; the rest undergoes municipal or on-site secondary waste treatment.

2. After consideration of previously proposed categorization schemes and evaluation of waste effluent characteristics we conclude that the industry can be conveniently divided into seven categories as follows:

(1) Wool Scouring
(2) Wool Finishing
(3) Greige Goods Mills
(4) Woven Fabric Finishing
(5) Knit Fabric Finishing
(6) Carpet Mills
(7) Stock and Yarn Dyeing and Finishing
(8) Specialized Finishing

Raw wastes from all categories show high treatability by secondary biological treatment.

3. The performance of plants with respect to BOD removal in all seven categories have been found. These plants remove substantially more than 90 percent of the BOD. Implementation of the proposed Level I guidelines will require approximately 95 percent BOD removal for the entire industry (weighted average) by July 1, 1977. With the exception of wool scouring, which has a very high raw waste load, all categories can achieve an average BOD of less than 25 mg/l, i.e., equivalent to or better than acceptable municipal treatment.

Of the heavy metals chromium is the only one of general concern; chromium using plants typically average 1 to 14 mg/l in their waste effluent. The technology for chemically removing chromium is well known and should be applicable to this industry.

4. Wool scouring shows the highest raw-waste discharge concentration, averaging 2,000-3,000 mg/l BOD5, or 100-200 kg BOD/1000 kg of product, and after biological waste treatment, effluents have a relatively high BOD 5. There are about 22 plants in this category; of the five largest,

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three have waste treatment and two discharge to municipal systems. The Wool Finishing segment of the industry consists of approximately 100 plants, of which essentially all the larger ones have waste treatment plants. One-third of the remaining plants have some waste treatment and only about 10 percent have no treatment at present.

5. Over 75 percent of the larger cotton and synthetic finishing plants (woven and knits) have waste treatment systems. Among the smaller ones, we estimate 60 percent have their waste treated in municipal systems. Greige goods mills are essentially dry plants and most are currently on municipal systems. Of the fifty largest carpet mills, practically all have their own waste treatment or are on a municipal system. Sixty percent of the carpet industry is within one town which handles the waste from all of these plants by municipal treatment.

6. Textile industry waste effluent shows such high treatability, Treatment plants within the textile industry have extended aeration activated sludge , often followed by a long (1 to 5 days) residence time in a polishing lagoon. Plants located in urban areas may find it more costly to meet guidelines set by the exemplary mills than will other plants which have available land.

7. Further improvement in the quality of these effluents should be directed towards the reduction of the dissolved salts. No discharge is established for Level II guidelines and Level III standards.

8, There is essentially no difference between old and new plants in raw waste loads per unit of product. In contrast to some other industries, old plants continually modernize and add new equipment. Although some sub-processes do show significant differences, for example, the use of pressure becks versus atmospheric becks in the dyeing of synthetic yarns -these differences are not sufficient to affect guideline values.

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SECTION II - Recommendations
Basis For Guidelines

The RFP defines Level I Guidelines (to be achieved by 1977) as the BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE as exemplified by the average of the best plants existing in the industry. Level 1 guidelines are primarily based on removal of BOD by conventional biological treatment as typified by activated sludge or aerated lagoons. Treatment Technology is also available (although not always well practiced) for removal of COD, suspended solids, heavy metals, color and control of pH and Level I guidelines are also recommended for these parameters.

The RFP defines Level II Guidelines (to be achieved by 1983) as the BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE as exemplified by the best existing plant, or modified if necessary by the application of technology from other industries. This industry as yet has only a few no discharge system or systems that have 100% recycle. Therefore, it is recommended that Level II guidelines be based on the application of desalinization techniques.

New source performance standards (Level III) should be based on the application of Level II technology with the maximum possible reduction of process water use through the utilization of in-process controls and water reuse.

LEVEL I GUIDELINES

Guidelines for each category of the textile industry are summarized in Table II-1, which gives the average effluent limits that are not to be exceeded on a monthly average and daily composite basis.

The recommended guidelines for BOD, COD and suspended solids are shown. For all industry categories, guidelines are recommended for chromium, phenol, color and pH, recognizing that effluents from some categories do not contain all of these pollutants.

LEVEL II GUIDELINES AND LEVEL III PERFORMANCE STANDARDS

As a first step, reductions (in most cases by a factor of two) in standard water usage is foreseen.

The removal of BOD, COD and suspended solids by physical, chemical and biological processes provides the pretreatment necessary for

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desalinization techniques for removal of dissolved solids and water reuse.

TABLE II-1

SUMMARY OF LEVEL I POLLUTANT GUIDELINES - (a)

Category	Maximum 20 Working Day Averages, kg/1000 kg (lb/1000 lb) BOD	COD	Suspended Solids	PH(b)
1. Wool Scouring	2.85	28	2.0	6-8.5
2. Wool Finishing	5.1	51	7.6	6-8.5
3. Greige Goods	0.15	1.17	0.22	6-8.5
4. Woven Fabric Finishing	3.3	45	5.0	6-8.5
5. Knit Fabric Finishing	3.6	45	6.1	6-8.5
6. Carpets	2.1	21	2.4	6-8.5
7. Stock and Yarn Dyeing	4.0	52	6.1	6-8.5

(a) In addition to the guidelines shown, the following apply to all categories.
Coliform organisms 200/ml MPN,
Total chromium-not to exceed 0.25 mg/l
Phenols-not to exceed 0.25 mg/l
Color-not exceed 200 ADMI units

(b) Values are the maximum permitted range.

Note: Daily maximum may not exceed twice the maximum 20 working day average.

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SECTION III
Introduction

Purpose and Authority

Section 301(b) of the Act requires the achievement, by not later than July 1, 1977, of effluent limitations for point sources, other than publicly owned treatment works, which are based on the application of the best practicable control technology currently available as defined by the Administrator pusuant to Section 304(b) of the Act. Section 301(b) also requires the achievement, by not later than July 1, 1983, of effluent limitations for point sources, other than publicly owned treatment works, which are based on the application of the best available technology economically achievable which will result in reasonable further progress toward the national goal of eliminating the discharge of all pollutants, as determined in accordance with regulations issued by the Administrator pursuant to Section 305(b) to the Act. Section 306 of the Act requires the achievement by new sources of a Federal standard of performance providing for the control of the discharge of pollutants which reflects the greatest degree of effluent reduction which the Administrator determines to be achievable through the application of the best available demonstrated control technology, processes, operating methods, or other alternatives, including, where practicable, a standard permitting no discharge of pollutants.

Section 304(b) of the Act requires the Administrator to publish within one year of enactment of the Act, regulations providing guidelines for effluent limitations setting forth the degree of effluent reduction attainable through the application of the best practicable control technology currently available and the degree of effluent reduction attainable through the application of the best control measures and practices achievable including treatment techniques, process and procedure innovations, operation methods and other alternatives. The regulations proposed herein set forth effluent limitations guidelines pursuant to Section 304(b) of the Act for the textile manufacturing source category.

Section 306 of the Act requires the Administrator, within one year after a category of sources is included in a list published pursuant to Section 306(b) (1) (A) of the Act, to propose regulations establishing Federal standards of performances for new sources within such categories. The Administrator published in the Federal Register of January 16, 1973 (38 F.R. 1624), a list of 27 source categories. Publication of the list constituted announcement of the Administrator's

intention of establishing, under Section 306, standards of performance applicable to new sources within the textile manufacturing source category, which was included within the list published January 16, 1973.

Methodology

The effluent limitations guidelines and standards of performance proposed herein were developed in the following manner. The textile industry was first categorized for the purpose of determining whether separate limitations and standards are appropriate for its different segments. Considerations in the industry categorization process included raw materials, the products, manufacturing process, and raw waste characteristics.

The raw waste characteristics for each category were identified through analyses of: (1) the sources and volumes of water and waste waters and (2) the constituents (including thermal) of all waste waters including toxic or hazardous constituents and other constituents which result in taste, odor, color, or aquatic organisms. The constituents of waste waters that should be subject to effluent limitations guidelines and standards of performance were identified.

The full range of control and treatment technologies existing within each category was identified. This included an identification of each distinct control and treatment technology, including both in-plant and end-of-process technologies, which are existent or capable of being designed for each subcategory. It also included an identification, in terms of the amount of constituents (including thermal) and the chemical, physical, and biological characteristics of pollutants, of the effluent level resulting from the application of each of the treatment and control technologies. The problems, limitations, and reliability of each treatment and control technology and the required implementation time were also identified. The non-water quality environmental impact were also identified, e.g., the effects of the application of such technologies upon other pollution problems, including air, solid waste, noise, and radiation. The energy requirements of each of the control and treatment technologies were identified as well as the cost of the application of such technologies.

The information, as outlined above, was then evaluated to determine what levels of technology constituted the "best practicable control technology currently available," "best available technology economically achievable" and "best available demonstrated control technology, processes, operating methods, or other alternatives." In identifying such technologies, various factors were considered. These included the total cost of application of technology in relation to the effluent

reduction benefits to be achieved from such application, the age of equipment and facilities involved, the process employed, the engineering aspects of the application of various types of control techniques process changes, non-water quality environmental impact (including energy requirements), the treatability of the wastes, and water use practices.
The data for the identification and analyses were derived from a number of sources. These sources included EPA research information, published literature, previous EPA technical guidance for textile manufacture, various industry associations, qualified technical consultation, and on-site visits and interviews at exemplary textile manufacturing plants in the United States. All references used in developing the guidelines for effluent limitations and standards of performance for new sources reported herein are listed in Chapter XIV.

General Description of the Industry

Since 1638, when the first commercial mill was erected at Raleigh, Massachusetts, the U.S. textile industry has burgeoned to a point where there are nearly 7100 plants in 47 states, employing about one million people, and in 1972 selling goods valued at just under $28 billion. These plants range from highly integrated manufacturing complexes that process basic raw materials into finished products, to small non-integrated contract plants that process goods owned by other producers.

According to the 1967 Census of Manufacturers, the textile industry, SIC Code 22, contains ten major SIC classifications. In recent decades, the industry has been concentrating in the Southeast--notably in the Carolinas, Georgia and Alabama--and this trend is continuing. Today 38 percent of the textile plants are in the Southeast and 92 percent are on the eastern seaboard. The rest, as shown by Table III-1 and

III-2 are scattered thinly throughout the country. Knitting mills, with almost 2,700 plants listed, constitute the largest group but there are also about 1,000 weaving mills of various types and over 1,000 plants which process miscellaneous textile goods. Most of the textile industry is contained within EPA Regions 1, 2, 3 and 4, with Region 4 accounting for a major proportion of the industry.

Table III-1

Region	Number of Mills	% of Total
South	2656	38
Mid-Atlantic	2821	40
New England	978	14
North Central	321	4
West	304	4
	7080	100

Source: 1967 Census of Manufacturers

The industry's basic raw materials are wool, cotton, and man-made fibers. Of the roughly 5.0 billion kilograms (11 billion pounds) of raw materials consumed by the industry in 1972, wool accounted for about 0.09 billion kilograms (0.2 billion pounds), cotton for 4.0 billion kilograms (4 billion pounds) and man-made fibers for 3.2 billion kilograms (7 billion pounds).

Among the man-made fibers, the most important are rayon, acetate, nylon, acrylic, polyester, polypropylene, and glass fiber.

The natural fibers are supplied in staple form, (staple being short fibers). The man-made fibers are supplied as either staple or continuous filament. In either case the fiber is spun into yarn, which is simply a number of filaments twisted together. The yarn is woven of knit into a fabric, and the fabric then dyed and treated to impart such characteristics as shrink resistance, crease resistance, etc. The finished fabric is delivered--directly or through convertors, jobbers, and wholesalers-to the manufacturer of textile products.

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Table III-2
Number of Textile Plants by Geographic Areas: 1967

	Textile Mills Products 22	Weaving Mills Cotton 221	Weaving Mills Synthetic 222	Weaving & Finishing Mills-Wool 223	Narrow Fabric Mills 224	Knitting Mills 225	Textile Finishing Exc. Wool 226	Floor Covering Mills 227	Yarn & Thread Mills 228	Misc. Textile Goods 229
	7,080	393	396	310	384	2,698	641	385	768	1,105
NORTHEAST REGION	3,799	78	196	216	258	1,616	423	83	304	625
New England Div.	978	21	64	127	121	113	98	35	128	271
Maine	56	4	7	18	-	3	-	3	11	7
New Hampshire	79	1	9	16	15	15	4	-	11	6
Vermont	14	-	-	7	-	-	-	-	-	-
Massachusetts	400	-	19	41	37	49	45	19	53	129
Rhode Island	293	4	23	36	51	15	31	10	34	89
Connecticut	136	4	6	9	15	28	18	1	16	39
Mid. Atlantic Div.	2,821	57	132	89	137	1,503	325	48	176	354
New York	1,521	17	33	39	50	964	144	16	70	188
New Jersey	558	25	37	10	31	192	131	3	28	101
Pennsylvania	742	15	62	40	56	347	50	29	78	65
NO. CENTRAL REGION	321	-	7	22	14	76	29	13	15	141
E. No. Central Div.	251	-	-	12	9	61	24	12	15	111
Ohio	74	-	-	5	3	19	7	-	5	28
Indiana	13	-	-	-	-	1	-	2	-	10
Illinois	76	-	-	3	3	14	13	-	4	35
Michigan	30	-	-	-	-	2	1	-	-	21
Wisconsin	58	-	-	2	-	25	3	3	5	17
W. No. Central Div.	70	-	3	10	5	15	-	-	-	30
Minnesota	24	-	-	6	-	8	-	-	-	8
Iowa	7	-	-	-	-	-	-	-	-	-
Missouri	34	-	2	3	-	5	-	-	-	18

Table III-2 (Con't)

	Textile Mills Products 22	Weaving Mills Cotton 221	Weaving Mills Synthetic 222	Weaving & Finishing Mills-Wool 223	Narrow Fabric Mills 224	Knitting Mills 225	Textile Finishing Exc. Wool 226	Floor Covering Mills 227	Yarn & Thread Mills 228	Misc. Textile Goods 229
SOUTH REGION	2,656	307	190	52	101	910	170	231	443	252
So. Atlantic Div.	2,214	254	178	43	83	770	145	199	387	155
Delaware	13	-	-	-	-	8	2	-	-	3
Maryland	30	-	-	3	6	5	5	-	5	-
Virginia	109	6	22	10	9	30	9	3	8	12
West Virginia	5	-	-	1	1	3	-	-	-	-
North Carolina	1,260	67	77	6	40	630	77	35	262	66
South Carolina	359	112	57	11	19	38	31	19	41	31
Georgia	407	67	21	11	6	44	16	142	70	30
Florida	31	-	-	-	-	12	-	-	1	-
E. So. Central Div.	344	34	10	7	18	130	19	24	51	51
Kentucky	27	-	-	-	-	10	-	-	2	4
Tennessee	149	4	3	2	6	76	11	13	13	21
Alabama	141	29	6	2	7	29	6	7	35	20
Mississippi	27	1	-	-	2	15	-	1	-	6
W. So. Central Div.	98	19	2	2	-	10	6	8	-	46
Arkansas	16	3	-	-	-	5	1	3	-	4
Louisiana	10	-	-	-	-	-	-	-	-	9
Oklahoma	6	-	-	-	-	-	1	1	-	-
Texas	66	15	2	2	-	4	-	-	-	31
WEST REGION	304	-	-	20	11	96	19	58	6	87
Mountain Division	18	-	-	-	-	5	-	-	-	-
Utah	5	-	-	-	-	2	-	-	-	-
Pacific Division	286	-	-	18	11	91	17	57	5	81
Washington	20	-	-	1	-	6	-	-	-	-
Oregon	20	-	-	8	-	5	-	-	-	-
California	245	-	-	[illegible]	10	80	16	56	5	6

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The many woven fabrics are produced by variations in the weaving pattern. Plain, or tafeta, weaves give such fabrics as broadcloth, calico, cheesecloth, muslin, seersucker, flannel and tweed. Twill weaves are represented by serge, herringbone, jersey, gabardine, and ticking. Because of their superior strength, twill fabrics are used for work clothes and men's suits. Satin weaves are smooth but weak; the best known are crepe satin, sateen, and damask. Dobby and Jacquard weaves are used to produce patterned fabrics. Dobby weaves are used in men's shirting and women's dress fabrics. Jacquard weaves are used extensively for upholstery and drapery materials. Finally, there are the pile weaves, which include velvets, plushes, corduroys and turkish toweling.

In transforming a fiber into one of these woven fabrics, two types of processes are used: wet and dry. The SIC code breakdown is not particularly useful for evaluating the waste effluent problems of the textile industry. These codes are gouped primarily by the process used--e.g., weaving or knitting--whereas the waste effluent problems stem from all the wet processes which are used to desize, wash, dye and finish the textile fabric. The wet processes of interest include: scouring, desizing, mercerizing, bleaching, bonding and laminating. Dry processes include: spinning, weaving and knitting. Although SIC Code 226 identifies textile finishing, Code 221 identifies weaving mills which may also be integrated mills that have a finishing operation or may be greige goods mills that have only dry processing. Knitting mills fall into a similar category; many of the mills identified as knitting mills, in fact, process dyed yarns and, therefore, essentially carry out dry operations.

There is no exact figure for the number of wet processing plants or the total water use by the industry, but the Census of Manufacturers gave for 1968 under Textile Mill Products a total of 684 wet plants which consume 412 billion liters (109 billion gallons) of process water per year. (This includes sanitary and cooling water, etc.) A more recent estimate, by the American Textile Manufacturers' Institute in 1970, found 346 plants using 394 billion liters (104 billion gallons) per year, estimated to be 83 percent of the total industry use.

Table III-3 gives details of the process water used and discharged divided as far as possible according to the ADL categories. The largest water users are undoubtedly the finishing plants, with a total of 269 billion liters (71 billion gallons) per year, averaging 2800 cubic meters per day (0.73 million gallons per day). The next highest category is the wool finishing operations, with 47.3 billion liters (12.5 billion gallons) per year averaging 27000 cubic meters per day

(0.7 million gallons per day) but consisting of a much smaller segment of the textile industry.

A summary of this data is presented in Table III-4, which shows that 110 billion liters (29 billion gallons) per year or 26.6 percent of the water was discharged to municipal sewers and 73.2 percent or 303 billion liters (80 billion gallons) per year to surface water. The 73.2 percent also divides into 24.2 percent that received no treatment, 21 percent that received primary treatment and 28.2 percent that received secondary treatment before discharge. Since 1968 many more treatment plants have been built and from a consideration of RAPP data and the recent survey by the ATMI, we estimate that about 35 percent of the water used is now discharged to municipal sewers, 15 percent receives no treatment, 5 percent receives primary treatment and 45 percent receives secondary treatment. Undoubtedly, the smaller mills or those using the least amounts of water have found it more economical to use municipal treatment instead of constructing their own facilities.

Table III-3 Water Use by the Textile Industry

SIC Code	ADL Category	Value of Shipments (Million dollars)	No. of Plants	Process Water Used 10^6 cu m/yr (BG/yr)	Average Water use/plant cu m/d (MGD)	Water Sewer 10^6 cu m/yr (BG/yr)	Discharged Surface 10^6 cu m/yr (BG/yr)	Treated Before Discharge Total 10^6 cu m/yr (BG/yr)	Treated Before Discharge Ponds 10^6 cu m/yr (BG/yr)
22	Total	9,235.5	684	413. (109.0)	2100. (0.56)	192. (50.6)	306. (80.9)	203 (53.7)	117. (30.8)
2297	1	49.5	9	2.6 (0.7)	1100. (0.28)	.38 (0.1)	3.4 (0.9)	2.3 (0.6)	- (-)
2231 +2283	2	758.2	67	47.3 (12.5)	2600 (0.68)	15. (3.9)	42.4 (11.2)	26. (6.9)	15. (3.9)
2211 +2221 +2241 + 226	4	4,787.3	348	269. (71.1)	2800 (0.73)	99.5 (26.3)	213. (56.4)	137. (36.3)	74.9 (19.8)
225	5	1,119.7	100	32. (8.4)	1100. (0.30)	28. (7.4)	11. (2.9)	8.7 (2.3)	2.3 (0.6)
227	6	1,067.6	50	30. (7.8)	2100. (0.56)	23. (6.1)	11. (2.8)	11. (2.8)	6.4 (1.7)
228 (-2283)	7	660.3	60	21. (5.6)	1200. (0.33)	16. (4.2)	16. (4.3)	15. (3.9)	14. (3.8)

Source: Department of Commerce -- 1967 Census of Manufacturers

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Table III-4 Water Discharged by the Textile Industry

	1968		1972	
	Amount 10^6 cu m/yr BG/yr	Percent of Total	Amount 10^6 cu m/yr BG/yr	Percent of Total
To Municipal Sewer	110. (29.)	26.6	166. (44.)	35.
To Surface Water:				
1. No Treatment	99.5 (26.3)	24.2	71. (19.)	15.
2. Primary Treatment	86.7 (22.9)	21.0	24. (6.)	5.
3. Secondary Treatment	116. (30.8)	28.2	213. (56.)	45.
TOTAL PROCESS WATER	413. (109.)	100.0	473. (125.)	100.0

Sources: Department of Commerce 1967 Census of Manufacturers
Refuse Act Permit Program Data
American Textile Manufacturers Institute
Arthur D. Little, Inc. Estimates

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SECTION IV - Industry Categorization

PREVIOUS APPROACHES

In deriving this industry categorization system, existing categorizations and other previous attempts at categorization have been considered. The principal systems investigated were:

a. SIC codes. These codes do not lend themselves to a classification of the industry with respect to characterization of the pollution loads generated. For example, Category 3, Greige Goods, includes 10 SIC categories.

b. The method advanced by the report, "A Simplification of Textile Waste Survey and Treatment" by Masselli, Masselli and Burford. This approach consists of synthesizing the raw waste load from a textile mill by additive contributions of the chemicals used. Tables of BOD values for many chemicals are given in the report. This method was judged too difficult to be implemented by persons not versed in Textile Chemistry and not knowledgeable about the chemicals used.

c. The previous Arthur D. Little Report prepared for the EPA. This approach employed unit processes to synthesize the raw waste loads. This method was also judged too difficult to implement by the EPA.

d. The preliminary system developed by the EPA in the "Denver" guidelines study.

e. The system developed by the Institute of Textile Technology and Hydrosciences in the recent study for American Textile Manufacturer's Institute, Inc., and Carpet and Rug Institute.

Based on knowledge of the various pollution problems, loads generated by the different unit operations in the textile industry, actual and potential waste treatment practices and current manufacturing and processing practices, these five approaches were combined and simplified.

The last two methods (d and e) and the present one have in common a categorization according to the products produced by a mill that in turn relates to type of wastes; the differences are in matters of judgment as to the balance between simplicity and how well a given category

accurately describes the wastes generated. The objective is to arrive at useful, realistic guides to field EPA personnel.

A comparison of the EPA and the ATMI/CRI categorizations with those used in this study is given in Table IV-1. The SIC codes, in relation to the ADL categories, are shown in Table IV-2. This latter table also indicates the number of plants in each category.

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TABLE IV-1

INDUSTRY CATEGORIZATION

ADL	EPA	ATMI
1. Wool Scouring	1. Wool Scour and Finish Mill (Integrated)	1. Wool Scouring
2. Wool Finishing	2. Wool Finish Mill	2. Wool Finishing
3. Greige Goods Mill	3. Greige Goods Mill - Woven and Knitted Goods	3. Greige Mill
4. Woven Fabric Finishing	4. Finishing Mill - Woven Products of Cotton, Synthetics, and Blends	4. Woven Fabric Finishing
5. Knit Fabric Finishing	5. Finishing Mill - Knitted Products of Cotton, Synthetics, and Blends	5. Knit Fabric Finishing
	6. Integrated Woven Goods Mill (Includes Manufacture of Greige Goods)	6. Greige Mill + Finishing Fabric
6. Carpet Mill	7. Carpet Mill - Dyeing and Finishing (Excluding Carpet Backing)	7. Carpet Backing & Foam
	8. Integrated Carpet Mill	8. Integrated Carpet Mill
7. Stock & Yarn, Dyeing and Finishing	9. Yarn Dyeing Plants - All Yarns	9. Stock & Yarn Dyeing & Finishing
		10. Greige Mill + Finishing & Fabrics
		11. Combined Materials Finishing - Stock, Yarn Wovens, Knits
		12. Multiple Operation, Commission House
8. Specialized Finishing		13. Specialized Finishing

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NUMBER OF TEXTILE PLANTS BY SIC CODE - Table IV-2

SIC Code	No. of Plants	Description	ADL Category
		WEAVING MILLS	
2211	393	Broad Woven Fabric, Cotton	3&4
2221	396	Broad Woven Fabric, Synthetic	3&4
2231	310	Broad Woven Fabric, Wools	2
2241	384	Narrow Fabrics	3&4
	1483	Sub Total	
		KNITTING MILLS	
2251	355	Womens Hosiery	5 (3)
2252	448	Hosiery (except Womans)	5 (3)
2253	1179	Knit Outerwear	3
2254	113	Knit Underwear	3
2256	541	Knit Fabric	5 (3)
2259	62	Knitting Mills, N.E.C.	3
	2698	Sub Total	
		DYEING & FINISHING (except Wool & Knits)	
2261	216	Broad Woven Fabrics, Cotton	4
2262	233	Broad Woven Fabrics, Synthetic	4
2269	192	Finishers, N.E.C.	4&7
	641	Sub Total	
		CARPET MILLS	
2271	61	Woven Carpets	3&6
2272	244	Tufted Carpets	3&6
2279	80	Carpets, N.E.C.	3&6
	385	Sub Total	
		YARN & THREAD MILLS	
2281	377	Yarn Spinning, Cotton & Synthetics	3
2282	181	Yarn Twisting, etc. Cotton & Syn.	3&7
2283	135	Yarn, Wool including Carpet	2

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2284	75	Thread Mills	3&7
	768	Sub Total	

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MISCELLANEOUS TEXTILES

2291	40	Felt Goods (except wool)	8
2292	142	Lace Goods	3&4
2293	151	Padding and Upholstery	3
2294	141	Processed Waste	3
2295	178	Coated Fabrics (excepty Rubberized)	8
2296	20	Tire Cord	8
2297	68	Wool Scouring	1
2298	169	Cordage and Twine	
2299	196	Textile Goods, N.E.C.	3&4
	1105	Sub Total	

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PROPOSED CATEGORIZATION

The system derived efficiently characterizes mills in the textile industry, according to their waste effluent problems. The system provides eight categories and takes account of different fiber types in addition to the pollution effects of different types of unit operation. Categories 1 and 2 essentially separate the wool processing section of the textile industry because of its particular effluent problems. Categories 3, 4, 5 and 7 cover the various types of processing for cotton and synthetic fibers. Category 6 covers the carpet industry and Category 8 is limited to specialized types of processing. These categories are described in detail in the following section, but will be summarized here.

Category 1 - Wool Scouring

Wool scouring and topmaking is conveniently separated as a category because a significant number of plants perform this function alone. The initial washing and cleaning of wool generates a wide variety of organic and inorganic products in the waste effluent. The raw wool contains suint, dirt, and grease along with oils such as lanolin which are not readily biodegradable. These extraneous materials account for 25-75 percent of the original weight. In addition, the preparation and cleaning of wool require a heavy use of detergents. Recovery of wool grease has some economic incentive in that it has market value. However, even with grease recovery, wool scouring wastes present a difficult waste to treat biologically

Category 2 - Wool Finishing

Wool finishing involves the use of specialized dyes peculiar to this fiber which often result in the presence of chromium in the waste effluent. In addition, phenols occur from dyeing polyester blends. Only a small amount of pure wool is now processed. The bulk of the operations involves wool-polyester blends which give high BOD loads from the dye carrier which is used. The resulting wastes are similar to those in Category 5, Knit Fabric Finishing.

Several major mills have integrated wool scouring and top making with wool finishing. Such mills can be accomodated by a combination of Categories 1 and 2.

Category 3 - Greige Mills

Although there are many greige goods mills, they carry out mainly dry operations (with the exception of sizing) and hence contribute little to the overall waste problems of the textile industry. In many plants the sanitary BOD load is comparable to the process BOD load. This category applies equally well to woven or knitted greige goods.

Greige goods manufacturing includes spinning and texturizing of yarns which require a lubricating oil, similar to mineral oil. This oil is applied to the fibers or yarns and stays with them, to be removed prior to dyeing in the dye house. However, some oil finds its way into the drains because of clean-ups and spills.

Prior to being woven, the yarns are coated with a sizing material to give the yarn both lubrication and strength that will permit it to withstand the severe mechanical demands of weaving. Cottons generally are coated with starch and synthetics with polyvinyl alcohol. Wool and wool blends are seldom sized, unless the yarns are quite fine. Since most wool yarns are blends, both starch and PVA may be used. The slasher, where the sizing is applied, is washed down about once a week and thus contributes to the liquid wastes. Generally the waste flow from the slashing operation represents less than 3% of the total.

Category 4 - Woven Fabric Finishing

This category is one of the most important, because such plants constitute much of the waste water effluent load in the textile industry. Integrated woven fabric finishing mills are also included in this category rather than in Category 3 because the greige goods section of these mills contributes only a small amount to the overall effluent load. The size used in preparing woven fabrics is a major contribution to the BOD loan from the plant.

Two sizing compounds are commonly employed: starch and polyvinyl alcohol (PVA). PVA tends to be less biodegradable than starch and therefore presents a lower BOD level but contributes a high COD level. In addition to high BOD, the wastes generally have high total dissolved solids, color, and a variety of dispersing agents. They also may be very alkaline from the use of caustic soda in mercerizing cottons.

The dyes and associated additives used in woven fabric finishing represent the most complicated problem, since the BOD load and color can vary considerably with the type of dye fabric being processed and the color effects to be achieved. Subcategories of cotton and cotton-polyester blends were suggested for this category at the start of this study, because of the difference in size used on cottons and on

synthetics as well as the types of dyes and the dye assists used. However, variations in unit operations from mill to mill have a greater effect on the raw waste load than that observed between the proposed subcategories. Consequently, such subcategory items were dropped. (The same situation occurred in Categories 5, Knit Fabric Finishing, and 7, Stock and Yarn, Dyeing and Finishing. A detailed discussion of this may be found in Guidelines Section IX under Category 7.)

Processing steps in this category include cleaning the greige goods, bleaching, mercerizing of cotton (treating with caustic), dyeing, washing and rinsing, followed by application of finishes such as soil repellants, anti-statics, etc.

Category 5 - Knit Fabric Finishing

The main difference between woven and knit fabric finishing is that the sizing/desizing and mercerizing operations are not required for knits; therefore, BOD levels are lower. Otherwise, the problems from finishing of the different fibers (cotton, polyester, and other synthetics) are similar to those from woven fabric finishing. It was first thought to be necessary to provide three adjustments in this category according to the type of fiber being processed, i.e., cotton, polyester, and other synthetics. As mentioned under Category 4, however, variations in unit operations obscure the benefits from such subcategorization.

Category 6 - Carpet Mills

Carpet mills form a distinct part of the industry although their effluents are similar in many ways to those of Category 5, Knit Fabric Finishing. Carpets use mostly synthetic fibers (nylon, acrylics and polyesters) but some wool is still processed. As in Category 2, Wool Finishing, such wool carpet mills produce synthetics as well. As a result, no subcategory for wool carpets is proposed.

Carpet sometimes is backed with latex in a separate plant and represents a particular problem for the disposal of suspended solids. The EPA and the ATMI categorization systems allow two different categories to take care of this problem. However, carpet is backed in separate mills mostly in concentrated industry areas, principally Dalton, Georgia, where shipment between mills is not a problem. Carpet mills in more remote areas that have their own treatment plants often do latexing in-plant with the finishing. Latex is settled in separate basins prior to release of those segregated streams to treating; hence the additional load on integrated mills is negligible. Mills that perform latexing only are treatable by coagulation to a level to meet recommended

guidelines for this category. Therefore, no separate category or subcategory is proposed for latex mills.

Category 7 - Stock and Yarn Dyeing and Finishing

Yarn dyeing and finishing are different from woven fabric finishing because there is no sizing and desizing operation. They are different from knit fabric finishing because of their mercerizing operations and water use. The combined differences are sufficient to justify a separate category. The waste loads from this type of plant can vary more than those from other types of integrated textile mills or finishing mills. Many multiple-operation, commission houses fall under this category.

As in Categories 4 and 5, this category was considered as a candidate for subcategories for different fibers but as discussed in Category 4, variations in unit operations obscure the benefits of such division.

Category 8 - Specialized Finishing

In this category various miscellaneous processes have been examined. The following are included in SIC 22: Coated Fabrics (except rubberized fabrics), Polypropylene Carpet Backing, Non-Wovens, Tire Cord Fabrics, and Felts.

CATEGORY AND PROCESS DESCRIPTIONS

Category 1 - Wool Scouring

General Description. Wool scouring is conveniently separated from other segments of the textile industry because of its uniqueness. Raw wool (grease wool) must be wet processed to clean it before the fiber may be dry processed to produce fiber, yarn or fabric for the further wet processing steps found in a finishing plant. Neither cotton nor the synthetic fibers require this initial wet-cleaning. Furthermore, most wool scouring mills are geographically separate from other textile operations. Exceptions exist where wool scouring is physically separated from, but shares the waste treatment plant with, finishing mills.

The grease wool contains 25 to 75 percent non-wool materials, consisting of wool grease (a recoverable material of some economic value) and other excretions and secretions of the sheep such as urine, feces, sweat and blood, as well as dirt consisting of both soil and vegetable matter. Additional materils that may be present are insecticides (sheep dip), and fugitive dyes used for identification. This variability in yield and in the composition of impurities and grease causes a correspondingly large variability in raw waste loads.

The wool grease constitutes a special problem in treatment since it does not appear to be readily biodegradable unless it is well-emulsified so that bacteria can reach it. Therefore, the grease recovery step is important to reduce pollution.

The 1962 Census indicates that this industry consists of 68 mills in SIC 2297, Scouring and Combing Mills. Category 1 scour mills include those that scour or scour and comb, but not those that only comb, which is a dry process. We estimate that of these 68 mills, less than half fall into Category 1.

The geographic distribution given in the 1967 census is as follows:

		Mill	Number with Less than 20 Employed
Northeast Region:	New England Div.	35	18
	Middle Atlantic Div.	17	10
South Region:	South Atlantic Div.	6	6
	West South Central Div.	6	3
Not Allocated		6	2
	Total	68	39

The 68 mills produced $89.9 million worth of goods in 1967, compared to a value of $6.6 million for the scoured wool alone, indicating that about 10 percent of the wool produced from both scouring and combing mills is accounted for by Category 1 Mills, wool scouring. We estimate that 21 mills do scouring alone, with geographic distribution as follows:

Massachusetts	-	6
Rhode Island	-	3
Connecticut	-	1
South Carolina	-	3
Virginia	-	2
Pennsylvania	-	2
Illinois	-	1
Texas	-	3
Total		21

Most small mills are connecting, or are connected, to municipal treating systems. The larger mills are treating their own wastes, with the exception of Wellman in South Carolina which is connecting to a municipal system. Two large Burlington mills treat wastes combined from carpet and woolen broadwoven fabric finishing plants, respectively.

As a guide to municipal/private treating systems, a report prepared by the Wool Manufacturers Council of the Northern Textile Association is included in the Appendix. It includes both Category 1 mills, Wool Scouring, and Category 2 mills, Wool Finishing. Excerpts are given below:

Mills Responding	29
Municipal Systems	21
Private Systems	7
Not Sure	1

RAPP data for Region 4 indicates that 74 percent of the mills in this category have no treatment and 26 percent have secondary treatment; and none is tied to a municipal system. Since the time the RAPP data was collected, many of the "nones" have added treatment systems. (Mills discharging wastes to a municipal treatment system would not normally be included in the RAPP data.)

Process Description. A generalized flow diagram of the wool scouring process is shown in Figure IV-1.

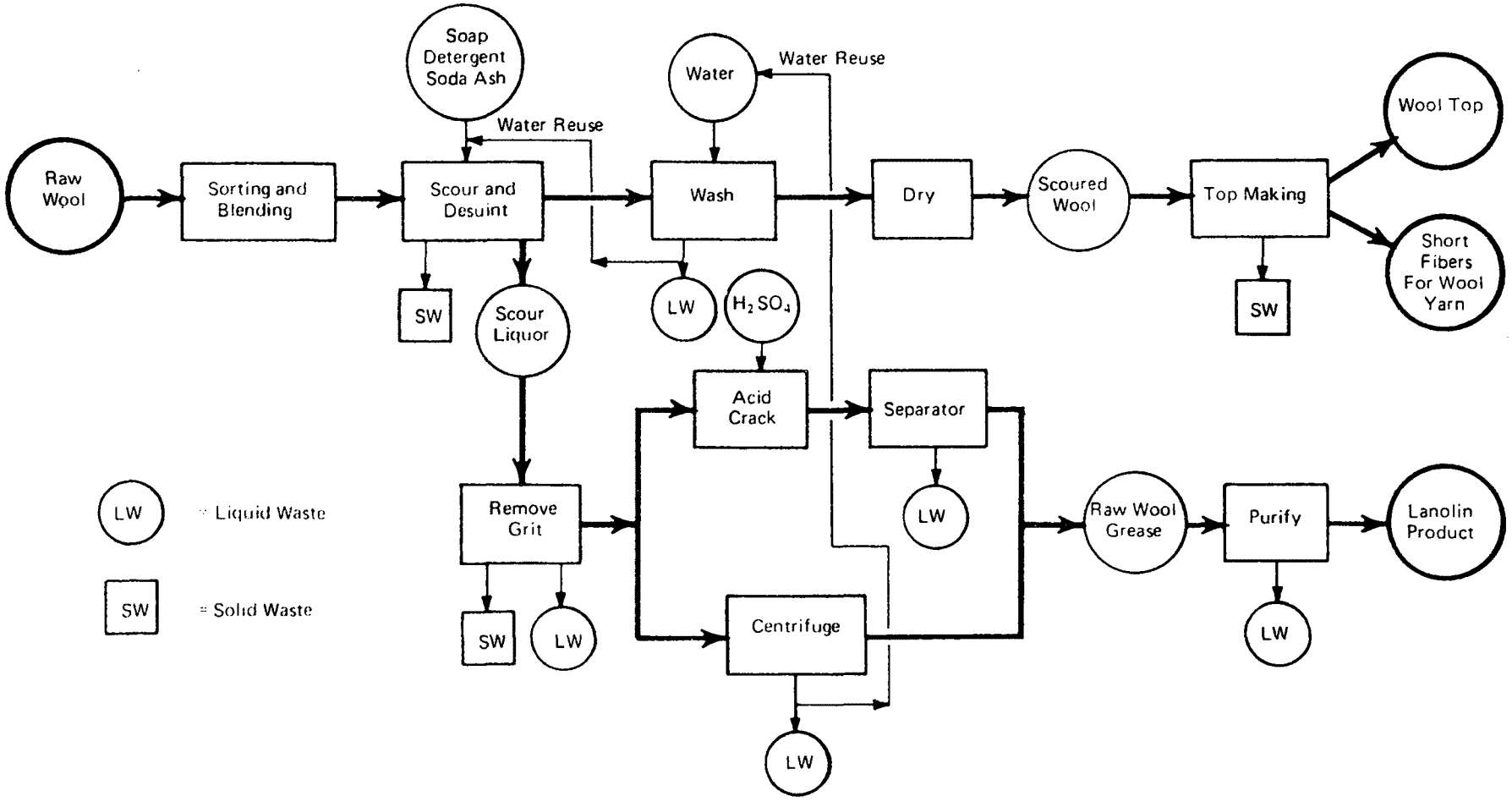
Scouring consists of sorting the fleece and feeding it to a hopper. The fleece is wet with fresh water in the first bowls. The wool then is carried through a series of scouring bowls where scour liquor flows countercurrent to it. Detergent is added in the third or fourth bowls to emulsify the greases and oils. The scoured wool is then dried. In mills where the cleaned wool is converted into top wool, the wool is combed and drawn and sometimes air washed to remove the short fibers (used for wool yarn) from the long fibers (used for worsted yarn).

In the scouring bowls, the heavier dirt and grit settles to the cone-shaped bottoms where it is blown down once an hour or so, and carried to the treatment plant by scour liquor.

The scour liquor, after picking up the soluble and less heavy dirt and grit, is piped to a separation tank where further settling of dirt and grit occurs. This material is also blown down and carried to the treatment plant once a day, or more often if the dirt content of the wool is high.

From the separation tank the scour liquor is processed to break the emulsion and recover the wool grease. Two methods are commonly used to do this: centrifuging and acid-cracking.

In centrifuging (as shown in Figure IV-1) the top low-density stream contains concentrated grease, which is further dewatered in additional centrifuges to yield the recovered, unrefined wool grease. The medium-density stream is combined with the relatively clean bottoms from the auxiliary centrifuges and recycled to the wool scouring train as fresh scour liquor. The high-density-bottoms stream consists mainly of dirt and grit, and is sent to the treatment plant.



Source: "Chemical Physical and Biological Treatment of Wool Processing Wastes," by Hatch, et al, 28th Annual Purdue Industrial Waste Conference, West Lafayette, Indiana, 1 May 1973.

FIGURE IV–1 CATEGORY 1: WOOL SCOURING

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An alternative means to break the grease emulsion for wool grease recovery is the acid-cracking grease recovery system, also shown in Figure IV-1. Sulfuric acid is added to the scour liquor and the mixture is heated to break the grease/water emulsion. The grease is separated from the liquor in a settling tank and recovered. The liquor is then treated with lime to neutralize the acid and subsequently passes through the waste treatment plant. Refer to Figure IV-2 for a typical material balance on grease.

In the centrifugal method, about 60 percent of the grease is recovered: the remaining 40 percent is attached to the dirt and grit. Centrifuging recovers over 90 percent of the grease from the scour liquor. In the acid-cracking method, pilot plant performance indicates a 98 percent recovery of grease from the degritted liquor. No data is available to indicate the initial split of grease between the grit and the raw liquor from the grit settling tank.

Grease yield, in total, is 8 to 15 percent by weight of the greasy wool, and this constitutes 50 to 65 percent of the wool grease initially present. (Ref. 141). Note that 1-3 percent of the wool grease present in the grease wool is allowed to remain on the wool as a conditioner.

Also, alkaline scouring has been used in which soda ash is added to the wash water. The soda ash combines with some of the wool grease to form a natural soap, thereby requiring less detergent but also lowering recovered wool grease yield.

Objections to recycling the scour liquor have been voiced by industry but appear to present no significant problem.

Some "raw" wools, mostly the Australian and New Zealand wools, are pre-scoured at the source. However, this fact does not appear to significantly affect this analysis of U.S. raw wool scouring mills.

Note that scoured wool is often converted into "tops" at the same mill. In this operation, the short fibers are separated mechanically from the long ones; the long fiber "tops" are used for worsted yarn and the short fibers are used to blend into woolen yarns. No added pollution occurs, but the water load is increased slightly by water washing to the air from an air washing step. The guidelines developed for Category 1 are based on the total product fiber and include both short fibers and tops.

Category 2 - Wool Finishing

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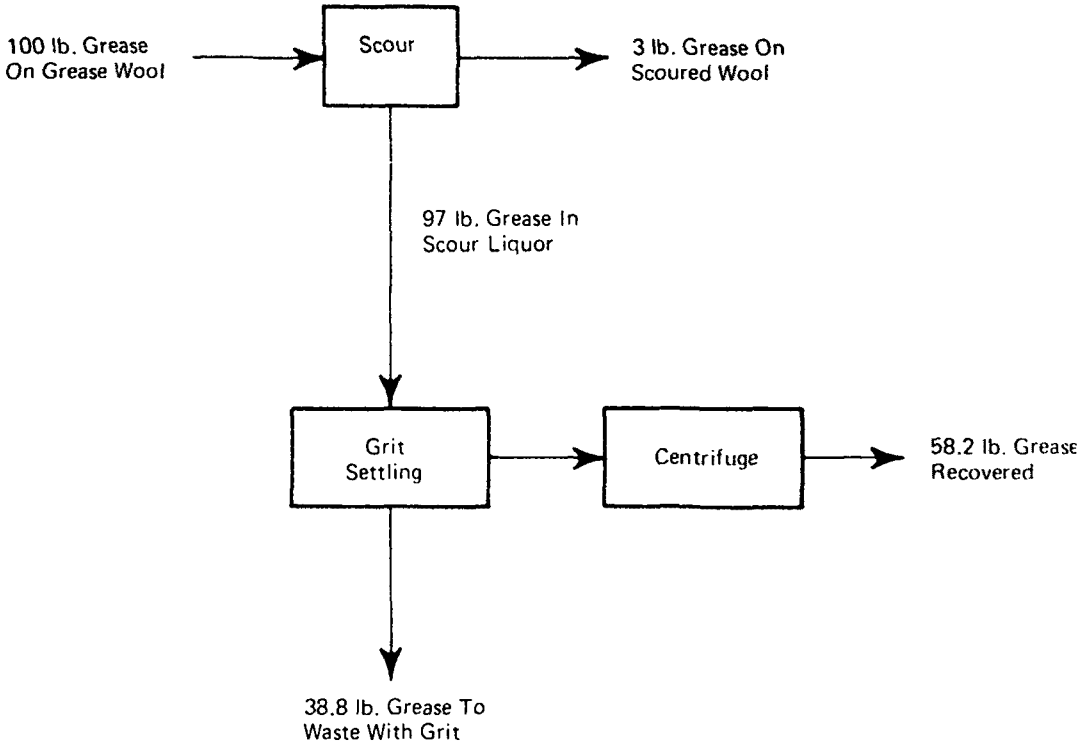

FIGURE IV–2 TYPICAL MATERIAL BALANCE: WOOL GREASE

General Description. This industry consists of many small mills -- most of them in the North (New England, New York and New Jersey) and most acting like commission houses -- and about 25 larger mills, mostly in the South (Virginia, the Carolinas and Georgia).

The industry contains about 310 mills in SIC 2231 according to census figures. Of these about 100 are involved in wool dyeing and finishing, with the remainder being greige goods mills.

Most small mills do commission dyeing, and even the larger mills that are part of the larger corporations commonly perform commission dyeing. Commission dyeing operations imply a wide range of fabrics and finishes as well as fiber types.

Probably not more than five mills still do more than 50 percent wool and wool belnds: the rest process primarily other fabrics.

The 1967 Census figures for SIC 223, wool manufacturing and finishing, indicate 310 mills total. These were distributed geographically as follows:

Northeast Region:	216	70%
North Central Region:	22	7%
Southern Region:	52	17%
Western Region:	20	6%
Total	310	100%

The geographic distribution of finishing mills alone is estimated as follows:

California	2	Ohio	1
Connecticut	1	Pennsylvania	12
Georgia	4	Rhode Island	19
Illinois	2	South Carolina	5
Maine	3	Tennessee	2
Massachusetts	11	Texas	2
New Hampshire	1	Vermont	1
New Jersey	7	Virginia	4
New York	13	Wisconsin	1
North Carolina	8		

As a guide to municipal/private waste treatment, a report prepared by The Wool Manufacturers Council of the Northern Textile Association is included in the Appendix. It includes both Category 1 mills, Wool

Scouring, and CAtegory 2 mills, Wool Finishing. Excerpts are given below:

Municipal treatment	21	72%
Private treatment	7	24%
Not sure	1	4%
Total mills responding	29	100%

RAPP data for Region 4 indicates the following:

Municipal treatment	8%
Private, secondary treatment	73%
No treatment	19%
	100%

Since RAPP data is for mills discharging to navagable waters, the figure given in the "municipal" category is not necessarily valid. Nevertheless, these figures indicate the northern mills are predominantly on municipal systems while most southern mills have privately-owned treatment plants.

The processes of carding and spinning wool into yarn, and subsequent weaving or knitting into fabric are included in Category 3, Greige Mills.

Yarns made from wool are classified into either woolen yarns or worsted yarns. Woolen yarns are characteristically of loose construction and composed of relatively short fibers; worsted yarns are of tight construction with few protruding fiber ends and composed of selected long fibers (tops). As a result, worsted yarns are stronger.

Wool finishing has been differentiated from other finishing categories because of its (1) predominant use of chrom-type dyes and (2) high water usage per pound of product.

As previously mentioned, however, few of today's wool finishing mills process all wool. Many of the woolen mills by name handle 20 percent or less wool with the balance being woven and knit synthetics. Also,

within the 20 percent or less portion, woolen/synthetic blends (most often with polyester) usually constitute the bulk of the fabric.

The high water usage appears to be caused by the fulling operation (peculiar to 100 percent wool fabrics) and by the fact that most wool and wool blend fabrics are more expensive than fabrics of other fibers, and the higher quality necessitates more washing to reduce crabbing (rubbing off of color). In addition, in Greige goods manufacturing, 100 percent woolen yarns sometimes have size applied to the warp yarns to reduce loose ends during weaving, but few 100 percent woolen yarns, no worsted-woolen blends, and worstedsynthetic blends have size applied. Because of the low percentage of wool actually processed in mills today, and the small amount of sizing used, this category appears in most ways similar to Category 5, Knit Finishing.

Variations occur in processing, similar to other finishing categories, in that some fabrics are woven or knit from yarns that are already dyed, either in the fiber or yarn form. A given mill may dye and finish part of its production while only finishing the remainder. This variation is unpredictable and is assumed to be included in the spread of data obtained.

Process Description. The wool finishing process is depicted in Figure IV-3. The three distinct finishing processes are shown as stock, yarn and fabric finishing. Because the pollution generated by the fabric finishing operation is similar to that generated by the other two, fabric finishing is included in this discussion. If the greige goods are 100 percent wool, they are first cleaned of vegetable matter (and cotton fibers) by carbonizing (soaked in strong sulfuric acid, dried, crushed and the char separated from the cloth), and then cleaned of spinning oils and any weaving sizes by a light scour (detergent wash). The 100 percent woolens are then dimensionally stabilized, principally by "fulling," or mechanical working of the wet fabric in the presence of detergents, to produce a controlled shrinkage or "felting." Worsteds and most wool-synthetic blends are not fulled. (Worsteds are hard, tightly-woven and dimensionally stable as received at the finishing plant; woolens are loosely-woven, soft and often are firmed up by fulling.)

The fabric is then dyed in batches in vessels called becks, washed in the same vessels, and taken to dry finishing operations. The only dry finishing operation of concern to water pollution is mothproofing.

The wet unit processes are described below in more detail.

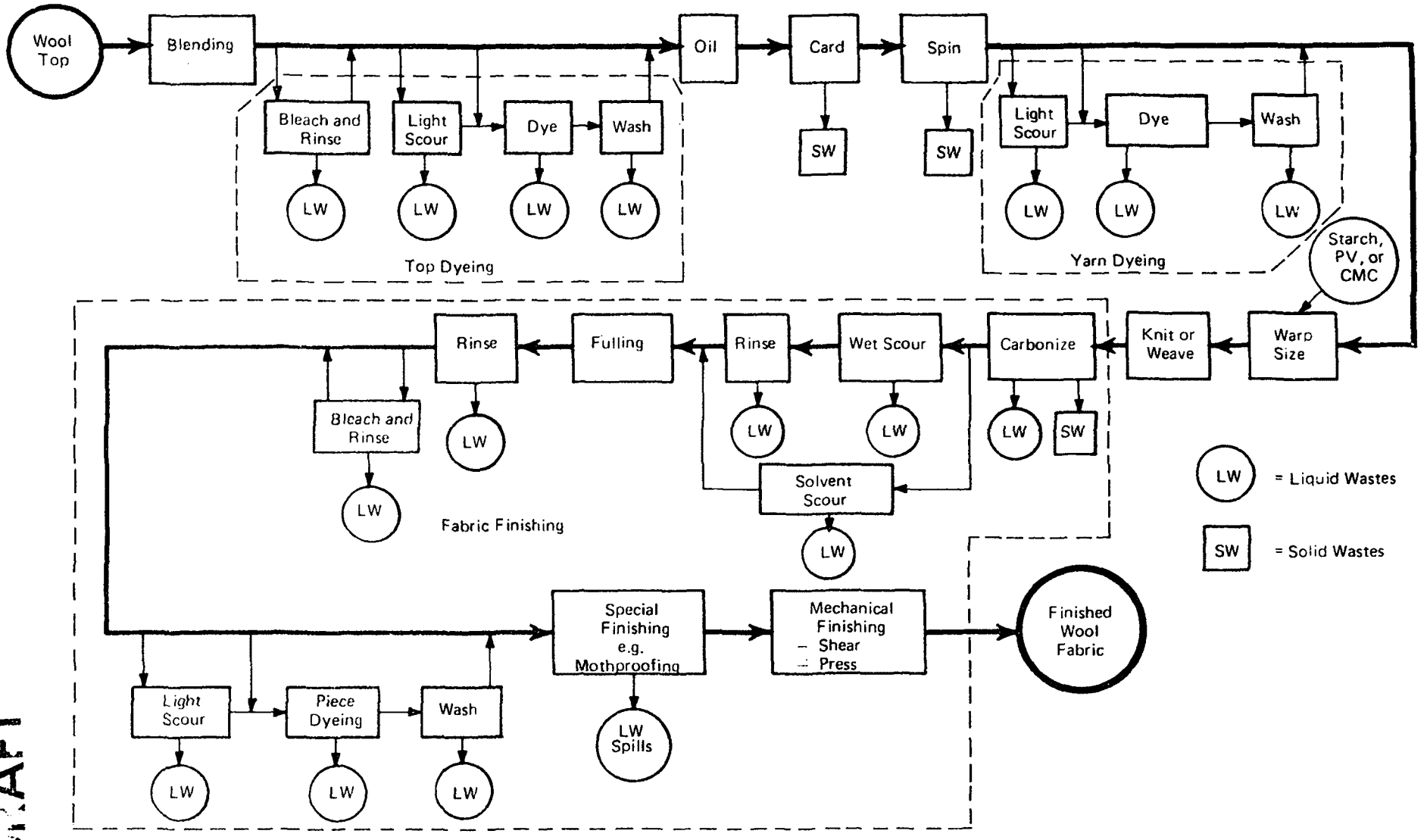

FIGURE IV–3 CATEGORY 2: WOOL FINISHING

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Light Scour. When greige goods are to be finished in the finishing plant, they are usually cleaned as a first step. This cleaning consists of washing with fresh water and detergent. The waste load consists of the detergent plus the oils and any sizes that were added to the material for lubrication in spinning, and for strength in weaving. When synthetic size i used, the BOD5 consists entirely of the spinning oils and the detergent.

Although the quantity of size varies somewhat, since it is put on the warp yarns only and the warp ratio varies, very little size is used in this category now. Therefore, the inaccuracy that arises from ignoring this variation is very small in view of the overall waste load of the finishing plant.

When the fabric is knit instead of woven, sizes are not used. However, the knitting oils and detergent used for light scouring remain as contributors to the waste load.

Carbonizing. Carbonizing consists of soaking the fabric in strong sulfuric acid, squeezing out the excess, and then heating the wet fabric in an oven. The hot acid reacts chemically with vegetable matter and any cotton fiber contaminant and oxidizes these contaminants to gases and a solid carbon residue. The fabric is then passed between pressure rolls where the charred material is crushed so that it may be separated by mechanical agitation and flowing air. A solid waste is produced, and the acid bath is dumped when it becomes too contaminated for further use, about once every two days.

Fulling. Fulling is usually used on 100 percent woolen fabrics but not usually on woolen/polyester blends and not on worsteds. Since this operation stabilizes the dimensions of the wool by "felting" it, the blends usually do not need it, nor do the worsteds, since they are a very tight yarn and weave to begin with. Fulling is accomplished by mechanical work performed on the greige goods while they are in a bath of detergent and water. Detergent is added as needed but no effluent occurs until the following washing step. This is true of both "dry" and "wet" fulling except that in the "wet" fulling, the water bath is dumped about once every 2 to 3 days. In "dry" fulling, just enough water is picked up by the fabric to lubricate it so the fabric is not standing in water between its turn in the fulling device.

The fulling is followed by extensive rinsing to prevent rancidity and wool spoilage. This step produced over 50 percent of the <u>hydraulic</u> load in an all-wool mill we investigated. The necessity for the extensiveness of

Crabbing. Crabbing is the name given to the operation used to align the fabric rectalinearly. Since the fabric comes in wet and goes out wet, no effluent of significance occurs.

Pre-Scour. The pre-scour step is a final cleaning of the greige goods prior to dyeing. Often, if a light scour or fulling is performed before dyeing, the pre-scour step is not used. On sensitive dyeings, however, both light scour and pre-scour are sometimes used. Detergents and wetting agents are added. This and subsequent dyeing and rinsing steps are performed in becks, commonly with a 20 to 1 water-to-cloth weight ratio.

Dyeing. In the dyeing process, the fabric is dyed in atmospheric becks or pressure becks. Pure wool fabric is dyed only in atmospheric becks, but blends (mostly with polyester) are dyed in either atmospheric or pressure becks. Knit woolen blend fabrics also are dyed in either atmospheric or pressure becks, but most often they are dyed in jet becks, a variation of the pressure beck that is supposed to reduce physical damage to the knits.

In conventional becks the fabric is sewn into a long tube that alternately soaks in a tube and then is pulled up and over a large diameter slatted wheel. In a jet beck, the fabric is pulled up and put back in the tub by the action of the dye liquor being pumped through a venturi and carrying the fabric with it. Pressurizing of becks is desirable for dyeing the polyester portion of the fabric, since little or no carrier need be used. At atmospheric pressures large quantitities of carriers are required to swell the polyester fiber and enable the dye molecules to penetrate.

In the dyehouse becks, the operation usually consists of filling the beck with water and a detergent for scouring (pre-scour, described above). The scour water is dumped and the beck is refilled with water and a wetting agent. After the fabric is wet-out, and the temperatures raised somewhat, the dyestuffs are added and the beck brought up to temperature (212°F in atmospheric becks, higher in pressure becks). After 2 to 4 hours, 90 percent or more of the dye is exhausted, and the dye bath is discharged to the sewer. This dye step is followed by a clear water rinse. Since the dyes are very expensive, effort is made to assure as high an exhaustion level as possible.

Blends are sometimes dyed in a single bath, sometimes in two separate baths. Therefore, the hydraulic load can increase by 50 percent in the case of two baths (including a rinse step after all dyeing is completed).

The more commonly used dyes for wool (or the wool in wool blends) are metallized dyes and top and bottom chrome dyes. Others used include reactive dyes, mill dyes, and others used for special effects. Use of chrome dyes is diminishing since their high fastness is superfluous in wool blends, given the lower fastness of the dyes used for synthetic fibers. When wool and synthetic fibers are blended, therefore, non-chrome wool dyes of fastness equivalent ot that of the synthetic fiber dyes can be used in the interest of economy.

Rework levels appear to be 3 to 4 percent of total production. When goods are reworked, they are either redyed to a darker shade, or stripped with reducing chemicals, rinsed and redyed.

After it is dyed, the fabric is rinsed with clear water (up to four rinses for some dyes).

Finishing. After it is dyed and rinsed, the fabric is removed from the beck and, when used, soil repellants and other finishing agents are padded onto it. Next, the fabric is dried and any subsequent dry finishing operations -- principally shearing (solid waste) and pressing (steam condensate) -- are performed.

Government fabrics of wool or wool blends must be mothproofed with Mitten-FF. Dieldrin no longer is used because of its high toxicity. Spillage appears to be the only way this material might find its way into the waste waters.

Any of the finishing chemicals can appear in the waste when the padding equipment is dumped and washed.

Category 3 - Greige Mills

General Description. Greige mills generally manufacture yarn and unfinished fabric. Category 3 applied to woven greige goods, and greige yarn production. However, knit grege goods production is almost always combined with a finishing operation and therefore may be included in the knit finishing category. The 1967 Census of Manufactures lists 1173 weaving mills (SIC 2211, 2221 and 2241) excluding wool, but some of these are integrated weaving and finishing mills which belong in category 4. Only 384 mills report water usage.

We estimate that there are 600 to 700 greige woven mills, 80 percent of which are in North Carolina, South Carolina, Georgia, Alabama and Virginia. Perhaps 20 percent of the 600 have their own waste treatment plants, with almost all the rest disposing of wastes at municipal

facilities. Less than 5 percent is believed to dispose of their wastes in waterways without treatment.

Process Description. Weaving textile yarns into a fabric requires application of size to the warp yarns in order to resist the abrasive effects of the filling yarns as these are positioned by the shuttle action of the loom. Greige mills apply the size and complete the weaving. A many operate as completely independent facilities. Figure IV-4 shows opera
tions generally performed at a greige mill.

A typical sizing formulation is composed of a film-forming material, a fatty or waxy component, and water. In some formulations, a water-soluble dye may be used to give the grey cloth an identifying color. A preservative may be used in some sizing mixtures.

The most common film forming materials are starch, polyvinyl alcohol and carboxymethyl cellulose. Other sizes, such as polyacrylic acid and styrene-maleic anhydride polymer, are used occasionally in weaving special cloths.

Starch is a traditional sizing material, but in the past several years the volume of polyvinyl alcohol used in the textile industry has increased substantially, since starch does not adhere well to the synthetic hydrophobic fibers. In many cases, mixtures of starch and polyvinyl alcohol are used.

When formulations based on starch are used, the add-on of size amounts to 10 to 15 percent by weight of the fabric. When polyvinyl alcohol is used, lower add-on, 3 to 8 percent by weight of the fabric, is typical. The range of add-on depends on cloth construction factors such as warp yarn diameter, "tightness" of the fabric, etc.

The size formulation is applied to the warp yarns on a slasher. In this machine, the yarns are drawn through the size bath, squeezed to give the desired add-on, and then dried by passage over a series of hot drying cans. The dry yarns are wound on a warp beam and are ready for weaving.

Weaving is a dry operation, but is normally done in buildings maintained at high humidity. Under these conditions, the size film is flexible, and yarn breaks on the loom are minimized. Yarns sized with polyvinyl alcohol may be woven at a somewhat lower humidity than yarns sized with starch. As indicated in Chapter V, cooling and humidifying water used in a greige mill represents a substantial portion of the total water usage.

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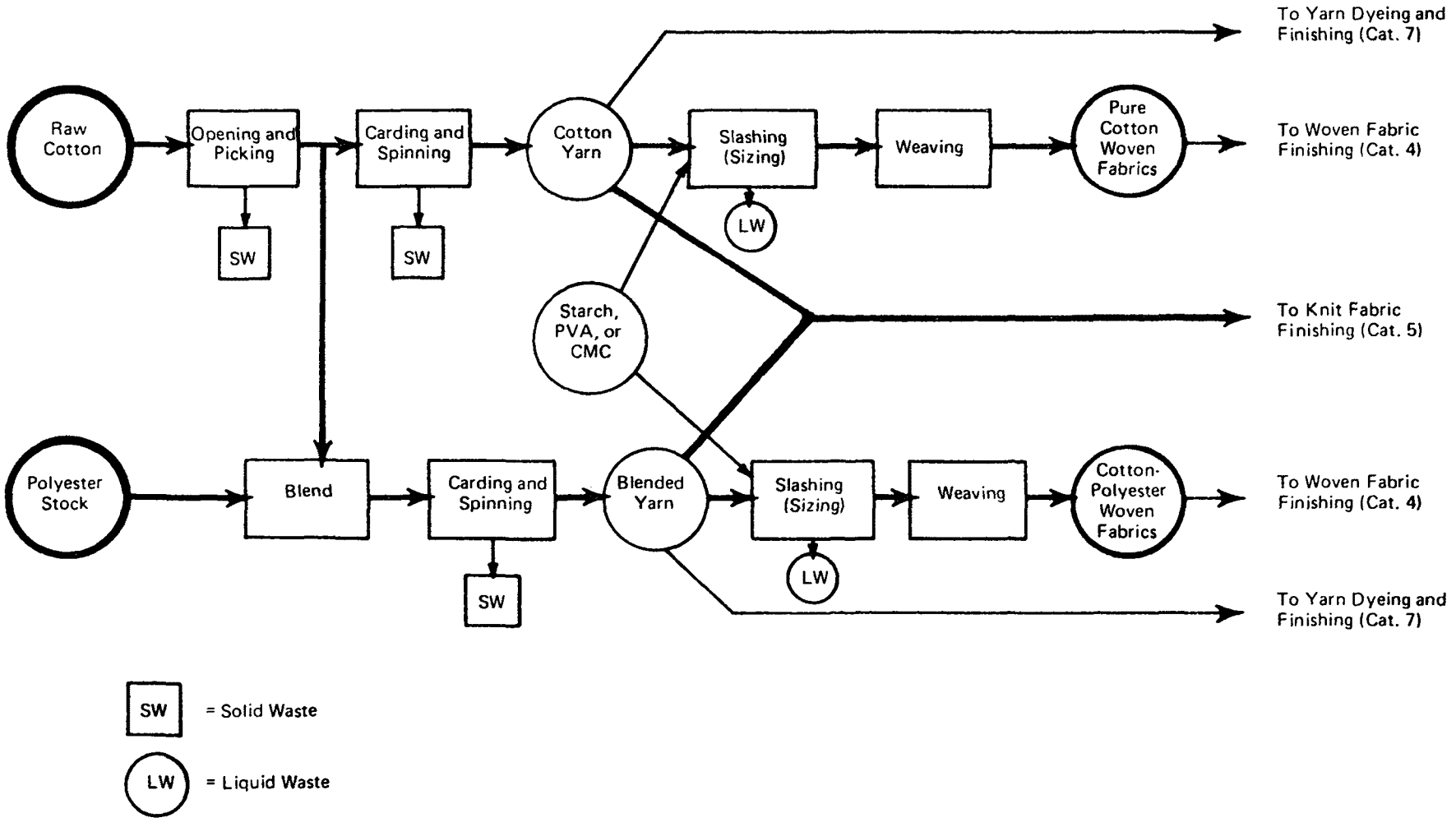

FIGURE IV–4 CATEGORY 3: GREIGE GOODS

Category 4 - Woven Fabric Finishing

General Description. This category encompasses mills which finish woven good (or integrated greige goods and finishing mills). Mills that finish a variety of textile materials, including some yarn and knit goods, and commission houses are included in category 4. 600 mills may fall into category 4. About 20 percent treat their own waste, that waste from about 75 percent enters municipal systems, and that 5 percent have no waste treatment.

This category predominates in the Southeast (North and South Carolina, Georgia, Virginia, Alabama), but there are some large operations in New York and New England.

Process Description. Wet processes which are used in finishing woven greige fabric may be divided into two groups: those used to remove impurities, clean or modify the cloth; and those in which a chemical is added to the cloth.

The first of these groups includes desizing, scouring, bleaching, mercerizing, carbonizing and fulling. Only cotton and cotton blends are mercerized. The last two of these processes are used only on wool and wool blends (See category 2.)

The second group of processes includes dyeing, printing, resin treatment, water proofing, flame proofing, soil repellency and a few special finishes whose use represents a very small proportion of the total.

Certain fabrics, including denims and some drapery goods, are "loom finished." In production of these goods, the warp yarns are dyed, woven to a fabric, and the fabric finished with a permanent size. For these fabrics, the first group of processes listed above (cleaning and preparing the cloth) is avoided entirely. For this reason, mills producing this group of fabrics may be a subcategory, although we have not treated it as such. The degree of finishing necessary to provide fabric ready for sale depends significantly on the fiber(s) being processed. The natural fibers (cotton and wool) contain substantial impurities, even after they have been woven as greige goods, and require special treatments to convert them to the completely white, uniformly absorbent form that is essential for dyeing, resin treatment, etc. Synthetic fibers contain only those impurities that were necessary for manufacture of the fiber and spinning to obtain yarn.

The different operations listed above have been described in the literature, and the contribution of each to wastes has been discussed. For convenience, a flow sheet for woven fabric finishing is given (Figure IV-5), and details about each process step are given below.

Desizing. The sizes (see Category 3) are removed completely from the greige fabric. Enzyme or sulfuric acid is commonly used to aid in dissolving the starch in water. When enzyme desizing is practiced, sodium chloride and a surfactant are frequently added to facilitate the process.

After the desizing agent has been applied, the goods are placed in a bin or a steamer to provide the residence time required. Residence times in storage bins are typically 12 hours or more. If elevated temperatures are used (by employment of J-boxes or steamers) the residence time is reduced to a few minutes at 210 or 212F or 30 minutes at 180F. Finally, the goods are washed with water to remove the decomposed starches from the fabric.

For desizing of polyvinyl alcohol and carboxymethyl cellulose, materials which are directly soluble in water, no decomposition is required. The goods are merely washed with water at 180F or higher on washers without the use of steamers, J-boxes, or padders.

Scouring. Scouring is done to remove much of the natural impurities of cotton, using 2 to 3 percent sodium hydroxide; phosphates, chelating agents and wetting agents may be used as auxiliary chemicals. The synthetic fibers require much less vigorous scouring; sodium carbonate and a surfactant may suffice. In the case of cotton/synthetic blends, Varsol may be used in conjunction with the aqueous scouring liquor.

The operation known as kier boiling is often employed to scour desized cotton and cotton/polyester woven fabrics. The kier is a large vertical cylindrical pressure vessel which can hold up to several tons of fabric. The goods (in rope form) are plaited into the kier by the kier plaiter, the cover is installed, and the scouring chemicals are recirculated through the goods and an external heat exchanger for temperature control. An aqueous mixture of sodium hydroxide, soap and sodium silicate is employed at temperatures of 220 to 250F and pressures of 10 to 20 psig. The goods are scoured for 6 to 12 hours. The kier is then cooled by recirculation of cooling water and the goods are displacement washed. In certain instances, difficult fabrics are double-scoured. The scouring step is designed to remove fats, waxes and pectins from the woven fabric.

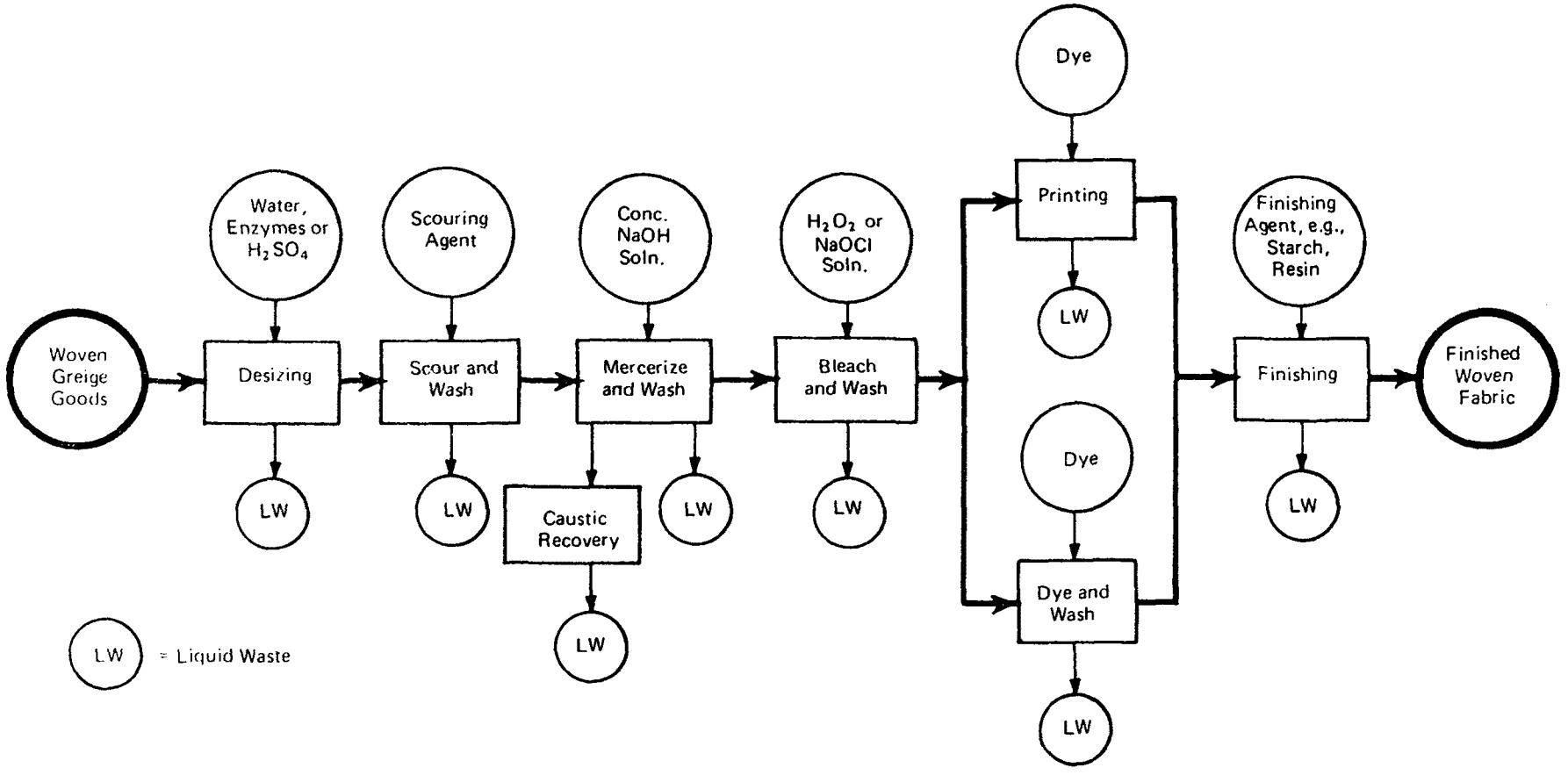

FIGURE IV–5 CATEGORY 4: WOVEN FABRIC FINISHING

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Certain heavyweight fabrics normally are not processed in rope form as required for kier boiling since creases result in streaks in subsequent dyeing steps. These goods are therefore processed in an open-width boil-out machine, also known as the progressive jig. The jig is loaded with a scouring solution and the goods are fed through continuously by the use of 8 or 10 transfer rolls. The system is heated with steam coils and the temperature and residence time are maintained for proper scouring of the goods. The goods are wound onto rolls in the machine and maintained in contact with scouring liquids for the necessary period. Then they are unrolled through wash boxes and folded into a cloth truck or onto a roll.

The scoured cotton may be used directly for producing dark shades or may be bleached by padding through hydrogen peroxide solutions, and subsequently washed, neutralized, and dried before dyeing.

Mercerizing. Mercerizing is one of the more important operations conducted in the preparation of woven cotton and cotton/polyester fabrics prior to dyeing, printing, and finishing.

In mercerizing the woven goods are immersed in 15 to 25 percent solutions of sodium hydroxide and a penetrant. This treatment increases tensile strength, increases surface luster, reduces potential shrinkage and increases the affinity for dyestuffs.

Physically, mercerization swells the cellulose fibers as alkali is absorbed into them, with higher concentrations, longer residence times, and lower temperatures favoring greater swelling. The mercerization step is conducted with the fabric either under tension or in the slack condition, with tension mercerizing favoring increases in tensile strength and slack mercerizing favoring increases in abrasion resistance.

Mercerization may be done on greige goods (after desizing), on scoured goods (after kier boiling or caustic treatment in a range) or on bleached goods. More complete mercerization results from treatment of bleached fabrics (in terms of fiber swelling), but mercerization of greige goods or scoured goods results in greater tensile strengths.

Mercerization is normally conducted continuously; the operation consists of the following steps:

(a) A scutcher and water mangle are employed to open the goods from the rope form, and a mangle is used to dewater the goods to a uniform moisture concentration.

(b) A multiple-contact saturating operation is conducted usually with three saturating bowls. The goods are fed through the system continuously which provides sufficient residence time and contact to completely saturate the fabric with caustic soda solution.

(c) Timing cans are employed to increase the residence time of the fabric in the sodium hydroxide solution.

(d) A tenter frame is employed to maintain the fabric under tension as the fabric travels through the system and the actual mercerization of the cellulose takes place.

(e) At the end of the tenter frame is a washing system that includes water sprays, vacuum units and wash water heaters and re-circulators to wash the fabric and reduce the caustic content while the fabric is still under tension in the tenter frame.

(f) The fabric is given a final wash in the recuperator, which removes the remainder of the sodium hydroxide from the fabric and reduces the residual pH to an acceptable level (i.e., 8.5).

Bleaching. Cotton and cotton blends normally are bleached with hydrogen peroxide. Other chemicals generally employed in the process are sodium silicate, trisodium phosphate, a surfactant, and a chelating agent. In bleaching some synthetics, chlorite may be used.

In order to improve product uniformity and increase throughput, continuous bleaching ranges are employed for the majority of the cotton and blended woven goods. The goods are fed in either rope or open width form (or in combinations) and, in certain cases, the desizing and scouring operations are placed in tandem with the continuous bleaching range. The following process units constitute a typical, continuous peroxide bleaching range, using J-boxes for storage:

Washing. The goods are washed, using either open width or rope washers to ensure removal of converted starches from the desizing step.

Caustic Saturator. As the goods continuously leave the washer they are squeezed through rolls to a minimum water content and then saturated with sodium hydroxide solution in additional squeeze rolls. The goods may be in either rope or open width form, but must remain in the

saturator long enough to permit them to become completely saturated with sodium hydroxide solution.

Caustic J-Box. The goods are then fed contiuously to the caustic J-box, whose function is to saturate the cloth for the necessary length of time at the desired temperature (205-210F). The throughput of the J-box is controlled to provide a residence time ranging from 40 minutes to one hour, resulting in saponification of natural fats and waxes carried in the cotton.

Caustic Washers. The caustic solution is then removed from the fabric by countercurrent washing, usually with large quantities of hot water to ensure complete removal.

Peroxide Saturator. The peroxide saturator is similar to the caustic saturator. It contains a solution of hydrogen peroxide and sodium silicate in sufficient concentrations to retain 1.5 percent of the hydrogen peroxide and 1.5 to 3 percent of the sodium silicate based on the dry weight of goods.

Peroxide J-Box. The design and operation of the peroxide J-box is the same as for the caustic J-box. The unit is operated at about 200F, with a residence time that varies from 40 minutes to 1 hour to bleach the fabric.

White Washes. The bleached goods are now washed to final purity before piling into bins or going directly to the dryer. Hot water is preferred for washing, but cold water is employed in certain instances. Flow meters are employed to regulate the flow of fresh water, and countercurrent conditions are maintained.

In certain instances, two stages of bleaching are operated, sometimes with sodium hypochlorite in the final stage.

Hypochlorite Saturator. The hypochlorite saturator is similar to the caustic and peroxide saturators. Its purpose is to apply a solution of sodium hypochlorite to the fabric to complete the bleaching operation. The solution is maintained at room temperature and the quantities are continuously monitoried in order to control the bleaching operation.

Hypochlorite J-Box. The operation of the hypochlorite J-box is similar to those discussed before, except that it is operated at ambient temperatures. Residence times are similar to those employed in peroxide bleaching, and the same unit may be employed for hypochlorite and peroxide bleaching at different times.

Washers. Two washers are normally required to neutralize and wash the goods after hypochlorite treatment. At least a portion of the first washer is used to apply sodium bisulfite or sulfur dioxide solutions to neutralize excess bleaching chemicals.

Steamers. In open width bleaching ranges, steamer units may be used instead of J-boxes to store goods after they have been impregnated with caustic or bleaching solutions. These are particularly useful in processing heavyweight fabrics.

Small Open Width J-Boxes. More recent bleaching technology employs more concentrated solutions and more drastic operating conditions and has resulted in the development of the small open width J-box which permits effective bleaching with residence times of only 10 to 15 minutes.

Continuous Pressure Scouring and Bleaching. The newest type of steamer for bleaching ranges is an enclosed type with pressure locks and seals. This enables the steamer to be operated as a pressure vessel and the reaction time for the chemicals is reduced from 40 minutes to only one or two minutes. The treatment of fabrics is a function of time, temperature and concentration. The increased temperatures made possible by pressure steamers reduce the time needed for complete chemical reaction.

The problems associated with equipment designed for operation at 25 psig and for continuous entry and removal of continuous webs have posed a substantial design problem. However, several machines are now available with satisfactory sealing devices, so they may perform well at these pressures. Some of these units utilize rolls as a sealing mechanism and others have developed a system involving a lip seal. In addition there are reports of pressure steamers which may be operated at pressures up to 45 psig and develop temperatures of 292F, resulting in residence times only of one or two minutes.

Sodium Chlorite Bleaching. Although sodium chlorite bleaching has had very little economic success in the bleaching of pure cotton goods over the years, its use in kier steamers and becks is now receiving more attention since many of the man-made fibers are sensitive to bleaching and can be bleached successfully with sodium chlorite. It is now used to a considerable extent either alone or in conjunction with other bleaching agents for preparation

Dyeing. Dyeing is the most complex of all textile finishing processes. Table IV-3 shows the dyes used in the textile industry, the

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Table IV-3

Types and Amounts of Dyes Used in the Textile Industry

Dye Types	Acrylic	Cotton	Wool	Acetate	Rayon	Poly-ester	Poly-ester PE/cotton	Nylon	Nylon/ Cotton	Amount Used[a] %
Acid			✓					✓		10
Azoic		✓			✓					3
Aniline Black		✓								-
Basic (Cationic)	✓					✓	✓	✓		6
Developed		✓			✓					-
Dyeblends							✓			-
Direct		✓			✓		✓		✓	17
Disperse	✓			✓		✓	✓	✓		15
Fiber-reactive		✓								1
Fluorescent		✓	✓		✓		✓	✓		1
Indigo		✓							✓	-
Sulfur		✓			✓		✓			10
Vats		✓			✓		✓			26
Natural		✓								-
Oxidation Base		✓								-
Mordant			✓							1

[a]Approximate percent of total textile use. Usage of dyes for which amounts are not shown totals approximately 10 percent (not including dye blends).

fibers they are generally used to color, and the relative amounts of each dye used by the industry.

When textiles are dyed, an excess of the dyestuff is used, and other chemicals are used to help deposit the dye, or to develop the color. Dye loadings vary widely even with a particular dye class, depending on the weight of fabrics being treated and the depth of color desired. The range of chemicals employed in dyeing also varies widely from place to place and operation to operation, and depends substantially upon the dictates of the marketplace.

Table IV-4 presents a summary of chemicals used in application of dyes to textiles. Dyed goods are generally, but not always, washed and rinsed to remove excess dye and chemicals from the cloth. Washing involves use of a detergent, and also may involve the use of soda ash or a sodium phosphate.

The chemicals used in dyeing may depend significantly on the dyeing procedure which the fabric manufacturers fins appropriate. Both batch and continuous dyeing are practiced, and both may be employed in the same finishing plant.

Textile goods are dyed continuously when the demand for a single shade is sufficiently high to justify the necessary equipment. Production of denims, in which the warp yarns are dyed continuously, is one example; no special chemicals are required as a result of dyeing continously. In Thermosol dyeing, which is practiced on woven cotton (or rayon)/ polyester blends, a dye blend is padded on the fabric, which is then dried and heated, washed, rinsed and dried. Thermosol dyeing requires addition of a gum to the dye mixture, so that the formulation will deposit uniformly on the cloth.

Piece dyeing, on runs which are not long enough to justify continous processing, are normally performed in an open beck, operated at boiling temperature, or in a sealed pressure beck, operated at about 250F. In modern units, the entire dye cycle (including washing and rinsing) is controlled automatically. Pressure becks have been found advantageous use of less carrier; wastes are decreased correspondingly.

Printing. Printing involves application of dyes or pigments in the form of a pattern on to fabric. Dyes penetrate and color the fiber; pigments are bonded to the fabric with a resin.

In general, the formulated print paste is applied to one side of the fabric only.

Vat, direct and other dyes may be printed; vats appear to predominate. The same chemicals used for the regular dyeing process are used in printing, but in addition, a thickener is used to give the mixture high viscosity. Many thickeners such as gum arabic, British gum, alginates, methyl cellulose and others have been used. Urea, diethylene glycol and glycerol are frequently used in the formulations.

Pigment print formulations are more complex. The pigments are blended with a resin binder (frequently melamine-formaldehyde), a latex, an aqueous thickener, Varsol and water.

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Table IV-4

Chemicals Use in Application of Dyes1

Dye Type	Auxiliary Chemicals Necessary	
Vat	sodium hydroxide sodium hydrosulfite dispersing agent hydrogen peroxide acetic acid sodium perborate sodium dichromate acetic acid	alternative chemicals
Direct	sodium chloride sequestering agent	
Disperse	orthophenyl phenol butyl benzoate bisphenyl chlorobenzene acetic acid monosodium phosphate dispersing agent	alternative carriers alternative
Sulfur	sodium sulfide sodium carbonate sodium dichronate acetic acid hydrogen peroxide acetic acid	alternatives
Acid	acetic acid ammonium sulfate of ammonium acetate sodium chloride	
Cationic	acetic acid or formic acid sodium sulfate	
Reactive	sodium chloride urea sodium carbonate	

Table IV-4 (Continued)

Chemicals Used in Application of Dyes[1]

Dye Type	Auxiliary Chemicals Necessary
	sodium hydroxide
Developed	developer sodium chloride sodium nitrite sulfuric acid sodium carbonate

---

[1In addition to the chemicals listed, all of the dye types will usually use a small amount of surfactant. After the dyeing has been completed, the dyed goods are washed and then rinsed. Washing will involve use of a detergent as well as soda ash and a phosphate.]

Vat dye prints must be oxidized, with sodium dichromate or other oxidant, to develop the color. Steaming and brief aging aid in the process. Pigment prints do not require chemical after treatment, but must be dried and heated to insolubilize the resin-pigment mixture.

Printing a fabric that contains polyester may require a carrier in the formulation.

Following complete application of the print mixture, the fabric is washed thoroughly to remove excess color and chemical.

Special Finishes (resin treatment, water proofing, flame proofing, soil release). Each of these finishes endows fabric with a particular property desired by consumers. The property is indicated by the name, except for resin treatment, which designates finishes that provide wrinkle resistance. Several of the treatments may be applied from a single bath.

As would be expected for processes that provide such diverse effects, the range of chemicals used is very broad. For resin treatment, a urea-formaldehyde-glyoxal compound ("DMDHEU"), a fatty softener, and a catalyst (zinc nitrate, magnesium chloride) are used together. Water repellents include silicones, fluorochemicals, and fatty materials, each generally applied with a catalyst. Soil release treatments include special acrylic polymers and fluorochemicals.

These finishes are generally applied by impregnation of the fabric followed by squeezing to the desired add-on. The moist material is dried and then cured by additional heat. The cured fabric is frequently packed for shipment without rinsing. Most resin-treated goods are subsequently cured in a garment factor and must not be rinsed, since the catalyst would be removed.

Category 5 - Knit Fabric Finishing

General Description. The knitting industry is characterized by a large number of plants and a structure organized along specialized product segments. The major segments are knit fabric piece goods, hosiery, outerwear, and underwear. The geographical distribution of knit mills, SIC code 225, according to 1967 census data is as follows:

	No. Plants	
Northeast Region	1616	
North Central Region	76	
South Region		910
West Region		96
Total		2698

While the industry has shown substantial growth in value of shipments, we estimate that through consolidation and other factors the current number of plants in this industry is about 2500. Of this number, we estimate that about 1100 plants have only dry operations. These are plants such as sweater mills in the outerwear segment, which knit goods from purchased or commission dyed yarns, or mills which have finished goods dyed on a commission basis and therfore have no process water requirements. Most of the sweater mills are located in the Northeast. In those isolated instances where sweater or similar mills dye their own yarn, these mills should be subject to category 7 guidelines.

Of the 1400 plants believed to have wet process operations, we estimate that 85 percent discharge to municipal treatment systems. The great bulk of these are hosiery plants (700-800) located primarily in North Carolina, Tennessee, an Pennsylvania. Census data on process water use and discharge indicates that in 1968, 90 percent of the hosiery plants discharged to municipal systems. The small number of isolated plants which may not be tied to municipal systems should be subject to category 5 guidelines. Of the remaining wet process plants, we estimate 100 have private waste treatment facilities and 90 have no waste treatment.

The knit fabric segment of the industry has about 540 plants. These plants are the source of finished knit piece or yard goods for the apparel, industrial, and household goods trades, and also serve to augment supplies of fabric to underwear and outerwear manufacturers. These plants are the main subject of category 5. The large knit fabric plants are located mainly in North and South Carolina and Georgia, but substantial numbers are also located in New York, and Pennsylvania.

The production of knit fabrics for women's and men's wear has been the fastest growing sector of the textile industry over the past decade. Synthetic fibers are the predominant types used in knit goods except for cotton goods produced for underwear and sleepwear. In the latter case, however, polyester has been replacing increasing proportions of cotton fiber. Plants which previously processed all-cotton are using greater amounts of polyester and the trend is expected to continue.

Process Description. The wet processing operations performed in knit fabric finishing are shown schematically in Figure IV-6. This is necessarily a generalized flowsheet; the specific operations employed in a given plant will vary from plant to plant. In general, the yarns are purchased in the undyed state, with a knitting oil finish to provide lubrication for the knitting operation. The amount of finish on the yarn ranges from 1 to 7 percent depending on the type of yarn and fiber. This is a significant difference from weaving yarns which are sized with starch or other polymeric materials. After the yarn has been knitted into fabric, the fabric may be processed by one or more of the alternative routes indicated in Figure IV-6. The wet process operations employed in a plant depend on the nature of the goods involved and the end product requirements. Typically, knits are processed in piece goods form. The fabric may be washed on continuous countercurrent washers prior to loading the fabric in dye machines to remove knitting oils and other contaminents, or washing may be the first step in the dye machine cycle. Warm water with a small amount of added detergent is used. In contrast, woven goods require more extensive treatment to remove starch or polymeric sizes.

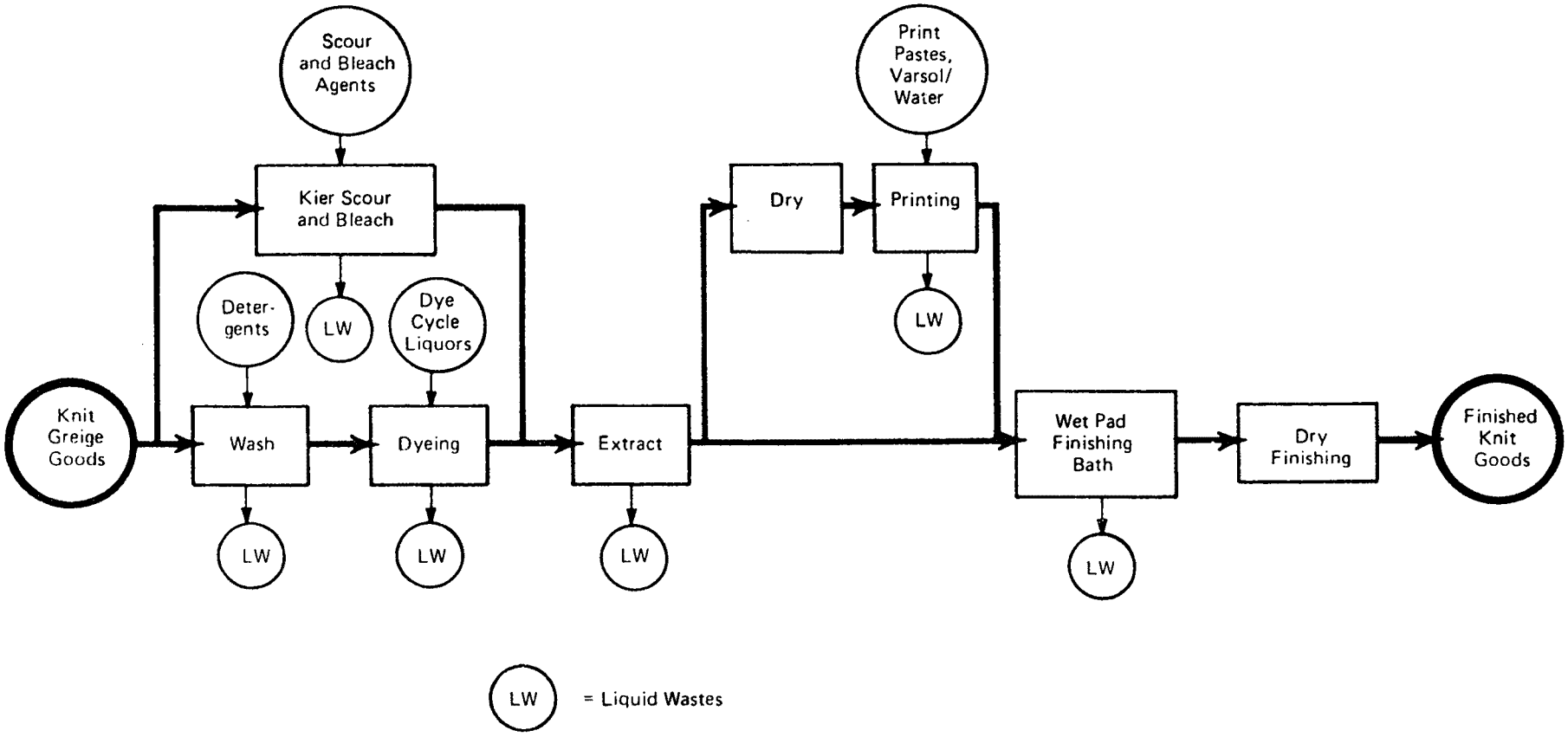

FIGURE IV–6 CATEGORY 5: KNIT FABRIC FINISHING

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The types of dyeing equipment generally employed include: atmospheric becks, pressure becks, jet (atmospheric or pressure) becks, atmospheric or pressure beam dyeing machines, and paddle type machines. Some plants may also package dye a portion of their yarns.

The types of dyestuffs, auxiliaries, and conditions employed for dyeing knit goods are essentially the same as for woven goods of comparable fiber composition. See the discussion under category 4 for details of the dyeing operation.

Some of the fabrics which are beam dyed are first wet batched. In the wet batching operation, the fabric is passed through a dilute aqueous surfactant bath at controlled temperature before being wound on a perforated beam. Batching helps control shrink and yield, and also enhances uniform penetration of dye liquors in the dyeing process. There is some waste generation from the wet batching operation; a small quantity of the dilute bath is dumped occasionally for cleanup and there is a continual slow drain of water from the wetted fabric which contains knitting and yarn lubricants.

In knit plant, finishing cotton fabric -- e.g., for underwear and sleepwear -- wet process operations also include scouring and bleaching in kiers or comparable equipment. Plants that process either cotton or synthetic goods may also have fabric printing operations. (See discussion under category 4 for details of these operations.)

Most knit fabrics are treated with softeners, and resin finishes, and in some cases, with water and oil repellents. These finishes are applied from a pad bath just prior to final drying and dry finishing operations. These baths are discharged periodically as required for fabric lot or formulation changes, but the total daily volume of discharges is very small.

Category 6 - Carpets

General Description. Tufted carpets account for well over 65 percent of the plants and 86 percent of the dollar volume, and constitute 74 percent of the employment in this industry. Therefore, the guidelines are generated principally around this segment. About 70 percent of the industry is located in Dalton, Georgia and these mills are connected into the municipal treating system. However, the remaining carpet mills are of sufficient quantity to warrant effluent guidelines.

Tufted carpets consist of face yarn that is looped through a woven mat backing (mostly polypropylene, some jute), dyed or printed, and then backed with either latex foam or coated with latex and a burlap-type woven fabric backing put over the latex.

The dominant face yarn is nylon, followed by acrylic and modacrylic, and polyester; the latter two groups in total are about equal to nylon. Since dyeing of these fibers in carpets differs little from dyeing fabric, the dyeing descriptions for these fibers given in other categories applies here. Beck, continuous dyeing, and screen printing are practiced.

The latex operational load on the waste treatment facility of an integrated mill, after adequate pretreatment by coagulation, is insignificant. Moreover, latex wastes are treatable by coagulation to a level to meet recommended guidelines for this category. Therefore, all wet processing carpet mills are covered in this category, including latexing only, finishing only, and integrated mills.

Census data for 1967 indicates 385 carpet mills in total, and 50 of these are wet processing. We estimate there now are 70 wet processing.

The distribution of the 385 mills is as follows:

Northeast Region	83	22%
North Central Region	13	3%
Southern Region	231	60%
Western Region	58	15%
Total	385	100%

In 1970, the industry product mix looked like the following:

SIC Category	Descript.	No. Plants	Emp. (thou)	Value of Ship. (mil)
2271	Woven	60	8.6	203
2272	Tufted	270	39.1	1914
2279	Other	85	5.3	98
227	All	415	53.0	2215

Since 1970, a significant number of woven carpet mills have either closed or changed over to tufted production.

In 1970, the face yarn consumption was dominated by nylon, with polyester, acrylic/modacrylic, and polypropylene of significance. The use of wool and cotton, rayon or acetate has been shrinking rapidly with the first mentioned group gaining. The following figures represent the relative share of each fiber:

Material	%	
Nylon	44	
Polyester	17	
Acrylic/Modacrylic	16	Growing
Polypropylene	7	
Wool	8	
Cotton, Rayon		Shrinking
Acetate, other	8	

±Source: Chase Report, op. cit.1

Since 1970, nylon has held its position. Acrylic/modacrylic has grown but polyester, because of flammability problems, has declined.

In 1968 the Tufted Textile Manufacturer's Association showed that about 45 percent of its members had their mills in Dalton, Georgia, with another 37 percent in Georgia. The remaining 18 percent is scattered through 11 states including Massachusetts, Texas, and California.

Many of the new mills are going into other states, principally California and other far western states. The bulk of these newer mills appear to be connecting into municipal systems.

Process Description. Carpets are yarn dyed, piece dyed, and printed. When yarn dyed carpets are made, the yarn is often dyed in another mill and brought to the carpet mill. (Yarn dyeing is covered in category 7.) The relative quantities of yarn, beck, and continuous dyeing, and printing and latexing may vary widely. (For instance, one exemplary mill dyes or prints only 30 percent of its production.

The yarn is tufted onto a polypropylene or jute woven backing in a dry operation (Figure IV-7). Following this, the tufted carpet can be either
printed or dyed. If printed, a semi-continuous screen printing operation is performed, followed by a wash and rinse step in the same machine. If dyed, the most common method is beck dyeing, in a manner quite similar to that described in previous categories for yard goods. The industry claims a higher liquor-to-fabric ratio, however, because of

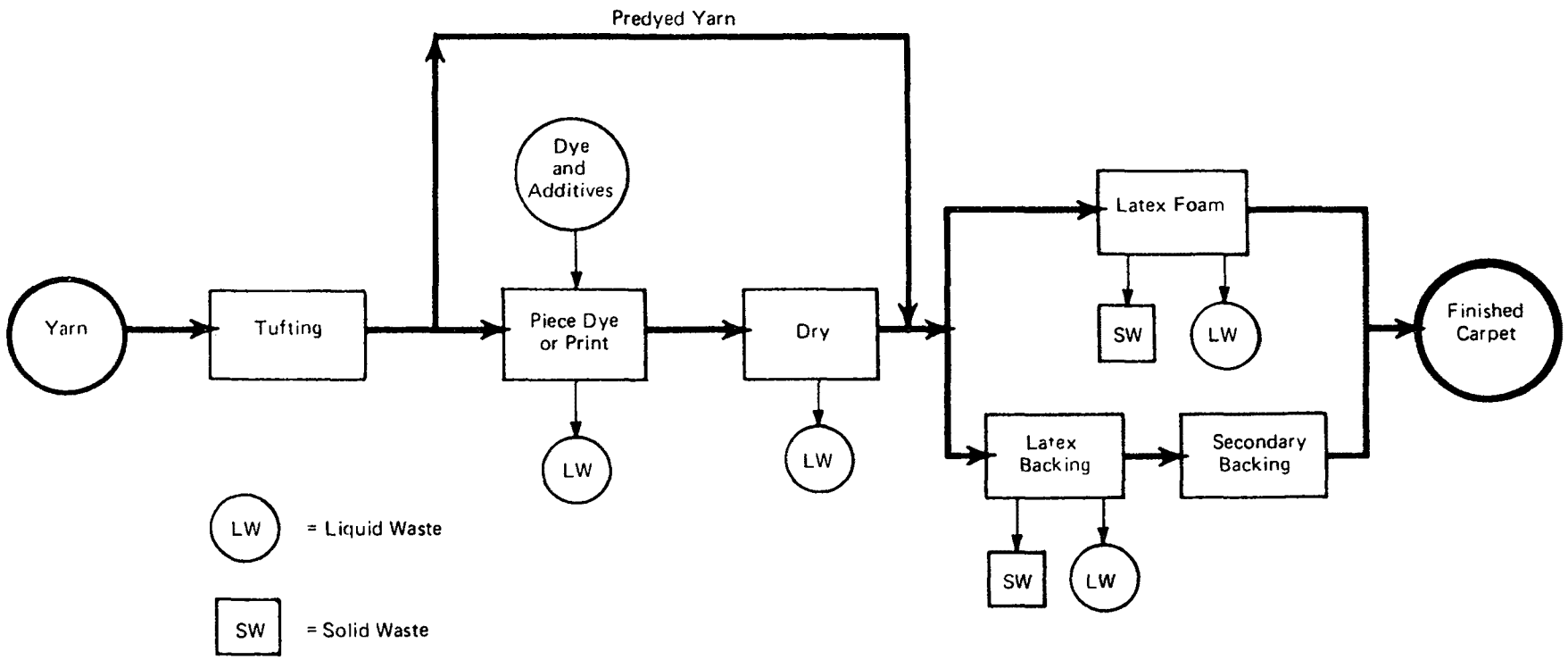

FIGURE IV–7 CATEGORY 6: CARPET MILLS

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the difficulty in making the carpet sink and become thoroughly wetted. Many small air bubbles become entrapped in the tufts.

The continuous dyeing appears very similar to the continuous pad-stream process used for cotton/synthetic blends broad-woven finishing. After it is dyed the carpet is dried in a tunnel drier. The carpet is then ready for application of either a single or a double backing.

For the single backing, a continuous applicator applies a foamed latex layer to the carpet's underside. In double-backed carpet, a layer of unfoamed latex is applied in the same manner, and a final fabric backing is pressed on, being cemented in place by the latex. In either case, a liquid latex waste is generated. Some of the latex becomes hardened, so a mixture of solid and liquid latex results. Some of this material is collected by shovelling it into a barrel for land-fill disposal. The rest is washed off by hosing and is usually conducted via a separate conduit to a latex coagulation facility before the relatively clarified liquor is sent to join the dye wastes for treatment.

Category 7 - Stock and Yarn Dyeing and Finishing

General Description. Category 7 includes plants which clean, dye and finish fiber stock or yarn. The plants may or may not have yarn spinning facilities. Sewing thread, textile and carpet yarn are typical products.

We estimate that 750 plants in the country fall into this category. Most (probably 80 percent) dispose of their wastes at municipal facilities. We believe that 5 to 10 percent treat their own waste and the rest have no waste treatment facilities.

About 60 percent of yarn dyeing and finishing is performed in Virginia, North Carolina, South Carolina, Georgia and Alabama, with the remainder distributed across the eastern U.S. and the Far West.

Process Description. The raw material for the plants considered in this category is crude yarn obtained from a spinning facility. The yarn may be natural, synthetic, or blended. The differences between processing the natural and synthetic fibers have been discussed under category 4 and are equally applicable to category 7, yarn processing. Wet processes used by yarn mills include scouring, bleaching, mercerizing and dyeing (Figure IV-8). The remarks made about each of these processes
under category 4 apply to yarn processing.

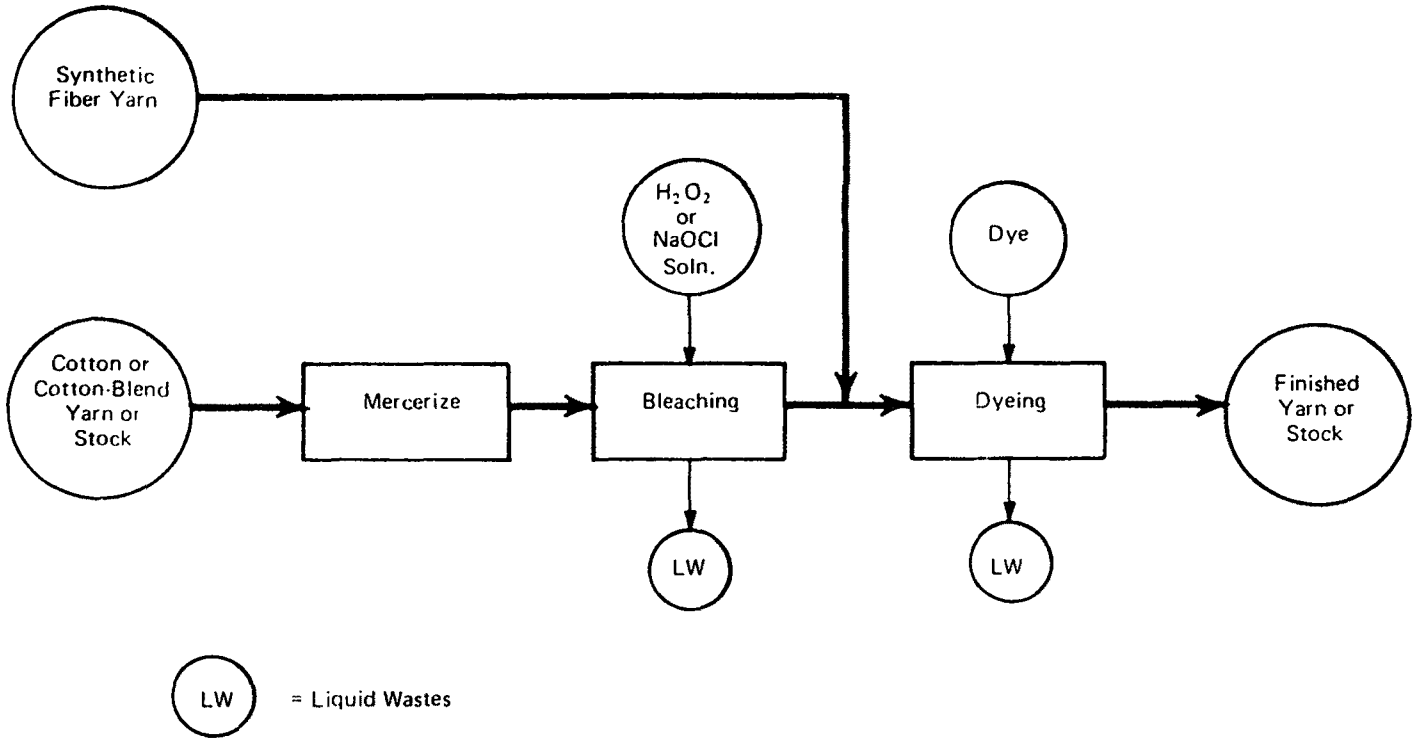

FIGURE IV–8 CATEGORY 7: STOCK AND YARN DYEING AND FINISHING

Several techniques are available for processing raw yarn into the finished product. The most common process is probably package dyeing, but other processes, such as space dyeing, are widely used. In the former process, yarn wound on perforated tubes is placed in a large vessel, which is sealed. The dye solution, at an appropriate temperature, is circulated through the yarn. The dyed yarn is washed, rinsed and dried. In space dyeing, yarn i knit and the fabric is piece dyed, washed, rinsed and dried. The fabric is then unravelled and the yarn is wound on cones.

Category 8 - Special Products

Coated Fabrics. Polyvinyl chloride (PVC) coated fabrics dominate coated fabric production included under SIC code 22. Rubberized, or rubber coated, fabrics are specifically excluded from this code and are assigned to SIC code 3069. WE estimate that PVC coatings account for 70 percent or more of total coated fabric production. These coatings are applied as 100 percent "active solids" systems either as plastisols (dispersion of polymer particles in liquid plasticizer) or as melts (flexible grade polymer plus plasticizer). The plastisols are generally coated by knife over roll coaters and the melts are applied by calenders. A minor portion, estimated at 10 percent or less, or coated fabrics is coated with polymer latices (PVC or acrylic). In this case some dilute aqueous waste is generated from equipment wash-ups. These dilute aqueous latex wastes should be subjected to the treatment control described under category 6 to remove latex solids. Plastisol coating and calendering of PVC coatings do not involve process water use. Therefore, these plants are dry operations.

Polypropylene Carpet Backing. Polypropylene carpet backing is produced by one of three basic methods: extruded film is slit and woven into a web; polypropylene staple fiber is formed into a nonwoven web and needled to provide mechanical strength; or continuous filament is melt spun, directly deposited into a nonwoven web, and bonded with heat (spunbonded process). None of these processes generates significant process waste water. The woven slit film and theneedled nonwoven processes are dry operations. The spunbonded process is a special modification of conventional synthetic fiber production and should be considered part of the synthetic fiber industry.

Tire Cord Fabric. Tire cord fabric plants prepare the cord fabrics used in the production of tires. These plants purchase yarns and twist and weave the yarns into a loose fabric structure. The fabric is then dipped in a latex based bath and dried in what is referred to as a Z-calendering operation. This treatment serves to prime the fabric to

provide adhesion to the rubber during vulcanization of the tire. The only process waste generated in these plants originates from occassional wash-ups of equipment. Our assessment of RAPP data from a number of these plants indicates that waste loads are extremely small. Since the wastes are dilute lates, threatment technology of the type recommended in category 6 should be employed to remove latex solids.

Dry Process Nonwovens. Nonwoven webs made by so-called dry processes (carded webs, air-laid webs, etc.) comprise the largest segment of the nonwoven industry. While the webs are formed by a dry process, binders are usually applied in the form of latex by dip, gravure roll, or spray application. Acrylic polymer type latices account for about 80 percent of total binders used. The binder formulations are conserved for use on a day-to-day basis. However, some dilute aqueous waste are generated by equipment wash-ups.

Based on our contacts with the three major producers in this industry, the practice is to discharge pretreated waste to municipal systems. Of the nine plants operated by these producers, seven discharge to municipal systems. Pretreatment consists of settling (alum coagulation employed in one instance). Where required, pH control is also employed. One of the plants discharges into a waste treatment plant which also serves a large woven goods plant. No data is available on this nonwoven plant. The one nonwoven plant identified as having its own waste treatment facility, does not now have adequate provision for removal of latex solids. In view of the limited data, and the similarity in the nature of the dilute latex wastes to those generated in carpet backing operations, we recommend that pretreatment and treatment technology employed for removal of latex solids from carpet plant wastes be applied to latex wastes from nonwoven plants.

Felts. Felts are composed of fur, hair, wool and synthetic fibers in various combinations. Synthetics are vastly predominant today. Felt is a nonwoven material formed by physically interlocking fibers by a combination of mechanical work, chemical action, moisture, and heat. After felting, the felt is rinsed. If dyeing is performed, it is done in the fiber form before felting. Oten the felts are finished with a resin of the resorcinol/formaldehyde or acrylic type. All six felt manufacturers who belong to the Northern Textile Association are discharging waste into municipal sewers. Therefore, guidelines are not proposed for this segment. Adequate pretreatment is performed by neutralization and fiber removal.

SECTION V - WASTE CHARACTERISTICS

Category 1 - Raw Wool Scouring

The raw waste from raw wool scouring is different from the waste from all other categories used in this study: it contains significant quantities of oil and grease, even after in-process recovery. The wool grease is not readily biodegradable nor easily precipitated chemically (Ref. #143). In addition, sulfur is brought in with the wool, as well as phenolic and other organic materials derived from the sheep urine, feces, blood, tars, branding fluids and sheep-dips used as insecticides. These items appear randomly in the effluent.

The detergent used to emulsify the grease constitutes about 10 percent of the total waste load to the treatment plant; i.e., on the order of under 10 pounds of BOD5/1000 pounds source wool (Ref. #141).

One analysis of raw wool contaminants is as follows:

Clean, dry wool	-	62.5% (by weight)
Regain moisture	-	10.0%
Suint & associated moisture	-	10.0%
Grease	-	6.0%
Dirt	-	11.5%

Suint is described as potassium salts of organic acids, and is derived principally from urine and dried sweat.

Analyses vary widely depending on the source of the wool, and as mentioned in Chapter IV, the total non-wool materials may be 25 to 75 percent of the grease wool by weight.

Category 2 - Wool Finishing

As mentioned, the metallized dyes used for wool are very fast (i.e., do not fade or rub off readily). Hence on 100 percent wool cloth, these dyes are often used. In the blends, however, the dyes used for polyester and other synthetic fibers have poorer fastness, so in these blends many woolen mills have converted to non-chrome dyes. As a result, an all-wool mill may be expected to have significant chrome in its effluent, but in a wool-blend mill, the chrome will be considerably less or even nonexistent.

Since the wool mills investigated appear to be working mostly on blends, principally polyester, carriers such as orthophenol, phenol, diphenyl, or benzoic acid derivatives will be present at significant levels in their raw wastes. Phenolics appear to be losing favor because of their odor, but current practice includes them and they will be present in most woolblend mill wastes.

As a result of the above, the principal component that distinguishes the wool mill Category 2 from Category 5, Knit Finishing, is the chromium used to dye the wool. However, since we are recommending a generalized guidelines on chrome, this difference is of no consequence.

The Category 2 mills (see Process description) have a higher water usage rate than any other finishing category. The heaviest contributor appears to be the rinsing after fulling. In addition, the wool and wool blends are more expensive fabrics and their higher quality necessitates more washing to reduce crocking, or rubbing off of color.

Category 3 - Greige Mills

Wastes at greige mills constitute residues in size boxes at the end of a day or a week, and water used for clean-up. The volumes of textile wastes in a greige mill are small. Significant amounts of water used in a greige mill (e.g., cooling water) may not enter the waste treatment plant.

The total waste load at a greige mill is typically greater than 90 percent sanitary and the remainder is industrial.

Treatability of greige mill wastes is related to the size used. Starch is very readily degraded biologically, and may be given a preliminary enzyme treatment to improve biodegradability. On the other hand, polyvinyl alcohol is consumed by organisms relatively slowly, though recent studies show that organisms acclimate to polyvinyl alcohol. (See Category 4 below.)

Category 4 - Woven Fabric Finishing

Wastes associated with finishing woven goods are indicated by the technology summarized for this category in Chapter IV. The wastes result from removal of foreign material during the cleaning and bleaching of cotton (and its blends) and from the various chemicals used in finishing the fabric. In the description which follows, individual

processes are discussed in the same order as will be found in Chapter IV, Category 4.

Desizing

Enzymatic removal of starch size generates starch solids, fat or wax, enzyme, sodium chloride and wetting agent in the effluent stream. The waste contains dissolved solids (both organic and inorganic), suspended solids, and some fat or wax; it has a pH of 6 to 8, is light colored, and contains no toxic materials.

Sulfuric acid removal of starch size generates waste containing starch solids, fat or wax and sulfuric acid. It contains organic and inorganic dissolved solids, suspended solids, and some oil and grease. It has a pH of 1 to 2 and is relatively light colored.

Polyvinyl alcohol and carboxymethyl cellulose are both removable with water alone. Desizing these materials will thus contribute suspended solids, dissolved solids and oil and grease. Since these sizes are used at about one-half the concentration of starch, the total solids generated in the waste stream are about one-half the level corresponding to starch use. When mixtures of starch and polyvinyl alcohol are used, desizing may involve the use of enzyme (to solubilize the starch) and water; total wastes generated would be intermediate between that developed by either size used alone.

Desizing may contribute 50 percent or more of the total waste solids in a woven goods finishing mill.

The contribution of starch to BOD of waste streams has been documented many times. On the other hand, polyvinyl alcohol has been considered very slowly biodegradable, and as such, a major source of COD. Recent studies performed by producers of polyvinyl alcohol in cooperation with textile mills, indicate that biological waste systems will develop organisms acclimated to polyvinyl alcohol, and when this has occured, biodegradation is relatively rapid and complete.

Scouring

The major chemical used in scouring cotton, crustic soda, appears in the waste stream. A surfactant and a small amount of sodium phosphate are

frequently used, and these also appear in the waste stream. The wastes will also contain cotton waxes, which amount to 3 to 4 percent of the cotton used.

Scouring liquors are strongly alkaline (pH greater than 12), and dark colored due to cotton impurities. They contain significant levels of dissolved solids and oil and grease. A modest level of suspended solids results from the presence of cotton impurities.

The natural cotton impurities removed from greige fabric by scouring contribute BOD and are biodegraded rapidly.

Scouring of cotton/polyester greige blends generates the same waste in proportion to the amount of cotton.

Scouring of synthetic woven goods generates a low level of dissolved solids from surfactant, soda ash, or sodium phosphate.

Mercerization

Mercerization wastes are predominantly the alkali used in the process. The waste stream contains high dissolved solids, and may have a pH of 12 to 13. BOD level is low, and is due to penetrant used as an auxiliary with the caustic. Small amounts of foreign material and wax may be removed from the fiber, and will appear as suspended solids, and wax in the wastes; these materials will contribute a small BOD load.

In large mills, caustic soda is recovered and concentrated for re-use, thus saving chemical and avoiding a sizeable waste load. Estimates have indicated that recovery of mercerizing caustic is justified when the caustic use is more than 5 million pounds per year (dry), and concentration of the alkali is not permitted to fall below 2%.

Bleaching

Bleaching with hydrogen peroxide contributes very small waste loads, most of which is dissolved solids. The dissolved solids are both inorganic (sodium silicate, sodium hydroxide and sodium phosphate) and organic (a surfactant and chelating agent). The waste stream contains a low level of suspended solids when goods containing cotton are bleached.

Dyeing

Dyeing processes contribute substantially to textile wastes. Color is an obvious waste. Examination of Table IV-4 shows that a high level of dissolved solids is expected. Suspended solids should be low. Carriers, which are essential for dyeing polyester and acetic acid, have high BOD. Sodium hydrosulfite has a high immediate oxygen demand. Plants using

sulfur dyes will contain sulfides in the raw waste, and dichromates may be a waste when vat dyeing is practiced.

Some of the wastes from dyeing textile fabrics are related to the production equipment and to the size of the mill. The use of pressure becks to replace atmospheric becks, and thereby decrease the amount of carriers employed, has already been mentioned. On long runs, where continuous Thermosol dyeing of synthetics or synthetic blends can be justified, carriers may be avoided; a gum will be used, and will contribute a low BOD.

Table IV-# also shows alternative chemicals that may be used as substitutes for soium dichromate. Controls are available for the reduction of vat dyes and their re-oxidation; use of the controls will minimize wastes.

Printing

Printing wastes are comparable in many respects to dye wastes. As stated in Chapter IV, printing requires use of gums, which will contribute BOD. Solvents (Varsol) and glycerine are also common constituents in printing, but pose no special waste treating problem.

Printing pigments will introduce some suspended solids into the waste.

Much of the wastes from printing comes from cleaning of make-up tanks and process equipment. These relatively concentrated wastes may justify segregated treatment, perhaps by incineration.

Other Treatment Wastes

Wastes from resin treatment, water-proofing, flame-proofing and soil release are small, since the chemicals are applied by padding, followed by drying and curing. The chemicals used are diverse and small amounts of them will enter the wastes.

Category 5 - Knit Fabric Finishing

The unit operations of knit fabric finishing are diagrammed in Figure IV-6. The unit operations that produce liquid wastes have been described in the preceding section, Category 4, Woven Fabric Finishing.

The main differences between knit and woven fabric wet processing operations are that knit yarns are treated with lubricants rather than

with the starch or polymeric sizes used for woven goods yarns, and that mercerizing operations are not employed with knit goods. Otherwise, the character of the wastes generated from comparable unit operations performed on different fibers--cottons, synthetics, and blends--are similar to those found in woven fabric finishing.

Lubricating finishes applied to knitting yarns generally are based on mineral oils, vegetable oils, synthetic ester type oils, or waxes, and may also contain antistatic agents, antioxidants, bacteriostats, and corrosion inhibitors. Specific formulations are proprietary with the yarn supplier or throwster who applies the finish. The amount applied varies with the type of yarn; general levels of add-on by weight percent on yarn are: untexturized synthetic yarns, 1 to 2 percent; texturized synthetic yarns, 4 to 7 percent; and cotton yarns 3 percent or less. These knitting oils are readily emulsified or soluble in water, and are removed by washing prior to the dyeing operation.

Category 6 - Carpet Mills

The carpet industry wastes are very similar in nature to those from Category 5, Knit Goods. When polyester is dyed, the carriers present the same problems as in other categories, but very little polyester is being used or will be used until a satisfactory answer to fireproofing is found. Therefore, the nylon, acrylic and modacrylic dyeings predominate. This means very little phenolics from carriers, and very little chrome from wool dyeing. Spin oils from the yarns are present.

A special waste, peculiar to this industry, exists because of the use of foamed and unfoamed latex backing. The latex is not soluble in water but is used in a highly dispersed form; hence suspended solids and COD could be a problem unless they are coagulated. This stream (from equipment washdown once a day to once a week) is usually segregated, acidified to hasten coagulation, and settled before it joins dyehouse wastes.

Municipal treating plants require pretreatment of the carpet mill wastes to remove fiber and latex. Any latex that enters the sewer lines tends to form strings and can cause appreciable deposits.

The pH of carpet wastes is usually close to neutral.

With the lack of other wet processing steps in the mill, the hot dye wastes sometimes present a problem to biological treatment systems.

The color problem is similar to that of other finishing categories.

Where carpets are printed, the thickeners present a high BOD load, as in fabric printing.

Category 7 - Yarn Dyeing and Finishing

Wastes generated in yarn processing plants will depend substantially on whether natural fibers, blends, or synthetics alone are processed.

When synthetics alone are handled, only light scouring and bleaching is required, and wastes would be low levels of detergent, soda ash, sodium phosphate, and perhaps a low bleach level. Wastes for this step would have low BOD, and dissolved solids. Dyeing would contribute a stronger waste, primarily due to carrier in the case of polyester, and to some acetic acid; wastes, of course, would contain some color.

Scouring, bleaching, and mercerizing of cotton generate BOD and color because of the fiber impurities, and a high level of dissolved solids because of the mercerizing. Because of the relatively low amounts involved, it does not appear reasonable to recover caustic soda.

SECTION VI

SELECTION OF POLLUTANT PARAMETERS

Selected Parameters

Selection of pollutant parameters was based on the EPA study which recommended effluent levels, tentative (Denver Guidelines); the American Textile Manufacturers Institute study which followed publication of the EPA document; on discussions with state water pollution control officials, concerned industry personnel, and internal ADL consultants; and on literature data. The following list of chemical, physical and biological pollutants was developed:

BOD5	pH
COD	Color
Suspended Solids	Alkalinity
Phenols	Temperature
Oils and Grease	Sulfides
Ammonia and Nitrate Nitrogen	Chromium
Phosphates	Other Heavy Metals
Dissolved Solids	Coliform Bacteria
Toxic Organic Chemicals	

These pollutant parameters have been identified in the industry's wastewaters; however, no category of the industry is known to have all of these pollutants present in its wastewaters. Pollutants used in cooling systems for algae and corrosion inhibition are not included in the above list although these might be encompassed in several of the parameters. It was assumed that effluent limitation guidelines developed for steam-electric power generation would be applicable to cooling towers. Similarly, in the case of backwash water from water treatment plants, it was assumed that guidelines developed for water treatment would be applicable.

Specific Pollutants

BOD5

The organic chemicals used in the industry uses are known to have a wide range of biological oxygen demand, varying from completely biodegradable compounds such as starch to highly refractory compounds such as dyes.

Concentrations of BOD5 in the raw wastes may vary from about 50 mg/liter to 3000 mg/liter. The values depend on the fibers processed, the chemicals used, and on processing methods.

Oxygen demanding portion of the wastes are treatable biologically, with only a few exceptions. The ease and degree of removal in a given time are quite variable.

COD

The chemical oxygen demand test is one method for determining carbonaceous substances; the COD concentration of wastewater streams from an industry with a significant amount of organic wastes would be expected to be high. Although the data base for evaluation is limited, the variability of COD appears to be high. The removal of chemical oxygen demand to the same efficiencies as BOD in a biological system is not at present attained. The efficiency of COD removal is specific to individual chemicals and processes and cannot be generalized for the industry.

Suspended Solids

Suspended solids are present in textile wastewaters as a process waste generated from the fibrous substrate, the chemicals used, and the biological treatment. Most of the solids may be removed in clarifiers, in settling basins, by filtration, or by other techniques.

Chromium

Selection of chromium as a pollutant parameter is based on its wide use as an oxidant in the form of sodium dichromate for vat and sulfur dyes and as a component of wool dyes. Substitutes are available, and several mills are abandoning its use, but it is still widely used.

Other Heavy Metals

Copper salts are still used in some dyeing operations of the textile industry. Since it is toxic in biological systems, it should be considered as a pollutant. Zinc nitrate is widely used as a catalyst for durable press goods, and small amounts will enter waste systems. Magnesium chloride may be used in the same process. Mercury was con

sidered because of its known occurrence in raw materials such as sodium hydroxide which is used in large amounts by the textile industry. In

normal operation, we would not expect the concentration of these materials in the wastewater to exceed the toxic limits.

Phenols

Phenols are widely used as carriers in dyeing polyester and blends. Some dye compositions (naphthols) will probably analyze as phenols also. In addition, some natural materials, such as lignin residues removed in scouring cotton, probably analyze as phenols.

Sulfides

Since sodium sulfide is used in one type of dyeing, and other sulfur containing chemicals are used, it was presumed that sulfides should be considered among the parameters. Small amounts of sulfides may be generated in processing wool.

pH

The variations in pH cannot be characterized across the industry since some processes require highly acid conditions and others highly alkaline. Neutralization is practiced where pH control is necessary to prevent adverse effects in biological waste treatment systems.

Color

Color is a major pollutant in the textile industry. Some color is water soluble and some is not (dispersed dyes). Biodegradability is highly variable. Many hues are used in dyeing, and all may appear in wastes; their combination in waste streatms frequently generates a gray or black color. As a pollutant parameter, color is an aesthetic rather than a toxicity problem, and there is no universally accepted monitoring method, although several techniques are being tried.

Alkalinity

Although many mills will continue to use alkalinity to follow treatment plant operation, we do not believe this parameter is warranted as a guideline.

Dissolved Solids

Dissolved solids, essentially inorganic salts, are an integral part of several textile processes. (See Chapter IV.) Some organic salts, such

as sodium acetate, are also present. Concentrations of dissolved solids can vary from only slightly greater than the level in the incoming water to perhaps as great as 5,000 ppm in wastewaters in certain segments of the industry.

Phosphates

Phosphates are widely used, particularly in scouring processes, and may also be added as nutrients to biological treatment systems. Phosphates form part of the total dissolved solids, but their importance in organism growth warrants special attention as a pollutant.

Oils and Grease

Grease is a substantial pollutant in wool scouring; in other textile categories, it is much less troublesome but may still be significant.

Ammonia & Nitrate Nitrogen

Nitrogen from textile processes as well as from the aerobic digestion of waste biological sludges may appear in wastewater as ammonia or nitrate nitrogen because of the many chemical forms it may enter into (the result of biological activity). Additions of ammonia or urea as a nutrient to nitrogen deficient waste is a common practice in the industry.

Coliform Bacteria

Sanitary sewage is a component of many textile waste treatment plants, and is often desired for its nutrient value. Consequently, coliform bacteria may be present in large numbers in raw wastes and in treated wastes. Some states require chlorination to destroy coliform bacteria.

Since fecal coliform organisms are not a true textile waste, we suggest that the guideline should be the same as for sanitary systems with secondary treatment (Federal Register, 38, 82, April 30, 1973).

Toxic Organic Chemicals

Dieldrin, a moth proofing agent used for carpets would fall into this grouping, but this chemical is no longer used. Some carriers, particularly chlorinated benzenes, are toxic and should not be used.

Temperature

Raw waste from many textile mills is hot, but temperature reduction occurs naturally in waste treatment, and temperature of the final effluent should be very close to ambient. Therefore, effluent water temperature does not represent a problem.

Condensed Parameter List

Many but not all of the above pollutant parameters can be observed in wastewaters from the different segments of the industry. The extent of industry data was highly variable.

BOD, COD, suspended solids and pH levels are minimum requirements applicable to the entire textile industry. COD is important but the significance of the test and its limitations are not sufficiently understood at present. Other parameters among the list given above should be measured in the industry categories where they have been identified in the waste effluent as indicated in Table VI-1.

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TABLE VI-1

Pollutant Parameters to be Measured in the Textile Industry

Parameter	Industry Category						
	I	II	III	IV	V	VI	VII
BOD5	x	x	x	x	x	x	x
COD	x	x	x	x	x	x	x
Total suspended solids	x	x	x	x	x	x	x
Chromium	x	x	x	x	x	x	x
Phenol		x		x	x	x	x
Oil & Grease	x	x					
pH	x	x	x	x	x	x	x
Sulfides	x	x	x	x	x	x	x
Color	x	x	x	x	x	x	x

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SECTION VII - CONTROL AND TREATMENT TECHNOLOGY

Wastewater Treatment Technology

The technology for control and treatment of waterborne pollutants in the textile industry can be divided into two broad categories: in-process and end-of-pipe. In-process control of waterborne pollutants in turn depends upon two major conditions: (1) altering the process requirements that generate water pollutants, and (2) controlling water usage in non-process as well as process areas. For example, pollutants can often be kept from entering water streams through the institution of better housekeeping procedures, containment of leaks and spills, good maintenance practices, and the segregation and treatment of selected concentrated wastewater streams.

At present, the textile industry is concerned principally with end-of-pipe treatment of its wastewaters. However, the application of wastewater treatment technology has often been instituted without detailed investigation of the alternatives to water and wastewater management within the process operations. This approach, of course, is a natural one to follow since institution of in-process changes for an operating plant is frequently time consuming and expensive. Furthermore, the incorporation of in-process control of waterborne pollutants demands attention to specific operations which are often proprietary whereas end-of-pipe wastewater treatment technology is based on generally similar principles which are available from consultants, equipment manufacturers and the company's own competitors.

The textile industry relies principally upon biological treatment of its wastewaters at the end-of-pipe. A large number of plants, especially small ones, send wastewaters into municipal sewage systems where they may be a minor portion of the total flow; however, in some instances the wastewater flow to a municipal plant is predominantly wastewater from textile plants.

Evaluation of data obtained from the plants surveyed indicate that the operatio biological systems is extended aeration, since no plant had an average residence time in the aeration basin of less that 17 hours. The consequent operating conditions are reflected in the relatively low levels of BOD5 per 28.32 Cu m (1000 Cu ft) of aerated basin as well as the low power inputs per kg (lb) BOD removed. This results in low rates of BOD5 removal per unit energy input to the aerators and relatively small amounts of excess sludge because of the high degree of oxidation of the

biologically active substances.
Where data on correlation of mixed liquid suspended solids were available, these were found to be within the usual range for extended aeration. The plants ranged in size from a 3.785 Cu m/d (1000 gpd) pilot plant to a 43,906 Cu m/d (11.6 mgd) plant. Although there is little necessity for equalization basins to ameliorate the effects of flow variability, some operational problems are unique to the textile industry as discussed in the following paragraphs.

Removal of fibers from the wastewater prior to their entering the aeration basin is often necessary to prevent floating scum from building on the surface of the basin or to prevent the aeration equipment from malfunctioning and reducing oxidation efficiency. Usually, these fibers are removed satisfactorily through the use of bars or screens.

The wool scouring portion of the textile industry must cope with the most severe wastewater treatment problems within the textile industry. This results from the high concentration of greases, salts, and other substances that are removed from the wool during scouring. The wool scouring wastes must be pretreated prior to putting them through the biological system. The high concentration of greases that are strongly resistant to biological degradation requires physical-chemical treatment ahead of the biological system. The greases are usually emulsified during the scouring with soap and detergents and consequently, present a severe removal problem.

Many treatment methods have been proposed and investigated at laboratory levels. Those which are used most frequently are based on the use of acids (to help break the emulsion) or centrifuges. Heating, filtration, sedimentation, etc., are employed to separate the greases; however, the reduction of greases to very low levels was not observed in any plants. Furthermore, discussions with industry personnel indicated that a broad spectrum of removal methods had been tried, but with no outstanding commercial success.

Suspended solids are removed from biologically-treated wastewater by gravity sedimentation. The concentrated slurries are recycled to aeration basins while the overflow from the clarifier goes to lagoons for further polishing or discharge to the receiving stream. Because of colloidal particulates from certain operations, chemical coagulation is required prior to biological treatment. This operation is usually carried out by the addition of coagulating chemicals and/or the use of coagulant aids to improve gravity sedimentation. In general, the clarifiers used in the textile industry are designed for overflow rates

considerably less than those usually found in biological treatment systems today. The average for 16 wastewater treatment plants was 15.4 Cu m/sq. m-d (378 gpd/sq. ft.) which is approximately 60 percent of the design values usually found acceptable. Excluding one extremely high value of suspended solids concentration, the average concentration of suspended solids from 25 plants was 57 mg/l. This concentration in conjunction with the aforementioned low clarifier overflow rates, indicates that the removal of suspended solids by gravity sedimentation is difficult.

The principal parameter for measuring the performance of the textile industry's wastewater treatment plants is the reduction in biological oxygen demand across the system as measured by the BOD5 test (7.1, 7.2). Excluding the high BOD5 values for wool scouring-- category 1, the average BOD5 concentration of the remaining plants was 21 mg/l, running from a low of 2 to a high of 83. Of this group only approximately 20 percent exceeded a 30 mg/l standard being recommended for municipal sewage treatment plants (7.3).

These data show that exemplary wastewater treatment plants for six of the seven categories are being operated to give values of BOD5 in the treated effluent comparable to or better than those generally accepted for treatment of municipal sewage. Of course, this performance is being achieved under operating conditions that differ from those for sewage. In effect, many of the wastewater treatment plants are being operated as a two-stage biological system since polishing lagoons of various residence times follow the aerated basin.

The long residence time in the aeration basins and polishing lagoons of the plants surveyed implies that land availability was of no grea# concern.

Chemical oxygen demand (COD) is measured less frequently than BOD5 since the later is the parameter of major concern to present regulatory agencies. As in the case of BOD5, the COD of wool scouring waste is greater than that of wastewaters from other categories, both on a concentration basis and as units/unit of production. Exclusive of the wool scouring waste, the industry's average COD for the plants surveyed is 222 mg/l with a low value of 68 mg/l and a high of 427 mg/l. The ratio of COD to BOD5 increases significantly across the wastewater treatment plants, which indicates the refractory nature of some of the components of the wastewaters. Although COD is probably a better measure of the pollutant level of wastewaters, other parameters such as total organic carbon (TOC) or total oxygen demand (TOD) might be even more indicative (7.4 - 7.7). No data on the latter two were obtained.

Although the ratio of COD to BOD is generally recognized as an indicator of the biologically refractory nature of wastewater pollutants, the variability in this ratio is affected by many factors, and one of the most important is the capabilities of a specific biological system to degrade carbonaceous substances. For example, PVA, one of the biggest sizes used in the textile industry, is considered to be essentially refractory in terms of its loading on an activated sludge plant, 1 percent BOD, whereas the theoretical oxygen demand is 36 percent. This would indicate that only 3 percent of the PVA is normally attacked in a five-day BOD test, or loosely speaking, 97 percent of it would pass unaffected through an activated sludge plant (7.8). Recent data shows that this is not the case; in some activated sludge plants where the organisms have become acclimated to the PVA, substantial PVA reduction is achieved. For example, Blair Mills, Belton, South Carolina, consistently shows over 90 percent reduction of PVA in its extended aeration (5 days) activated sludge plant (7.9).

Other waste treatment plants report varying amounts of PVA removal and some unpublished laboratory work indicates that up to 20 days residence time in an activated sludge is required for effective removal. Obviously, one of the big differences between waste treatment plants, with respect to effective removal of PVA is the different types and relative proportions of each microorganism that eventually evolve in the individual activated sludge plants, because of the different types of raw waste loads.

From the above discussion, it can be seen that the biological refractivity of certain carbonaceous substances may be uniquely a function of the biological system acclimated to a specific wastewater composition. Nevertheless, an indication of the COD concentration that might remain in a biologically-treated wastewater can be obtained by assuming that the COD test is composed of the sum of two components: (1) the biologically degradable carbonaceous substances in the wastewaters, and (2) the non-biodegradables. This is tantamount to the following equation:

$$COD_{measure} = COD_{non\text{-}degradable} + b(BOD5)$$

where b is the conversion factor for BOD5 to COD. From this relationship where both influent and effluent analyses for COD and BOD5 were available, the values of COD non-degradable and b were calculated as well as the estimated COD at 15 and 30 mg/l of BOD5 (Table VII-1).

This approach indicates that if all of the BOD5 contributors were removed

from the wastewaters only three of the plants would achieve COD concentration levels less than 100 mg/l. Whether this would indeed occur in a biologically active system with sufficient residence times to lower the BOD concentration to near zero is problematical since only truly non-biodegradable substances would report as CODND. Nevertheless, this approach is believed to indicate the carbonaceous substances that might be expected in the effluents from wastewater treatment facilities operating with the best practicable technology currently available.

The wastewaters from the textile industry usually contain ample phosphates which are available as nutrients for the microorganisms of the biological system. Indeed, there is more apt to be an excess of phosphates, due to

Table VII-1

Calculated Values of COD Non-degradable

Category	Plant	Slope b	CODND (mg/l)	COD at 15 mg BOD5/l	COD at 30 mg BOD5/l
I	A	3.41	1,700	1,750	1,800
	B	4.26	437	500	565
II	C	2.13	82	113	145
	D	1.87	142	169	197
	E	4.87	19	92	165
IV	M	1.62	174	198	222
	L	1.48	182	203	226
	O	2.56	172	210	247
	S	3.27	70	119	168
V	W	2.85	270	312	355
	Y	1.75	398	424	450
VI	BB	4.59	203	271	341
	CC	0.75	439	450	461
VII	GG	0.96	60	74	88

the high usage of detergents, and a deficiency of the nitrogen necessary for maintaining a viable biomass in the system. Consequently, nitrogen, in the form of nitrates or ammonia, usually must be added to the wastewaters to maintain high removal efficiencies in the treatment plant.

Textile process operations often require high-temperature water, however, heat reclamation is also widely practiced as a matter of economics so the wastewaters sent to the treatment plants usually do not present any significant thermal shock problems. Furthermore, the long

residence time generally found in the wastewater treatment systems serves effectively to prevent rapid changes in temperature. The most important temperature effect is not expected to be high temperatures, but low temperatures. In northern areas, the low wintertime temperatures in biological treatment systems will materially reduce the biological activity and thus the efficiency of BOD5 removal.

Color in the wastewaters of the textile industry is inherent in the nature of the operations. Since color chemicals are specifically formulated for resistance to degradation under the oxidizing conditions of the world, it is not surprising that removal of color in aerobic biological systems is erratic. Although color concentration normally is reduced somewhat in the biological systems surveyed, data obtained were in arbitrary units, most often APHA(Y) standard. Color removal efficiency is known to be highly specific to the individual plant and the particular processes being operated at a given time. Although a number of research and development projects have been carried out, there is no one generally accepted method for color removal. Use of adsorptive technology--such as flocculation and activated carbons--and anaerobic treatment appear to offer the best possiblity for removing color; as noted earlier, however, the effective application depends upon specific knowledge about individual wastewater streams. Chemical oxidation by chlorine, ozone, etc., has been tried, as well as ion exchange, electrodialysis, ultrafiltration, and reverse osmosis. These treatment techniques are discussed in detail in Section VII-6.

Chromium is the most significant heavy metal of concern in the textile industry although others are employed selectively. There is good evidence that at low levels of chromium in the raw waste (less than 15 ppm) an activated sludge treatment plant removes a substantial portion. Reference 7.12 states that 50 ppm of Cr+6 fed continuously lowers the BOD removal efficiency of a waste treatment plant by only 3 percent.

Pollution experts within the textile industry have noted that chrome removal across a waste treatment plant is proportional to the amount of BOD removed (more specifically the excess sludge removed) and is inversely proportional to the amount of suspended solids carried over in the final effluent from the secondary clarifier.

The removal of chromium ions by chemical treatment methods is well known although it was not found in the textile plants surveyed. It is apparent that such systems will have to be applied at plants using chromium. One of the simplest chemical system involves reducing the Cr+6 using SO2, and precipitating the resulting Cr+3 with NaOH, which is sent to a settling lagoon. Good practice is to carry out the chemical

precipitation of the chrome on the segregated streams that have chrome, and feed the effluent from this system to the activated sludge plant for treatment for BOD.

Wastewaters from ancillary operations such as cooling towers, steam generating facilities and water treatment plants may be significant factors in the wastewater volumes emitted from the textile industry. In those instances where one must handle cooling tower and boiler blowdowns that contain corrosion inhibiting chemicals, algacide and biocides, the technology for selective removal is usually available. Of course, the best practicable control technology currently available for process wastewaters will not remove soluble inorganic salts which predominate in these blowdowns. Toxic and hazardous substances in these systems can be controlled either by eliminating them, replacing them with less toxic and hazardous substances or treating isolated streams to remove them. Selection of a course of action to cope with toxic and hazardous materials in these blowdowns is more a question of economics than a question of technology.

Reliability, operability and consistency of operation of the wastewater treatment processes found to be most frequently used in the textile industry can be high if appropriate designs and operational techniques are employed. The end-of-pipe treatment utilizing extended aeration biological systems is a well established technology that requires attention to a limited number of variables to insure a high degree of reliability. Although many variables can affect the operability of a biological system, in general the best overall performance is achieved when the highest consistency of flow and wastewater composition occurs.

Since the textile industry is predominantly a batch type process operation rather than continuous, such as the petroleum or petrochemical industry, it follows that both flow rates and wastewater composition will vary significantly. That the industry recognizes this variability is apparent from the nature of the wastewater treatment systems, i.e., long residence time systems which hold sufficient volumes so that high instantaneous flow rates or high concentrations can be rapidly equalized to prevent "sharp loading" of the biological system. Removal of greases, oils and fibers, and in certain instances control of pH, prior to aeration preconditions the wastewaters for most effective operation of the biological system.

The most important operational aspects of these extended aeration systems are equipment reliability and attention to operating detail and maintenance. Spare aeration equipment (usually floating surface aerators) improves the possiblity of consistent operation; however, many

treatment systems have an adequate overcapacity already installed as insurance against the results of equipment failure. In general, auxiliary power for operation of the wastewater treatment system would not be required unless the plant was equipped with a source of auxiliary power and could, therefore, keep operating despite failure of the primary power source. Operability and consistency of performance could be improved if parallel treatment systems existed, each of which was capable of handling the total load. However, this is rarely justifiable on either an economic or practical basis; it is more desirable to install spare equipment at critical points, for example, sludge return pumps. Perhaps of equal importance is a design that permits rapid and easy maintenance of malfunctioning equipment.

Therefore, control of the biological treatment plant and the consistency of the results obtained are largely a matter of conscientious adherence to well-known operational and maintenance procedures. Automatic control of biological treatment plants is far from a practical point. Although in-line instrumentation for measurement of pH, dissolved oxygen, temperature, turbidity and so on, can improve the effectiveness of operation, its use is minimal in the textile industry's existing wastewater treatment plants. Nevertheless, no practical in-line instrumentation can replace the judicious attention to operational details of a conscientious crew of operators.

In Process Control

Ancillary Process Control Technology. A big portion of the textile waste loads is inherent in the methods of textile processing and independent of the efficiency of the processing plants. For example, size is applied to warp yarns to give them mechanical strength in the weaving operations; all of this size must be taken off before subsequent bleaching and dyeing. A finishing plant can use variable amounts of water in removing this size, but the raw waste load due to size is unchanged. The same applies to spinning finishes on synthetic fibers, which are put on the yarn as a lubricant and to reduce static in the high-speed spinning and textile operations. All of these "temporary" finishes must be removed before dyeing of the yarn, so again the raw waste load is almost independent of scouring efficiency.

Although these "base" raw waste loads are constant, a plant can reduce the other raw waste loads--such as spills, reworks, etc.--in many ways. These are considered below.

The principal axiom in reducing the waterborne pollutant loads through control external to the process is to prevent pollutants from entering

the water streams. Although this seems obvious, its successful application requires continual attention by operating personnel. In fact, it is synonomous with creation of an effective work safety program. In the textile industry, with its large number of batch operations, one of the most important aspects of reducing waterborne pollutants is to institute an effective water management program--including expanded use of liquid-level-controls, flow indicators and flow meters, adequate capacity for generating hot water for wash operations, etc.--in conjunction with a good maintenance program which will insure that leaks from valves, pipes, pumps, etc., are promptly repaired so as to prevent process fluids from entering floor drains, etc. Except for category 1 the concentration levels of pollutants at the inlet to the wastewater treatment plants are not excessively high for industrial wastewaters (an average BOD5 of 347 for 25 plants). Consequently, a significant reduction in hydraulic capacity should normally effectively lower the total emitted pollutants from a given wastewater treatment plant even if the concentration level in the effluent rose moderately. Obviously, if process operations can be changed to reduce the pollutant load to the waste water treatment plant simultaneously with a reduction in hydraulic flow the emitted pollutants will be reduced even more.

The textile industry is not a large volume handler of liquid chemicals that would be water pollutants if storage tanks failed catastrophically or if spills or leaks occurred during loading and unloading operations. Consequently, the need for curbing and diking to prevent entry of spilled or leaked liquids into waterstreams is not as great as in other industries. However, where significant quantities of liquid chemicals are stored and handled, provisions should be made for containment in the case of accidents. Alternatively, provisions could be made for draining to catch basins or, if appropriate, to the wastewater treatment plant. Procedures and methods for preventing spills and leaks should be the pramount consideration, but passive systems for containment or preventing their entry into water courses should be part of any control plan. Only through assessment of the potential for pollutants to enter water streams from accidential occurences and the development of action plans is it possible to develop a high degree of assurance that spilled liquids will be prevented from polluting water courses.

In summary, strict attention to housekeeping procedures and process operation, can minimize abnormal waste loads.

<u>Conventional Processing With Better Water Economy</u> The greatest potential for improved water economy in the textile industry stems from the use of better washing methods. About 80 percent of all the water used in textile wet processing is used for removing foreign material--either

that carried on the raw fiber, or materials resulting from treating operations such as sizing, scouring, dyeing and finishing. Furthermore, most applications of treating materials are already carried out at low liquor ratio for the sake of material and time economy. It follows that important water economies in conventional processing can be made only by reducing the amount of wash water.

It is clear that in some segments the opportunities for water economies in washing should be considerable. For example, a typical cotton bleaching sequence calls for washing the fabric six times (following desize, scour, bleach, mercerize, dye and finish steps). Although washing requirements differ from step to step, we shall assume that at each of these steps the fabric must be washed 99 percent free from the last treating solution. At one extreme, simple dilution would require 45.4 kg (100 pounds) of water for each .454 kg (pound) of contaminant to be removed or 272 kg (600 pounds) of water per .454 kg (pound) of fabric through the 6-step process. This amounts to some 265 l (70 gallons) of water per .454 kg (pound) of fabric. On the other hand, a 20-stage extraction could reduce contaminants by 99 percent by the use of only about .91 kg (2 pounds) of water per state of 5.4 kg (12 pounds), say 5.7 l (1.5 gallons), per .454 kg (pound) of fabric through six stages. It is to be emphasized that no washing machine in actual use or conceptualized in mechanical design at this time can approach 20-stage performance. Existing methods frequently use about 9.1 kg (20 pounds) of water or more per stage, or about 54.5 kg (120 pounds), 57 l (15 gallons), per .454 kg (pound) of fabric through six stages.

It is relatively easy to conceive of fabric washing devices that achieve some of the theoretical water savings. The problem is to make machines that are reasonable in cost; not damaging to the relatively fragile fabric surface; easy to thread up, capable of accommodating a range of fabric widths, weights and types; and durable enough for continuous high speed operation. In the past generation a good deal of progress was made in washer design. The Tensitrol machine and the Williams-type high turbulence open-width machine are examples. Driving force for these improvements in performance was, in general, need for improved washing effectiveness per machine (with resulting saving in floor space and capital expense) and need for machines which minimized adverse effects on the fabric, especially effects due to excessive tension and abrasion. Water economy was not a high priority in the design, since textile mills were usually located near abundant water supplies.

Water usage can be improved substantially as design engineers take water economy into more active consideration. For example, so-called "double laced" box washers have recently been introduced, with claimed savings

of up to 40 percent in number of machines (7.14). Significant water savings are claimed, but detailed quantitative data are not available. More complex open-width washing machines designed to induce greater turbulence, have been offered without great success. Since the physical aim to be accomplished is clear, i.e., breaking down an effective thick diffusion film in the fabric interstices, it is likely that more efficient open-width machines can be developed. The problem is to provide suitable incentives for the development, testing and use of such machines.

Rope washers generally are more effective than open-width washers, but may be suspectible to further improvement if back-mixing can be controlled in a practical manner.

In addition to better washer design, there are opportunities for water economy in more counter-current flow. A finishing plant operator prefers to use fresh water at every machine, for ease of control and adjustment, and for freedom from danger of cross-contamination. However, some opportunities for counter-flow are neither unduly difficult nor hazardous to quality. For example, it is almost always acceptable (but not always practiced) to counter-flow water from machine to machine where several machines are used in series at the same point in the process. For example, it is common to use 5 or 6 or more open-width box washers in series after scouring or mercerizing operations, or two Tensitrol-type rope washers after scouring operations. It is best for water economy to counter-flow the water through the series. This is frequently but not universally practiced today. Furthermore, it is almost certainly practical to counter-flow water from some later stages to some earlier stages. For example, white washer effluent can almost certainly be used as feed water for caustic washers. Additional opportunities for backflow of water also exist. However, there are limitations; wash water from dyeing operations, for example, always contains color, and is generally unsuitable for re-use without cleanup. Caustic scour and desizing wash waters are heavily laden with dissolved and suspended solids and unsuitable for re-use.

In principle, water cleanup could be used around particular machines or groups of machines, thus extending water economy still further. Preliminary consideration of investment and operating costs indicates that this is generally less conomical than pooling effluents and operations of one large treating plant. Closing of water cycles around individual operations or groups of operations will probably be limited to very special circumstances.

In summary, it is reasonable to suppose that further water economies can be achieved by machine improvements and by wider use of counter-flow.

New Process Technology

Solvent Processing

Serious study of textile processing in organic solvents dates back at least 15 years, although batch applications of special finishing, such as water repellants has been practiced for more than a generation. In the late 1950's, Imperial Chemical Industries pioneered a solvent system for continuous scouring of cotton piece goods. Several large machines of this type have been operated in the United States at various times since 1960. During the 1960's, a number of continuous solvent scouring and finishing ranges were devised and tested in Europe. In most of these cases the development work has been carried out by solvent suppliers or equipment manufacturers.

In the course of this work it has become clear that chlorinated solvents such as perchloroethylene and trichloroethylene are the most advantageous materials now available. It has also become clear that suitable machines can be manufactured and operated so as to control air pollutions in the work space. Solvent loss remains an economic problem. Extremely tight control is needed to keep solvent loss per operation below 5 percent of fabric weight. To date, there has been no appreciable commercial use of solvent finishing for woven goods. However, solvent processing has established a firm if specialized position in knit fabric finishing, especially in the finishing of synthetic knits.

Solvent processing has found commercial use only where superior fabric properties have been achieved. For example, solvent applications of stain repellent finish to upholstery and drapery materials are widely practiced. In this case, aqueous treatment is not always possible, because the fabric is sensitive to water. Similarly, solvent scouring and finishing of synthetic knit fabrics is widely practiced because it is, in these cases, advantageous to quality to avoid wetting with water. Some finishes, furthermore, are not available in water soluble or dispersible form and can be used only in solvents.

On the other hand, very substantial research and development efforts in the last decade or so have not led to replacement of aqueous processing to any appreciable extent. Some of the important problems are summarized below.

It is obviously an immense task to introduce solvent processing (or any other completely new processing means) throughout a whole, complex textile scouring, bleaching and finishing process. Aside from investment considerations, whole families of solvent-compatible reagents, dyes, and finishing materials are needed. At present, these are generally not available.

Given the above situation, it is natural to consider piecemeal introduction of solvent processing, starting with the most advantageous or easiest uses. Because the useful solvents are expensive, about $1500.00 per 3.785 cu m (thousand gallons), and toxic, they must be carefully contained during processing, and recovered as completely as possible. Also, residues from scouring operations or from spent reagents must be removed from the solvent (usually by distillation) collected, and dealt with. These solid or semi-solid residues can be difficult. For example, they usually contain some chlorinated solvent residue which complicates disposal by either incinerator or land fill routes.

Adoption of a complete solvent processing scheme avoids the problem of dealing with both aqueous and solvent wastes. As noted above, however, a complete line of textile processing and finishing compounds would first be required. Some thousands of different dyestuffs and chemicals are now used in commercial textile processing. Only a limited number can be directly transferred to solvent use.

On the grounds noted above, it is becoming clear that solvent processing generally will be introduced only as superior results are demonstrated. In general, this implies better properties in the finished fabric, although processing advantages may lead the way in a few cases. The prospects for solvent processing are outlined below for each of several important finishing steps.

Solvent Desizing. Solvent sizing and desizing are discussed in a later section.

Solvent Scouring

Woven Fabric. Despite intense effort (7.15, 7.16) solvent scouring of woven fabrics has not established a firm place. The properties of solvent scoured fabrics are not generally superior. The wastes generated are the same with respect to organic content, but, of course, free from the alkali generally used for aqueous scouring.

Knit Fabric. Solvent scouring of some synthetic knit fabrics is well established and growing. Commercial use is based on superior results, fast drying (compared with water) and easy extension to specialized solvent finishing. Contribution to water pollution abatement is modest because scouring of knits does not contribute very heavily to textile pollution loads.

Bleaching. It is possible to bleach from solvent sytems and large scale demonstrations have been carried out (7.15). However, the process used generates both aqueous and solvent wastes. No advantages have been demonstrated with respect to fabric properties.

Dyeing. A very large effort has been devoted to solvent dyeing. Some fibers are commercially dyed from solvent systems, notably nylon sportswear and carpets by the STX beam dyeing process (7.16). The advantages and limittations of solvent dyeing, both practical and theoretical, were discussed at length in a January 1973 AATCC Symposium. Collected papers, available from the American Association of Textile Chemists and Colorists Research Triangle Park, North Carolina, 27709, should be consulted for details. Although many important textile fibers can be dyed from solvent systems, practical applications will apparently be limited to special cases.

There are not grounds for broad reliance on solvent processing to solve current liquid effluent problems arising from dyeing operations.

Finishing

Woven Goods. It has been shown that many functional finishes can be applied from solvents (7.17, 7.18). Some advantageous properties have been demonstrated, but no practical use has been achieved. It is believed that advantages shown so far have been insufficient to justify a changeover from the familiar aqueous systems. In any event, chemical finishing is but a modest contributor to textile effluents, since the aim is to capture a very high fraction of the active agent on the cloth.

In special cases, i.e., water-sensitive fabrics, solvent finishing has become fairly standard practice. Application of stain and soil resist finishes to upholstery fabrics is a typical example.

Knit Fabric Finishing. Synthetic knit fabrics lend themselves admirably to combination scouring and finishing from solvents. Some modern finishes such as silicone polymers for single-knits, can be applied only from solvent. In other cases, solvent processing recommends itself because of ease and speed of drying, or because of superior properties

developed by solvent finishing. Although much of this development started with batch operations in dry cleaning machinery, high developed continuous processing machines are now available from several manufacturers, both domestic and foreign. It is clear that solvent processing of knit fabrics is established and growing.

In summary, solvent processing is clearly finding a place in modern textile processing. There are, however, no grounds for supposing that aqueous processing will be totally displaced by solvent processing.

Recovery and Re-use of Warp Size

Most woven goods require the use of warp size during manufacture. The sizing, traditionally starch, coats the warp yarns and binds the individual fibers together. This action is necessary to preserve the warps from excessive abrasion damage during weaving. The sizing is generally removed as the first operation in the fabric finishing sequence. Warp size constitutes, on the average, about 5 percent of the weight of the fabric, and it all ends up in the effluent waters. Accordingly, it is a very substantial contributor to the total BOD and COD in textile mill effluents. Sizing waste accounts for about half the total BOD and COD load from textile operations.

Since the advent of synthetic fibers, newer sizing agents have been developed. A solubilized cellulose derivative, and polyvinyl alcohol have been widely used. At this time, PVA, alone or in blends with starch, is the most popular size for the important cotton/polyester blend fabrics.

Adaption of PVA has led to complications in regard to effluent standards. PVA reports very low values in the conventional BOD5 test. However, it has a higher COD than the starch it replaces. Recent work indicates (7.19) that, despite the BOD5 test results, PVA is degraded extensively in biological treatment plants. Both its alleged treatability and its alleged resistance to attack have been cited as advantages. These questions will presumably be resolved in the near future.

Solvent methods offer one possible route to allocation of the heavy pollution load from warp sizes. The concept is to apply a solvent-soluble polymer, then remove it by solvent washing following weaving and, finally, to recover the polymer for re-use. There is every reason to suppose that suitable polymers can be found. At least two companies (ICI and Dow Chemical) are actively working in this direction (7.20). Early indications are that solvent-applied warp size can be effective.

The future potential of the process depends upon successful recovery and re-use of the size. The most important problem to be expected is in clean-up of the recovered size for re-use. As a practical matter, most woven goods contain natural fiber (principally wool or cotton) and these fibers contain solvent-extractable material.

Since the size is to be used repeatedly, some means to purge impurities is mandatory. While this is a difficult problem, the potential advantages of solvent size and desize are substantial. We believe that solvent size/desize will eventually find practical application. It is unlikely that such use will be based primarily on pollution control, since, as noted above, conventional sizing agents are more or less readily amenable to conventional biological treatment. EPA regulations will, in all probability, lead to universal adoption of secondary treatment of textile wastes and hence more or less complete solution of the size waste problem before solvent size-desize is ready for large-scale use. Consequently, it is likely that adoption of new sizing technology will be based on demonstrated advantages over conventional methods rather than on pollution control considerations alone.

Specific Process Categories

Category 1-Wool Scouring. One of the problems in defining wool scour wastes and in controlling the process for optimum performance is that detergent is added on a fixed flow basis, and the demand for it varies widely with the natural variations in the fleece as received. Future effort may profitably be spent in developing a method to measure the detergent demand and control its addition accordingly; less detergent will be used, BOD load reduced and perhaps a more easily separated emulsion will yield higher grease recoveries.

In addition, in the centrifuge recovery system described, rewashing of the grit for recovery of up to 40 percent more grease than is presently being recovered, appears possible with developmental efforts.

Furthermore, the value of centrifuge-recovered wool grease is higher than that of acid-cracked grease (20¢ per pound in 1973).

Anaerobic treatment of wool grease as a substitute degreasing process has been investigated and found to be promising. However, 68 percent digestion was noted. The apparent success of aerobic methods operating at over 90 percent digestion indicates that further anaerobic development is probably not worth pursuing.

Re-use of the waste treatment plant effluent as make-up water to the scouring train may be feasible. One of the obvious problems is that dissolved salts will build up.

With the resulting more concentrated solutions, incineration and recondensing the water may be economically reasonable. The grease problem precludes present forms of reverse osmosis and other separation techniques.

Solvent scouring has been used to remove the wool grease from the wool. Jet fuel, benzene, carbon tetrachloride, ethyl alcohol, methyl alcohol and isopropyl alcohol have been tried. The problems of flammability and explosive hazards, and of efficiency of solvent recovery have prevented its use in the United States.

Solvent scouring requires subsequent detergent washing to remove the dirt. More efficient methods of grease recovery using the water scouring process appear capable of achieving grease recovery levels comparable to that with solvent methods, and hence would probably offer the better choice for further reducing pollution load in the future.

Category 2 - Wool Finishing. Further effort should be extended to segregating waste streams within the mill. In particular, many of the rinse waters appear satisfactory for reuse both for subsequent initial rinses and for pre-scouring steps and perhaps for fulling rinses. These approaches require careful evaluation because of the tendency for wool fiber to "sour" if soaps and other materials are left on them for many hours. Substantial investments in repiping and in storage facilities are needed to accomplish this water reuse.

Solvent scouring is practiced in several mills in place of initial detergent scouring, to remove spin oils, sizes, and fugitive tints. The savings in detergent costs appear to justify these systems resulting in a lower BOD load and somewhat lower water use.

Category 3 - Greige Mills. Aqueous wastes generated in sizing yarns amount now to machine clean-up and incidental wastes. In one exemplary plant, aqueous wastes were less than 0.8 l/kg (0.1 gal/lb) greige cloth produced. Reduction of wastes at these mills is therefore insignificant.

Category 4 - Woven Fabric Finishing. The possibilities for reducing water consumption in finishing woven fabric were discussed earlier. In this section we will emphasize pollutants other than water.

Scouring, mercerizing and bleaching generate substantial wastes, particularly in textiles containing cotton. Large textile users already recover spent caustic soda and this should be extended to other users.

Better control and automation of dyeing processes could bring about reductions in dye and chemical usage as well as in water.

There is no simple way to reduce the amounts of auxiliary chemicals essential for dyeing, e.g., salts, sodium hydrosulfite and a few others. Some mills are abandoning the use of chromates, and substitutes are generally as effective. The use of pressure becks for dying polyester is increasing, and reducing carrier usage significantly. Printing processes frequently use solvents (Varsol) which can be recovered by flotation and distillation.

Category 5 - Knits. The general comments concerning dyeing and finishing made under category 4 apply.

Category 6 - Carpets. Continuous dyeing has been stated to use 20 to 25 percent of the amount of water used in beck dyeing. Stock dyeing and printing rinse also are similar lower level uses. However, a mill can use a continuous process only if the volume of a given shade is sufficiently high.

If polyester regains as a major face-yarn material, there will be a major increase in raw waste per kg (pound), which can be abated to some extent by the use of pressure dye becks, as in categories 4 and 5, that permit a reduction in the use of carriers and their attendant heavy BOD load.

Complete recycling of water, since water use is centered on dyeing and rinsing in this industry, depends on the same technology developments for removal of dyes and salts that all other finishing categories depend upon.

Category 7 - Stock and Yarn Dyeing and Finishing. Mills in this category scour, mercerize, bleach and dye cotton, or scour and dye synthetic fibers. Possible future developments that might apply to these mills are discussed in this section under category 4.

ADVANCED WASTE TREATMENT TECHNOLOGY

In all categories of textile plants, we assume good secondary treatment, i.e., that activated sludge will be combined with preliminary and possi-

bly post screening and filtration. The definition of advanced treatment systems is therefore confined to tertiary treatment of the secondary effluents, dewatering and incineration of sludges, and possibly to preconditioning of some specialized waste streams to render them compatible with the activated sludge process.

The polluting species that such advanced waste treatment systems must contend with are typified by those commonly experienced in the effluents of category 4 textile plants using modern secondary treatment:

flow	4,000 - 30,000 cu m/day (1-8 mgd)
BOD5	4-30 mg/l
COD	500 mg/l
TSS	300 mg/l
Cr	0-4 mg/l
Phenol	500 mg/l
color	moderate
pH	7-11
alkalinity	800-1300 mg/l ($CaCO_3$)
phosphorous	2-4 mg/l

Source: A. D. Little, Inc., data

The chemical species which make up the BOD, COD, and suspended solids fractions are not well characterized; even less quantified are such other unacceptable characteristics of the effluent as color, foam, nutrients, salts, bioactive agents, and other refractory organics.

In some cases, advanced treatment systems have been tried out on textile wastes and their effectiveness in dealing with these various pollutant parameters has been assessed. In other cases it is necessary to predict their usefulness to the textile industry from experience with other similar waste streams or by an understanding of the physico-chemical principles involved. In most cases, pilot plant work must be done before the effectiveness or cost of advanced treatment processes can be predicted with any confidence for a specific waste stream.

In the past, many advanced processes have been rejected for use in the textile and other industries after some experimentation. However, as pressure increases to achieve maximum pollution control of waste streams, some of the criteria previously used to evaluate methods may no longer apply.

We have grouped the processes under consideration according to the overall chemical or physical mechanism of their operation:

1. phase change
2. membrane separations
3. sorption
4. chemical precipitation

This section describes their general nature, experience with their application to waste water treatment in general, and to textile waste water in particular (if any). (Cost factors are discussed in Chapter VIII.)

Figure VII-1 shows the general schematic for a textile waste treatment process
utilizing advanced treatment. Chemical clarifaction removes suspended solids, much of the residual COD, some residual BOD5, and certain elements of color--particularly dispersed dyes. Sand filtration polishes the clarifier supernatant liquor prior to activated carbon absorption which removes more COD, BOD5, other color elements of the waste stream and certain refractory organics such as phenol. At this stage, the waste stream should contain acceptable levels of all components except dissolved solids; ion exchange removes these. Disinfection with chlorine may be required as a final step.

Other advanced treatment methods may replace one or more of the process steps described. Reverse osmosis removes trace organics--BOD5 and COD--, color, and dissolved solids and may replace activated carbon treatment and ion exchange. Distillation or freezing may replace all tertiary treatment steps except possibly for chemical clarification for certain waste streams. Electrodialysis is a substitute for ion exchange.

Distillation Multistage Flash. The multistage flash (MSF process consists essentially of pumping hot salt, brackish, or contaminated water through suitable nozzles into a chamber in which the temperature and pressure are lower than that of the water itself. Part of the water flashes off instantly as steam which passes through demisters to remove entrained droplets of impurities and condenses on tubing cooled by entering feed water. The distilled water drops off the tubes into a trough and is collected as the product water.

In order to improve the efficiency of the process and recover most of the heat energy a multi-stage system is preferred in which the latent heat from the condensation of the steam produced in the evaporation chamber is used to preheat the cooler feed water flowing in the condenser tubes counter current to the brine in the flash chambers. Thus, the chief thermal energy requirement is that needed to raise the feed water

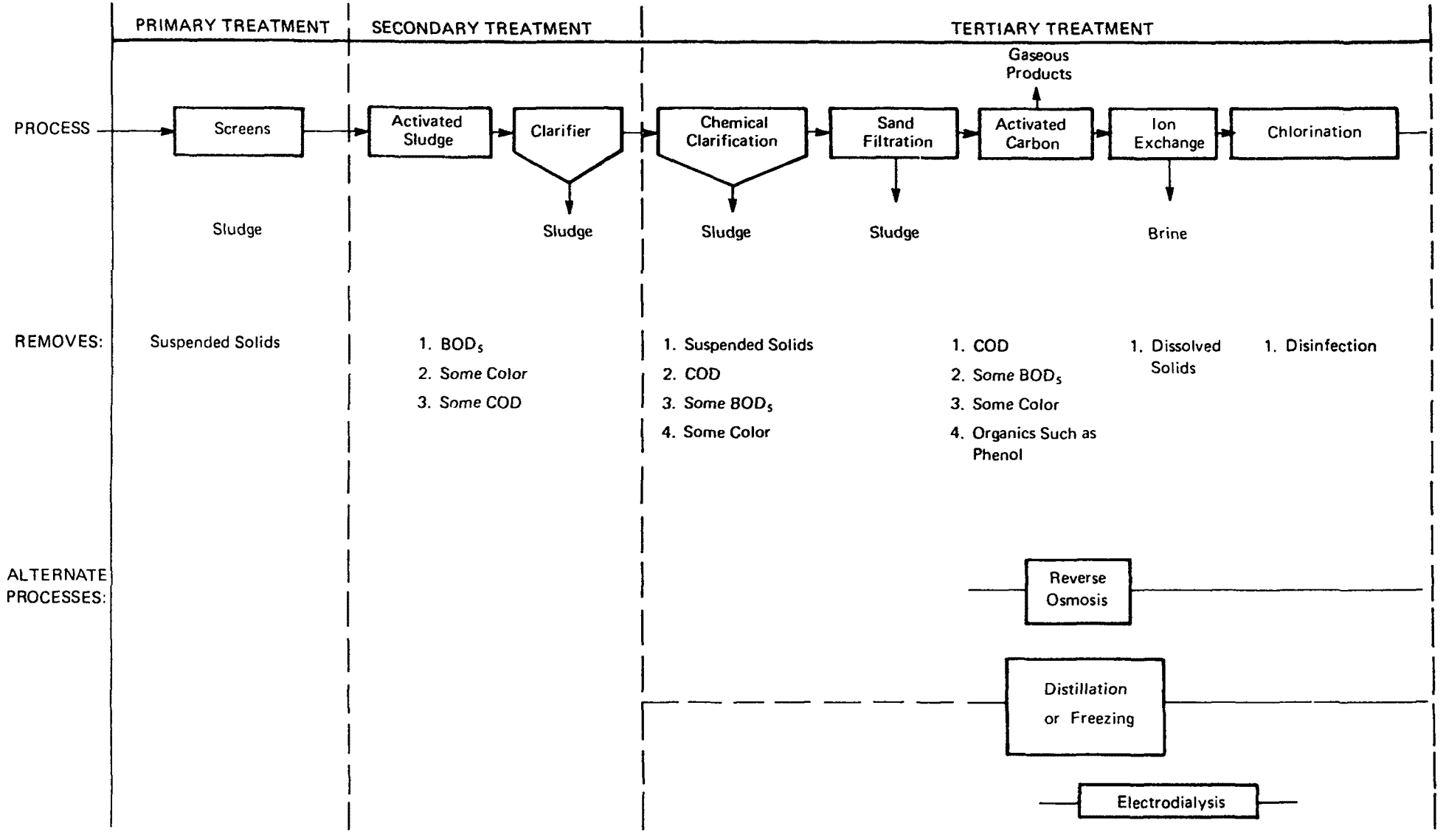

FIGURE VII-1 TEXTILE WASTE TREATMENT USING ADVANCED TREATMENT

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from ambient temperatures to the temperature of the outgoing brine. Figure VII-2 shows a simplified flow diagram of two major types of MSF plants: once-through and recirculation. In a single-purpose plant the steam needed to heat the brine is supplied by a separate boiler designed particularly for the water plant. In dual purpose units, the steam for heating the brine is obtained from the lowpressure side of an electric power plant steam turbine which operates in conjunction with the water plant. This permits certain fuel cost economies but requires coordinated operation of the two plants. Recirculation of the brine improves thermal efficiency considerably and all modern MSF plants are of this design.

In a cross-tube plant, the condenser tubes are placed at right angles to the flow of brine in the flash chambers; consequently, the individual tubes are shorter than in a plant where the condensing tubes are installed through the flash stages in the direction of brine flow. In recent years, however, the long-tube plant has become more popular and condenser tubes as long as 105 feet have been employed. Plant designs using tubes up to 360 feet have been proposed but the difficulties in transportation or fabrication at the site have discouraged their use.

Two types of feed water treatment are generally employed to reduce scale formation, Frequently a proprietary material is used, containing a polyphosphate or polyelectrolyte as the active ingredient. These compounds do not prevent scale from forming but rather modify its character so that it may be easily washed out or dissolved by weak acids periodically. Often acid treatment is used, with sulfuric acid generally preferred. The acid is added continuously to the feed water in small amounts to reduce the pH below 7 and decompose the carbonate compounds that cause hard scaling in the tubes and flash chambers. In many of the units using acid, the carbon dioxide released by the acid is removed in a separate decarbonator placed in the feed water circuit after the reject stages. Otherwise the carbon dioxide is removed with the other dissolved gases by the steam jet deaerator. In modern units steam jet deaerators are used to dearate the flash chambers and to produce a vacuum.

Vertical tube distillation. The vertical tube evaporator (VTE), a long-tube vertical distillation type of desalting plant, is second only to MSF type plants in the total volume of water produced worldwide. The Desalting Plants Inventory Report No. 2 published by OSW lists 96 VTE plants with a combined capacity of 206,000 cu m/day (54.4 mgd) as compared with 229 MSF plants which produced 554,000 cu m/day (146.3 mgd).

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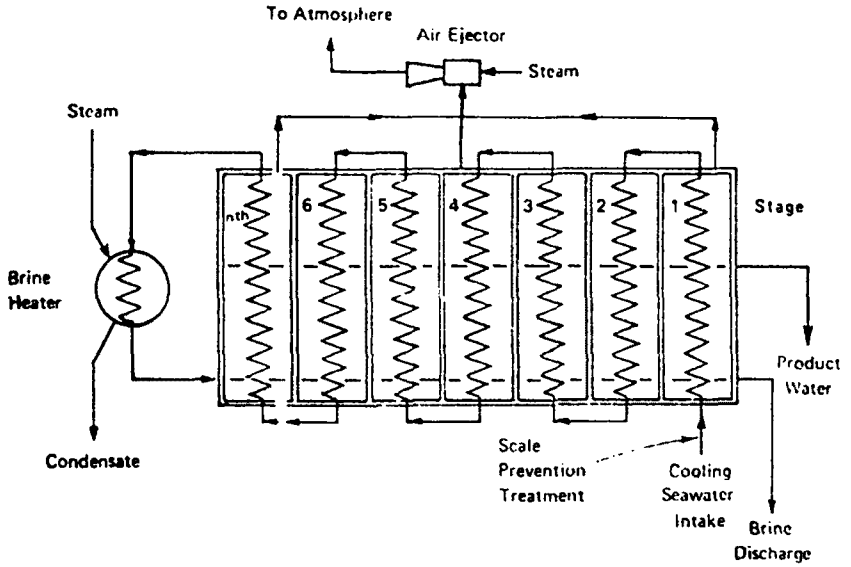
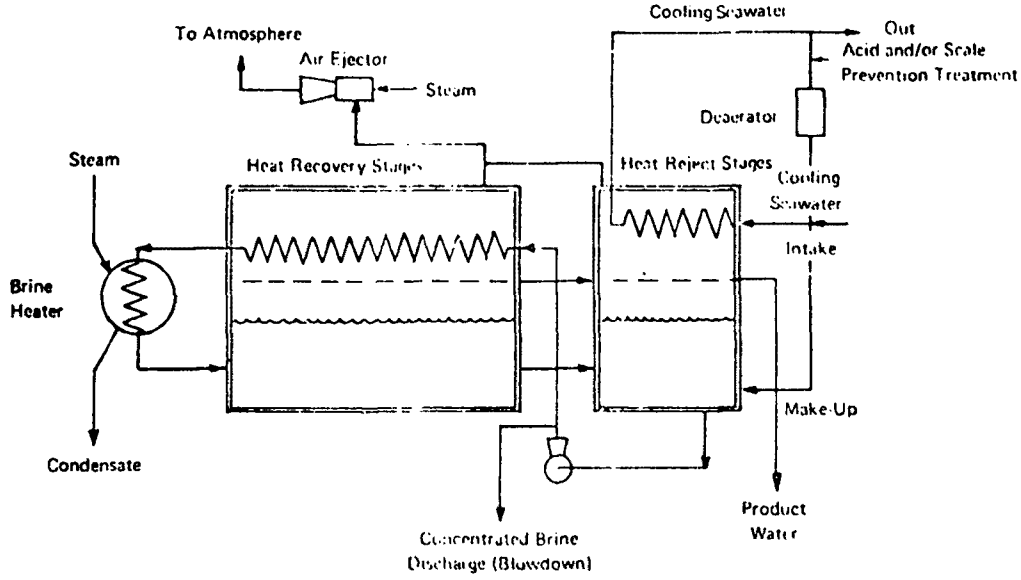


A. Cross Tube – Once Through – Plant



B. Long Tube - Recirculation – Acid Treatment – Plant

FIGURE VII-2 SIMPLIFIED FLOW DIAGRAM OF TWO TYPES OF SINGLE EFFECT MULTI-STAGE FLASH DISTILLATION PLANTS

In the climbing-film vertical evaporator, the most common design, the brine is maintained at a predetermined level insidethe vertical tubes, which are heated externally by the incoming steam in the first effect or by the hot product vapors in subsequent effects. (See Figure VII-3.) This is in direct contrast to a submerged tube type of unit where the steam is inside and the boiling brine is outside the tubes. The vapors from the boiling brine rise in the vertical tubes into a vapor chamber and are led from there into the vertical tube heat exchanger in the next effect where the heat is given up to the brine circulating in these tubes.

The resulting fresh water condensed on the outside of the tubes is removed and combined with product from the subsequent effects. The combined product is cooled in a final condenser with feed water. The incoming feed water is fed into the first effect and the concentrated brine flows in the same direction as the vapors. The brine in each effect circulates either by natural temperature differences or by forced circulation.

In another modification, known as the thermal recompression evaporator, part of the vapors from the last effect are entrained and compressed by expanded live steam from the boiler. The resulting mixture becomes the heating medium for the first effect. This scheme is particularly advantageous where high-pressure steam is available as a source of heat and it can be used in conjunction with a single or multiple effect vertical-tube evaporator.

Relevance of distillation processed to textile waste treatment

The wastewaters from the textile industry may have a moderately high concentration of organic chemicals in comparison with the concentrations in brackish or saline waters. Because organic chemicals may have appreciable vapor pressures at the temperatures of evaporation, vapor - liquid equilibrium relationships will determine whether these organic pollutants can be removed successfully by evaporation. The more volatile species could easily appear in the condensate where only a small fraction of the total water has been evaporated. In addition, wastewater could be distilled to produce a highly concentrated stream containing the pollutants. Therefore, removing a large fraction of the total water will accentuate the steam distillation effect and remove more organic chemicals, since the amount obtained in the vapor phase is a function of the concentration in the liquid phase. Consequently, the application of distillation (evaporation) to wastewaters demands a thorough knowledge of the physical chemistry of these wastewaters, especially vapor-liquid equilibria, and the subsequent determination of

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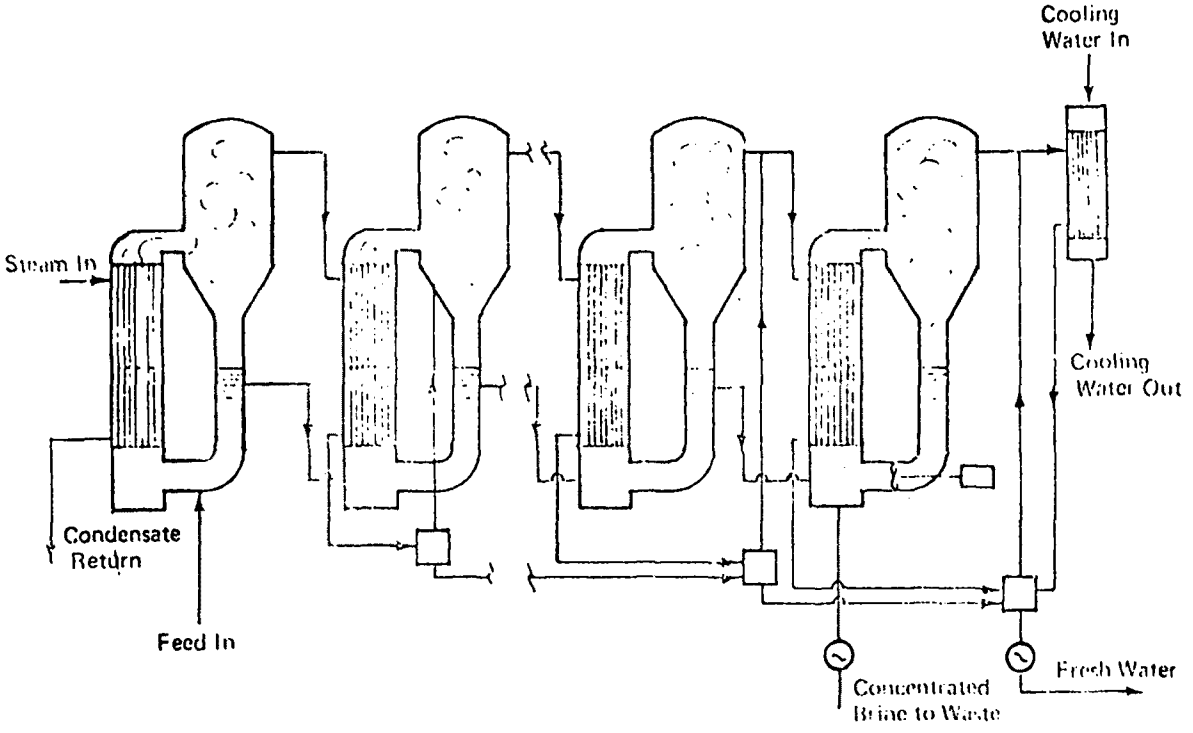

FIGURE VII-3 SIMPLIFIED PROCESS FLOW DIAGRAM, CLIMBING FILM, VERTICAL TUBE EVAPORATOR

the quality of the condensate acceptable for reuse since the condensate presumably would not be disposed of to receiving waters.

In some instances, it might be necessary to treat wastewater biologically by activated carbon adsorption to insure adequate removal of organic species. Therefore, a thorough consideration of the entire process chemistry will be required before one can determine whether evaporation can be successfully applied to wastewaters containing biologically active carbonaceous substances. If the wastewater streams contain very low concentration of organics and high concentrations of dissolved inorganic salts, the applicability of evaporation is more readily predicted, being essentially an evaluation of economics.

Evaporation equipment is available; whether it will operate satisfactorily on wastewater streams that contain high levels of carbonaceous substances is a moot point. For example, the deposition of carbonaceous substances on heat transfer surfaces or the occurrence of foaming could be severe deterrents to the applicability of evaporation. Carryover of mists, in addition to the steam distillation effects discussed earlier, could reduce significantly the quality of the water produced. In many instances, it would be necessary to limit the fraction of the total wastewater stream evaporated so that concentration levels in the evaporation system will insure operability.

As with most tertiary treatment methods, there would remain the problem of final disposition of the concentrated contaminated waste stream.

Freezing Techniques

Description. It has long been recognized that individual ice crystals formed in chilled impure water are composed of pure water. Much effort has therefore gone toward the development of practical processes to take advantage of this phenomenon for the desalination or purification of water. Attention is presently centered on two types of equipment. (5.2)

The vacuum freeze vapor compression (VFVC) system has the longest history. In this type of device, feed water is chilled and exposed to a slight vacuum. Some of the water vaporizes and the resulting loss of heat of vaporization causes ice crystals to form in the system. In other words, the feed water boils and freezes simultaneously.

The ice crystals are separated mechanically from the brine by means of sieves and scrapers and transferred to melting chambers. At the same time the water vapor formed during the boiling-freezing stage is com-

pressed and introduced also to the melting chamber, where it condenses on the ice crystals. In practice the system is more complicated, with particular care being required to wash the ice crystals free from feed water and to maintain the correct temperatures and pressures throughout.

The second type of design employs as the vaporizing constituent a secondary refrigerant which is insoluble in water. Usually, liquid butane under pressure is bubbled through the feed water, vaporizing, expanding and causing ice crystals to form. As in the vacuum freeze system, the crystals are then separated mechanically and washed by liquid butane. The secondary refrigerant system has the advantage that the equipment operates at higher pressures and smaller volumes of gas (butane), resulting in less expensive and more reliable pumps and compressors.

Experiences outside the textile industry. A few small VFVC plants have been erected in this country and abroad for desalination of seawater, but have not had enough service to develop useful histories.

Their principal advantage appears to be that they are relatively insensitive to the nature of the chemicals in the feed water and, because they operate at low temperatures, resist the scaling and corrosion problems which plague most other types of plants. None has been used for waste water treatment. The secondary refrigerant system is still in the pilot plant stage of development.

Experiences within the textile industry. Neither type of freezing plant has been used in the textile industry for waste water treatment.

Applicability. Waste water treatment by freezing might be attractive to the textile industry because of its tolerance of high levels of salts, organics, suspended solids and other materials in the feed water. It can be operated at brine-to-product ratios as low as about 0.02, and brine concentrations as high as 60,000 mg/l TDS. This, of course, considerably reduces the cost of ultimate brine evaporation or disposal. Unfortunately, there is insufficient service data to permit firm calculation of maintenance costs and reliability.

Membrane Processes

Introduction. Within the past 5 to 10 years, a number of synthetic semi-permeable membranes with controlled permeation properties to salts and macromolecules have become available in quantity. These have made possible a number of novel waste treatment processes which were previously laboratory curiosities. In this section we discussthe

application of three membrane processes to waste treatment and to textile wastes in particular: electrodialysis, reverse osmosis, and ultrafiltration.

Electrodialysis relies upon membranes which are permeable to either cations or anions, and impermeable to the oppositely charged ions. Salts are removed from solution under the action of an electric field. Reverse osmosis, conversely, relies upon membranes which are permeable only to water, and impermeable to salts. Water travels through the membrane under the action of a hydraulic pressure gradient, rejecting salt. Ultrafiltration differs from these two processes, in that the membrane is permeable to both salt and water, but not to macromolecules or suspended solids. Salt and water pass through the ultrafiltration membrane under a pressure driving force, while macromolecules and colloids are held back.

Despite the differences in the basic principles, these three membrane processes have one important trait in common: at the completion of the process the original waste stream is split into two components, a high-volume purified stream, and a low-volume waste stream containing high concentrations of the original contaminants. At some point, this concentrate must be removed from the membrane process, evaporated and disposed of. The exact concentration factor at which the concentrate stream is removed depends upon the balance between the further cost of the membrane process and the cost of evaporating this small volume. This tradeoff must ultimately be considered in the final evaluation of the cost of the membrane processes for treatment of textil wastes.

The following sub-sections discuss each of these membrane processes in some technical detail, and their applicability to textile plant wastes. In most cases, very little direct data on the treatment of such wastes by membrane processes is available. Their applicability must be extrapolated from their use in related processes.

General Description. Reverse osmosis for desalinization of sea water and brackish water has been under extensive investigation since the discovery in the early 1960's of high flux membranes capable of rejecting salts (VII5.3). Much of the research and development work was funded by the Office of Saline Water, with a view toward recovering potable water from sea water. Although this aim still has not been fully attained at prices competitive with other processes such as flash distillation, improved technology arising from these programs and increased commercial interest has resulted in some successful utilization of reverse osmosis for removal of dissolved salts from industrial waste streams.

The process of reverse osmosis (Figure VII-4) relies upon the ability of certain specialized polymeric membranes (usually cellulose acetate or nylon) to pass pure water at fairly high rates and to reject salts when saline feed streams are passed at high pressures over the surfaces of the membranes. The applied hydraulic pressures must be high enough to overcome the osmotic pressure of the saline feed stream, and to provide a pressure driving force for water to flow from the saline compartment, through the membrane, into the fresh water compartment. The cost of recovering clean water increases with increasing salinity of the feed stream. (This principle must be explicitly considered when the economics of salt removal from waste streams is calculated: at some point the stream will become sufficiently concentrated to make it cheaper to evaporate the residual brine than to continue reverse osmosis.)

Figure VII-5 shows a schematic flow diagram of a typical reverse osmosis system. Feedwater is pumped through a pretreatment section which removes suspended solids (by screening and cartridge filters) and, if necessary ions such as iron and magnesium which may foul the system. The feedwater is then pressurized and sent through the reverse osmosis modules. Fresh water permeates through the membrane under the pressure driving force, emerging at atmospheric pressure. The pressure of the concentrated brine discharge stream is reduced by a power recovery turbine, which helps drive the high pressure pump, and then is discharged.

The design of the modules containing the reverse osmosis membranes is crucial to the efficient operation of the process. As salt is rejected by the membranes, it concentrates at the membrane surface and results in a situation known as "concentration polarization," where the salinity at the membrane surface is many times higher than in the bulk feed solution. Since the driving force for water transport decreases with increasing osmotic pressure at the membrane surface, concentration polarization can have a very deleterious effect on water flux.

Concentration polarization can be minimized by high fluid shear at the membrane surface to aid the back-transport of polarized salt into the bulk of the process stream. This is accomplished by flowing the feed stream at high velocities in thin channels (laminar shear) or in wide channels to produce turbulence (VII 5.7).

Three types of reverse osmosis configurations are currently popular (VII 5.8). The first, known as the "spiral wound" configuration, uses flat-sheet cellulose acetate membranes wound in a spiral to produce a multitude of thin channels through which the feed water flows under high laminar shear. This configuration is inexpensive, produces high water

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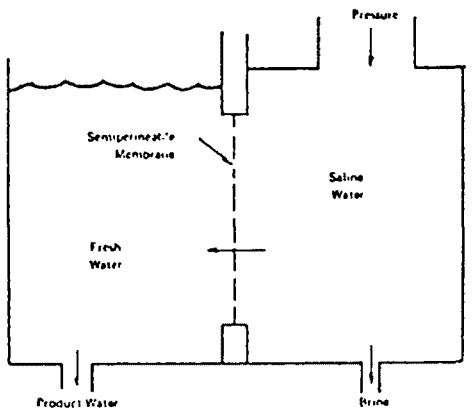

Source: Southwest Research Institute

FIGURE VII-4 PRINCIPLE OF REVERSE OSMOSIS

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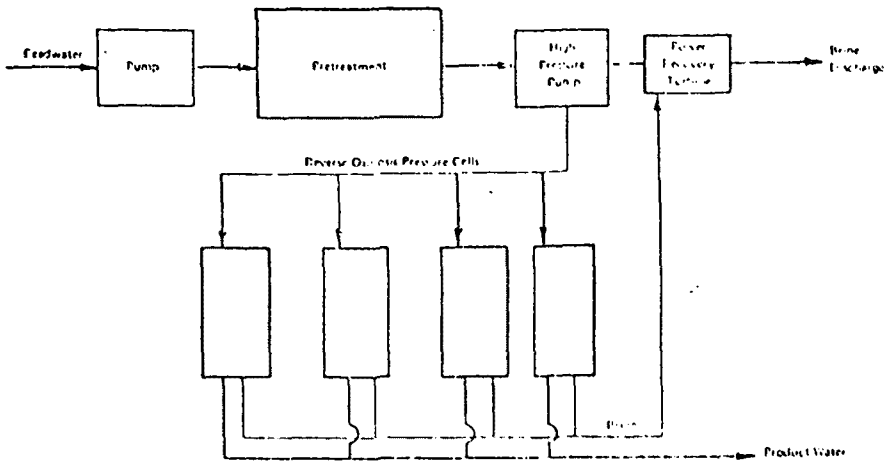


Source: Southwest Research Institute

FIGURE VII-5 SCHEMATIC DIAGRAM OF THE REVERSE OSMOSIS PROCESS

fluxes, and consequently efficient use of membrane area. Its major difficulty is that the resulting thin channels become easily fouled and plugged, so a process stream must have a very low level of suspended solids.

The second configuration uses tubular cellulose acetate membranes to bring about turbulent flow and overcome concentration polarization. The membrane is formed into a tube--with an inside diameter of about 1 inch, and the "active" (salt rejecting) face of the membrane on the inside of the tube--through which the feed stream is recirculated at high turbulent speeds. Membrane utilization is not as efficient as in the spiral wound configuration, but there is less trouble with flow distribution, fouling and plugging. This system can handle highly contaminated wastes with high concentrations of suspended solids.

Finally, a reverse osmosis system using a multitude of hollow nylon fibers has shown considerable utility on commercial waste streams. A bundle of fibers, with the "active" side of the nylon membranes on the exterior of the fibers, is encased in a module. Feed water is passed at high velocities between the fibers, and fresh product water permeates into the interior lumens of the fibers from where it is collected. This configuration results in rather low utilization of membrane area, but since the cost per unit area of the membranes is considerably lower than the cost of the cellulose acetate membranes, the ultimate cost of water recovery is competitive for low salinity feed streams. This configuration, like the spiral wound one, is highly susceptible to fouling by suspended solids, and requires thorough pre-treatment of the feed stream.

Application to Textile Wastes. The major application of reverse osmosis to textile wastes would appear to be in removal of salt from secondary sewage plant effluent. The technology appears adequate to reduce the effluent salts to potable levels (less than 200 mg/l). The process should also result in excellent color removal, and substantial removal of residual BOD and COD. The major limitation appears to be cost: for large plants, 19,000 cu m/day (5 mgd) or greater, costs are 13 to 19¢/1000 liters (50 to 75¢/1000 gallons). (VII 5.8). However, the costs increase greatly for smaller plants, because of greater labor costs.

The major technical limitation of the process for treatment of secondary sewage from textile wastes is the requirement of feed stream quality. High levels of suspended solids greatly reduce water flux rates through the membranes, and increase costs substantially. It will therefore be necessary to coagulate or filter out the suspended solids in the feed.

Grease and oil in the feed may also retard fluxes to some degree, although this effect reportedly is not as great in the tubular configurations. Additional constraints are imposed by the susceptibility of the membranes to chemical attack. The cellulose acetate membranes used in the spiral wound and tubular configurations can be used only between pH 5 and 9. Thus alkaline streams will need to be neutralized. Nylon hollow fibers have been used on streams with pH between 4 and 11, making these membranes more acceptable for non-neutral wastes. In addition to treatment of secondary sewage effluent, reverse osmosis has been considered for a number of other applications in textile wastes. An experimental hollow-fiber reverse-osmosis pilot plant operates on the total waste stream from a textile plant (VII 5.9). This system, which requires extensive prefiltration of the feed stream, has allowed 80% recovery of the product water, with good color removal. Data on flux rates, cost, or longevity is inadequate to extrapolate to the ultimate utility of the process. It is expected that flux decline, because of suspended solids, may be a problem, and COD may not be removed adequately.

Another potential application of reverse osmosis is recovery of sizing materials. Carboxymethylcellulose (CMC) and polyvinylalcohol (PVA) will both be retained at great efficiency by reverse osmosis, allowing these sizing materials to be concentrated for reuse. The savings from reuse of these sizing streams may offset the costs of the smaller plants required to process just the sizing waste streams.

Ultrafiltration.

General description. Ultrafiltration is similar to reverse osmosis in that it relies on the permeation of water through a semipermeable membrane under a hydraulic driving pressure. The distinction between reverse osmosis and ultrafiltration lies primarily in the retention properties of the membranes: reverse osmosis membranes retain all solutes, including salts, while ultrafiltration membranes retain only macromolecules and suspended solids. Thus salts, solvents, and low molecular weight organic solutes pass through ultrafiltration membranes with the permeant water. Since salts are not retained by the membrane, the osmotic pressure differences across ultrafiltration membranes are negligible. Flux rates through the membranes usually are fairly high, and hence lower pressures can be used than are practical in reverse osmosis. Typical pressure driving forces for ultrafiltration are 20 to 100 psi.

Ultrafiltration processes face problems of concentration polarization similar to those encountered in reverse osmosis. However, instead of

salts concentrating at the membranes surface, causing high osmotic pressures, the concentrating species are usually macromolecules or colloidal suspended solids which cause a "filter cake" to form atop the ultrafiltration membrane, with a subsequent decline in product water flux rates. As with reverse osmosis, concentration polarization is minimized by high fluid shear rates or turbulent flow. Membrane module designs to minimize concentration polarization include thin channels tubular designs for turbulent flow, and hollow fiber designs. The latter have the "active" side of the membrane on the inside of the fibers, with permeant water collected from inter-fiber spaces. Membranes may be made from cellulose acetate, polyelectrolyte complexes, nylon, or a variety of inert polymers. Hence, highly acidic or caustic streams may be processed, and the process is not usually limited by chemical attack of the membranes. (VII 5.10)

Applications of Ultrafiltration. Because of costs, ultrafiltration has been used only when: (1) product water must be of extremely high quality, completely sterile and colloid-free; or (2) the waste stream contains a contaminant of value which may be recovered by ultrafiltration. Illustrative current uses include:

(1) Production of colloid-free water for pharmaceutical use. Ultrafiltration is used to remove colloids and suspended matter from tap water. (The water is also subjected to ion exchange to remove salts.) Costs for ultrafiltration are estimated to be 14¢/1000 liters for a 190 cu m/day plant (54¢/1000 gallons for a 50,000-gallon/day plant.)

(2) Recovery of electrodeposition paint from waste streams. This is one of the two or three major industrial applications of ultrafiltration. Electrodeposition plants produce a dilute waste that contains a significant quantity of colloidal electrodeposition paints and associated salts. Ultrafiltration concentrates the paint for reuse, while the permeant water can be reused as rinse water. Pollution is reduced considerably, and the saving in paints adds up to 30 per cent, allowing the cost of the ultrafiltration system to be completely amortized (VII 5.11).

(3) Recovery of whey protein and lactose. Whey from cheese factories has been a major pollutant of streams in cheese producing areas. Cheese whey contains an extremely high level of dissolved inorganics (up to 10,000 mg/l salts) and a very high BOD (4 per cent lactose sugar, 0.5 per cent protein, typically.) With present legislation, it is no longer possible to dispose of untreated whey by dumping into rivers, and the quantity and high BOD of the streams

place a considerable load on municipal sewage systems. Ultrafiltration has been used to concentrate and remove the sugars and salts from the protein in whey streams, resulting in a valuable by-product (VII 5.12). The lactose can then be crystallized out, and reverse osmosis used to desalt the remaining water. This process has now moved from a pilot plant operation (funded by the EPA and USDA) to successful commercial operation in several dairies (VII 5.9).

Application of Ultrafiltration to Textile Waste Streams. Since ultrafiltration does not remove salts and low molecular weight organic compounds such as dissolved dyes, its utility in textile waste treatment would appear to be limited.

Concentration and recovery of disperse dyes by ultrafiltration may be feasible, but this will by practical only where a single color is in the waste stream, so that the dye may be reused. Concentration of polymeric cotton sizing materials (PVA and CMC) is technically feasible since the UF membranes will retain the polymers and pass the polymerfree water at reasonable fluxes (VII 5.9). An experimental system at the J. P. Stevens plant is being used to test the feasibility of PVA concentration by ultrafiltration, with the ultimate aim of re-using the sizing polymer. The membrane in this system is a new experimental "dynamically formed" membrane based on deposition of organic surfactants on porous carbon, but the process should be feasible on more conventional UF membranes at a cost of 13¢ to 26¢ per 1000 liters (50¢ to $1.00 per thousand gallons) of water removed.

Electrodialysis

Description. The production of potable water from brackish waters by electrodialysis is a mature desalting process. Economically, the process is usually limited to feed waters having total dissolved solids up to 10,000 mg/l and more commonly it treats waters with 1000 to 2000 mg/l solids. It is not practical to reduce the total solids in the produce water to a few mg/l as is done in distillation plants; about 200 mg/l is the highest purity attainable in a practical plant.

The general principles of electrodialysis are as follows. The process involves the separation of a given flow of water containing dissolved and ionized solutes into two streams, one more concentrated and one more dilute than the original, by specially synthesized semi-permeable membranes. Some ion exchange membranes are permeable only to cations; thus, only positive ions will migrate through them under the influence

of an electric field. Other ion exchange membranes, permeable only to anions, will permit migration of negative ions only.

In electrodialysis, water is fed, usually in parallel, into the compartments formed by the spaces between alternating cation permeable and anion permeable membranes held in a stack. At each end of the stack is an electrode having the same area as the membranes. A d-c potential applied across the stack causes the positive and negative ions to migrate in opposite directions. Because of the properties of the membranes, a given ion will either migrate to the adjacent compartment or be confined to its original compartment, depending on whether or not the first membrane it encounters is permeable to it. As a result, salts are concentrated or diluted in alternate compartments. The process is shown diagrammatically in Figure VII-6 (VII 5.1).

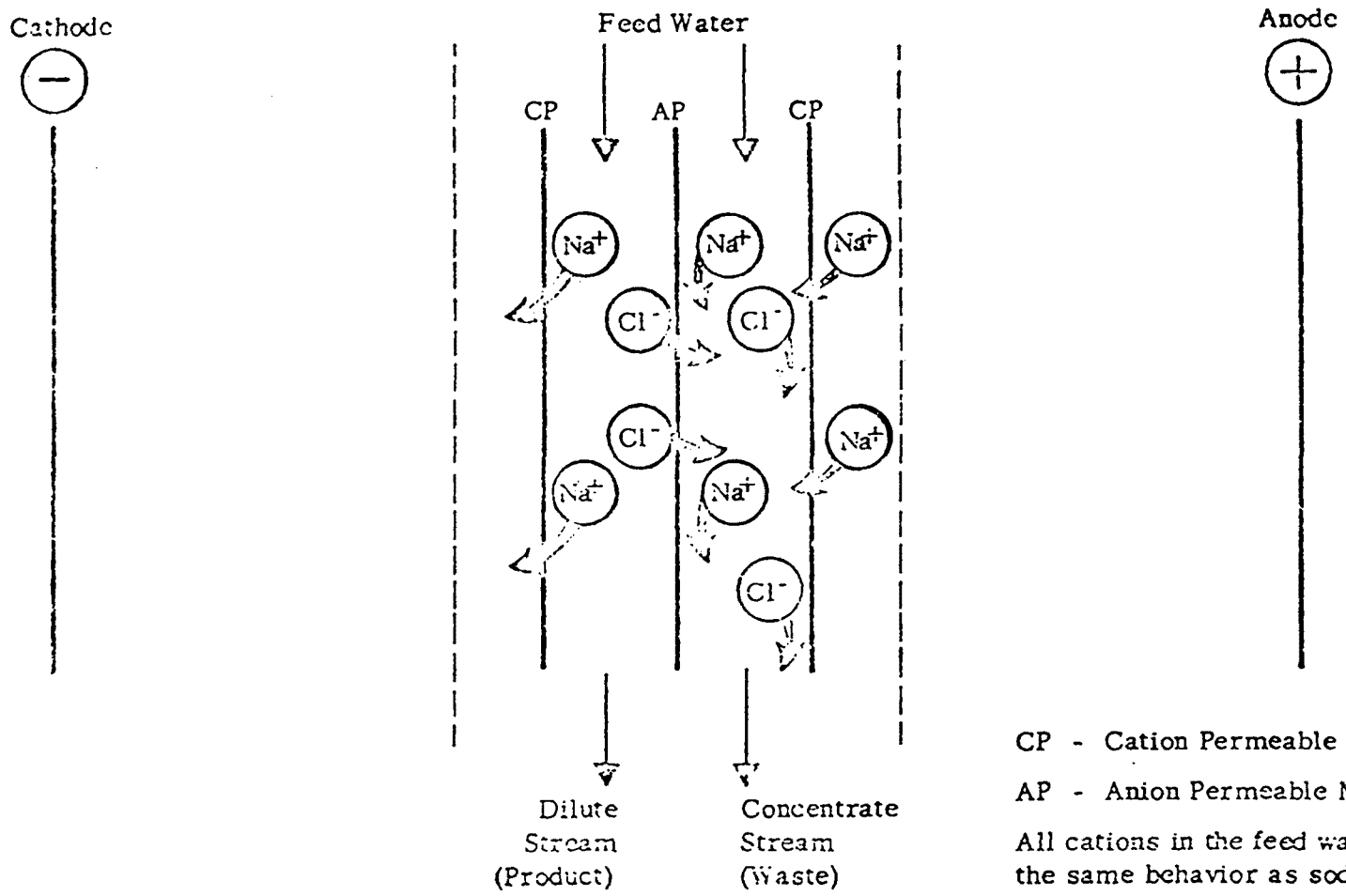
To achieve high throughput, the electrodialysis cells in practice are made very thin and assembled in stacks of cells in series. Each stack consists of more than 100 cells. Feed water is first filtered to remove suspended particulate matter which could clog the system or foul the membrane and, if required, is given an ion exchange treatment to remove oxidizing materials such as ferrous or manganous ions which would damage the membranes. Very high organic levels may also lead to membrane fouling. The catholyte stream is commonly acidified to offset the increase in pH which would normally occur within the cell, and an anti-scaling additive may be required as well. An operating plant usually contains many recirculation, feedback and control loops and pumps to optimize the concentrations and pH's at different points and thus maximize the overall efficiency. A typical electrodialysis flow sheet is shown in Figure VII-7.

Experience Outside the Textile Industry. Electrodialysis has been used successfully for more than a decade to convert brackish (2000-5000 mg/l TDS) water to potable water (500 mg/l TDS). While this does not represent a waste water treatment application per se, it can provide useful reliability and cost data from the some 150 plants which have been built.

Electrodialysis has also been used successfully to demineralize milk products (whey) for a number of years and has been employed in a few cases by the chemical process industry where it is necessary to remove ionized mineral constituents from process streams (VII 5.13). It has not been used for treatment of any conventional secondary effluent.

Experience Within the Textile Industry. Electrodialysis has not been used to treat textile plant wastes. Some efforts have been made by Ionics, Inc., to investigate its use in dye removal. Unfortunately, because of their large molecular size, dye materials do not traverse the membranes readily. There may be some possibility of using electrodialysis to remove dissolved salts from dye solutions, but this has not yet been demonstrated.

Applicability. The mechanism of the electrodialysis process limits it to the removal of relatively small, mobile, ionized constituents from the waste stream. Sodium, potassium, chlorides and sulfates readily pass through the membranes. Larger ions, and those doubly charged, such as phosphate, calcium or barium, have limited mobility in the membranes and tend to remain in the feed stream. There may be some incidental transport of small dissolved organic species through the membranes but it is not significant.



CP - Cation Permeable Membrane

AP - Anion Permeable Membrane

All cations in the feed water show the same behavior as sodium (Na^+), and all anions the same behavior as chloride (Cl^-).

FIGURE VII-6 DIAGRAMMATIC REPRESENTATION OF ELECTRODIAL YSIS

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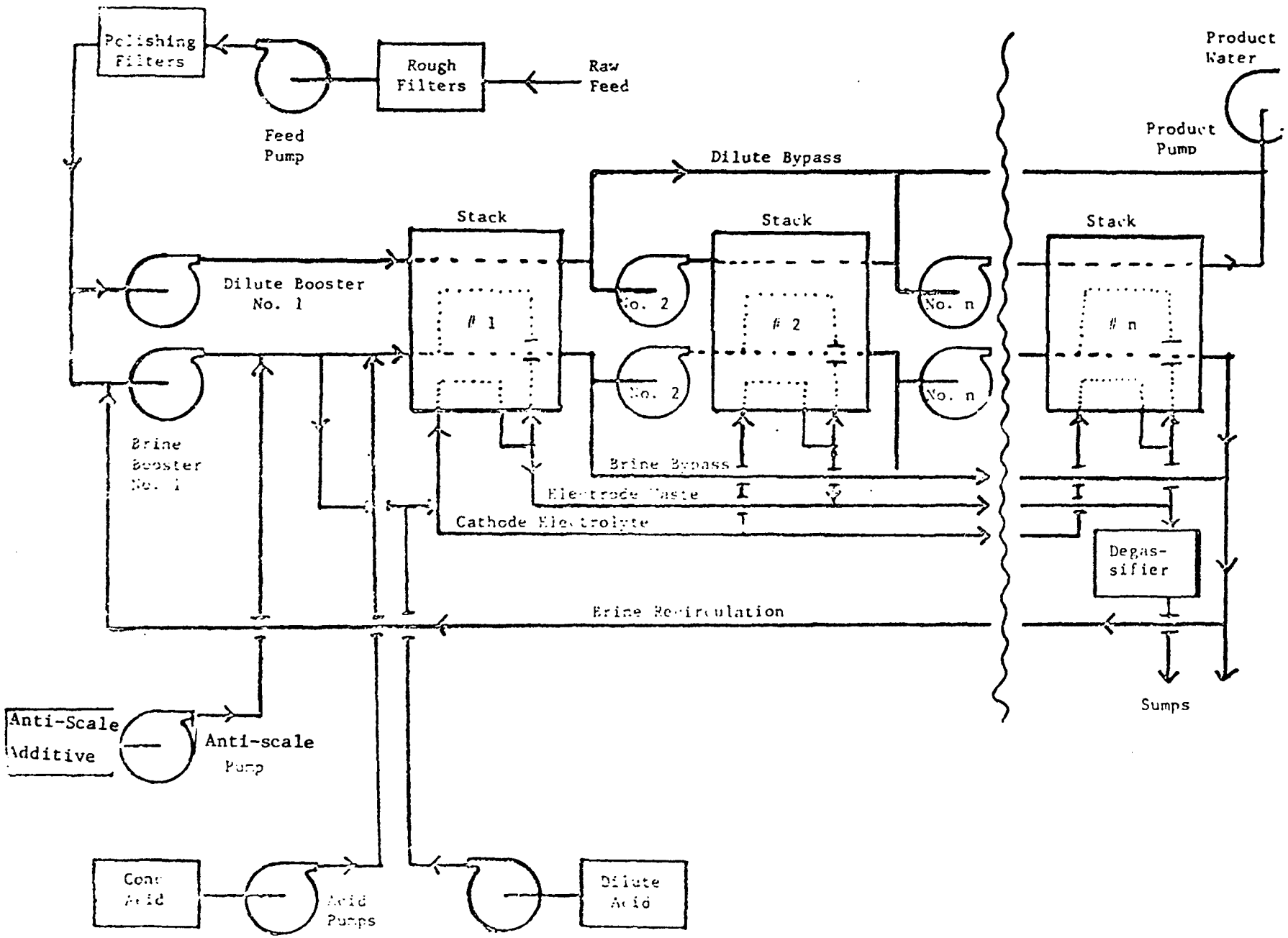
FIGURE VII-7 TYPICAL ELECTRODIALYSIS PLANT WITH N STACKS IN SERIES



Suspended solids in the feed stream are undesirable. They may erode the membranes, plug the small tortuous pathways through which the feed flows, and foul the membrane surfaces. High levels of organic materials must be avoided as they may attack the membranes (frequently polystyrene based) or lead to surface fouling. Thus feed water to the plant should have a low BOD and COD and these will not be substantially changed by the process.

If strongly alkaline, the feed stream must be neutralized or rendered slightly acidic to prevent degradation of the anion membrane, which usually contains quaternary ammonium groups. Iron and manganese in the feed water must be removed if their total concentration in the feed water is greater than about 0.3 mg/l.

Calcium sulfate scale can also accumulate if the calcium concentration in the brine goes above about 400 mg/l. Addition of a sequestering agent to the feed permits operation to a higher concentration, but not above about 900 mg/l. For this reason, the brine rarely constitutes less than 10 to 15 percent of the feed water volume (VII 5.6).

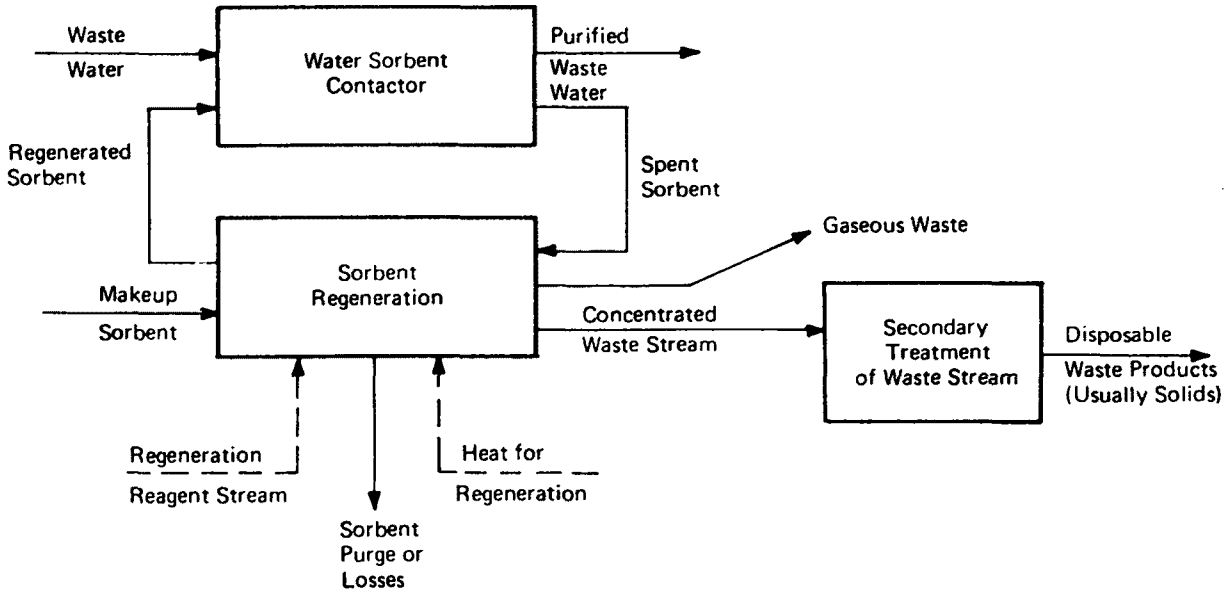
As the purity of the product water increases, its electrolytic conductivity decreases. This higher resistance makes it increasingly less efficient to remove the remaining salt. In addition each stack of cells in series reduces the salt concentrations by a more or less fixed percentage. Thus the equipment necessary to remove 250 mg/l salt from a 500 mg/l stream is comparable to that required to remove 2500 mg/l from a 5000 mg/l stream. For these reasons, most plants today do not produce produce water at less than 500 mg/l and very few operate as low as 200 mg/l.

Sorption Systems

Introduction. This group of advanced waste treatment processes is concerned with methods in which the waste water is contacted with a material which sorbs components of the water. The material is usually regenerated and the sorbed material ejected into a gaseous or more concentrated liquid waste stream (Figure VII-8). The concentrated liquid waste stream is normally converted to a solid waste by evaporation. Such processes include adsorption on activated carbon and ion exchange.

Treatment by Activated Carbon

Physical Principles. Activated carbon is a commercially available and particularly versatile absorbent (VII 5.14) primarily



VII-8 SCHEMATIC OF SORPTION PROCESS
FOR WASTE TREATMENT

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because of its relatively low cost (22 to 110¢/kg or 10 to 50¢/lb) and large surface area (about 112 lectares per kilogram or 126 acres per pound) which relates directly to its capacity for adsorbed material (0.7 to 0.9 kilograms of adsorbed material per kilogram of carbon).

The most popular form of activated carbon is the granular, which is easily handled, deposits the minimum of fines into the water stream, and may be regenerated by heat (or in specialized applications by chemical streams) with less than 10% loss per cycle (VII 5.15). However, attempts are being made to develop techniques for the use of powdered carbon (VII 5.16), which is considerably less expensive (about 22¢/kg or 10¢/lb) than granular carbon (66¢/kg or 30¢/lb) but which is difficult to separate efficiently from the waste water and regenerate.

Activated carbon, while acting largely as a general absorbent, shows some selectivity (VII 5.17):

Strongly Absorbed	Weakly absorbed
weak electrolytes	strong electrolytes
sparingly soluble materials	very soluble materials
high molecular wt. compounds	low molecular wt. compounds

The amount of a given material absorbed is a function of its chemical nature, the amount in solution, the pH and the temperature. To a first approximation, adsorption follows a characteristic Freundlic type isotherm.

$$x/M = kCl/n$$

where: x is the amount of material adsorbed
M is the weight of adsorbent
C is the remaining concentration of desorbed material
k and n are constants that depend on the adsorbent, pH and temperature

Typical adsorption capacities of activated carbon at different residual COD levels are illustrated in Figure VII-9.

Process Design. Several types of water carbon contactors have been proposed and utilized. These are summarized schematically in Figure VII-10. Usually one or more fixed bed columns are linked in parallel Carbon capacity is utilized more efficiently by placing several fixed bed columns in series, the spent upstream column being replaced

with a regenerated column at the downstream side as appropriate. A recent, more efficient development is the use of moving bed systems,

The carbon is usually regenerated in multiple hearth furnaces; in some cases, such as in the adsorption of phenol, partial regeneration may be achieved by chemical treatment (VII 5.18). A schematic of a treatment process including thermal regeneration is illustrated in Figure VII-11.

The detailed design of actual plants is discussed in the next section.

Use of Carbon Absorption in General Applications. The Environmental Protection Agency has undertaken detailed studies of the use of activated carbon for the tertiary treatment of municipal wastes - primarily at Pomona, California and Lebanon, Ohio (VLL 5.19). The Pomona plant has been run for over four years and deserves detailed description (VII 5.20).

The plant has a capacity of 1100 cu m/day (0.3 mgd) and is a four-stage, fixed-bed, granular activated carbon plant. The general design is illustrated in Figure VII.12. The carbon is periodically backwashed to remove entrapped suspended solids (the secondary effluent then need not be pretreated) and regenerated when necessary (after a steadystate adsorption capacity of about 0.4 to 0.5 kilograms of COD per kilogram of carbon has been reached) in a vertical six-hearth furnace. Carbon losses averaged 8 1/2 percent per cycle. One complete cycle of the 12,200 kilograms (26,800 pounds) of carbon in the plant is achieved each year of operation.

The effectiveness of the plant in improving water quality is illustrated in Table VII-2.

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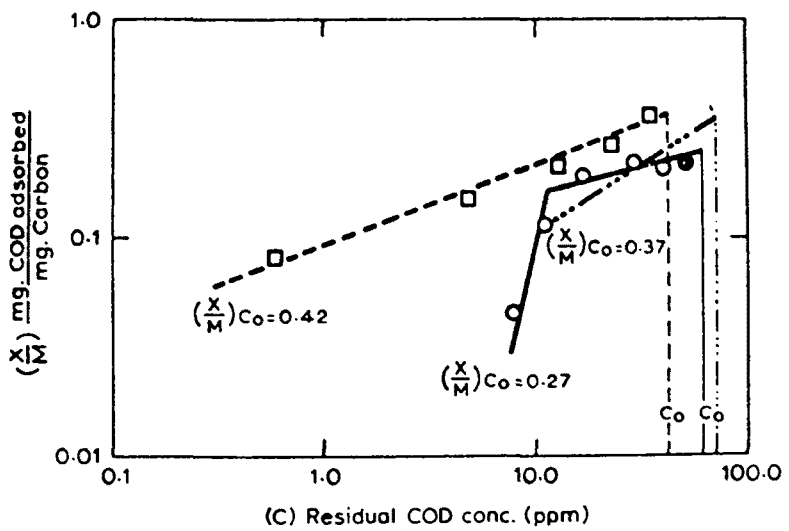

FIGURE VII-9 COD ISOTHERMS USING VIRGIN CARBON AND DIFFERENT SECONDARY SEWAGE EFFLUENTS (after Masse, 1967).

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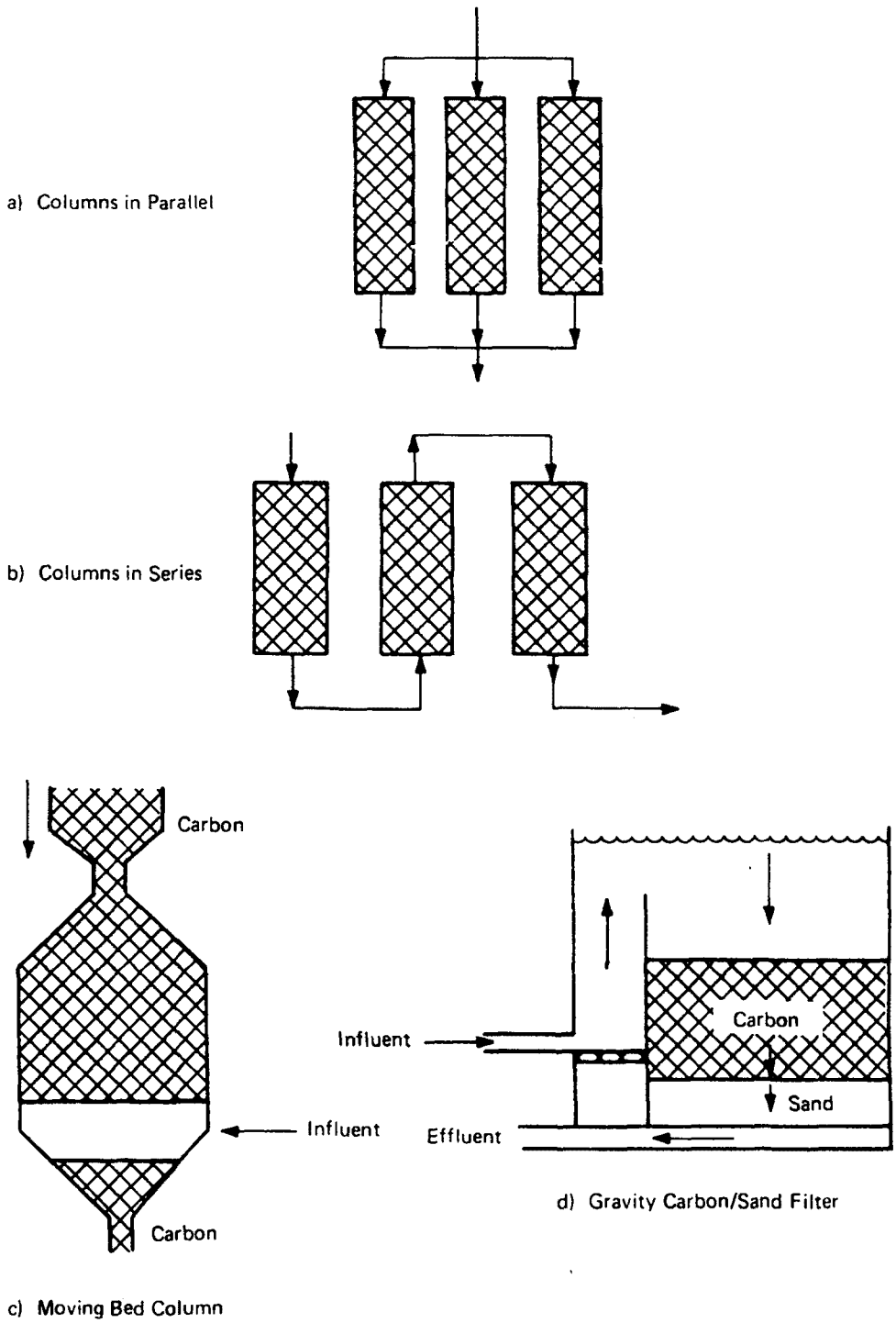

FIGURE VII-10 SCHEMATIC OF ACTIVATED CARBON WATER CONTACTING SYSTEMS

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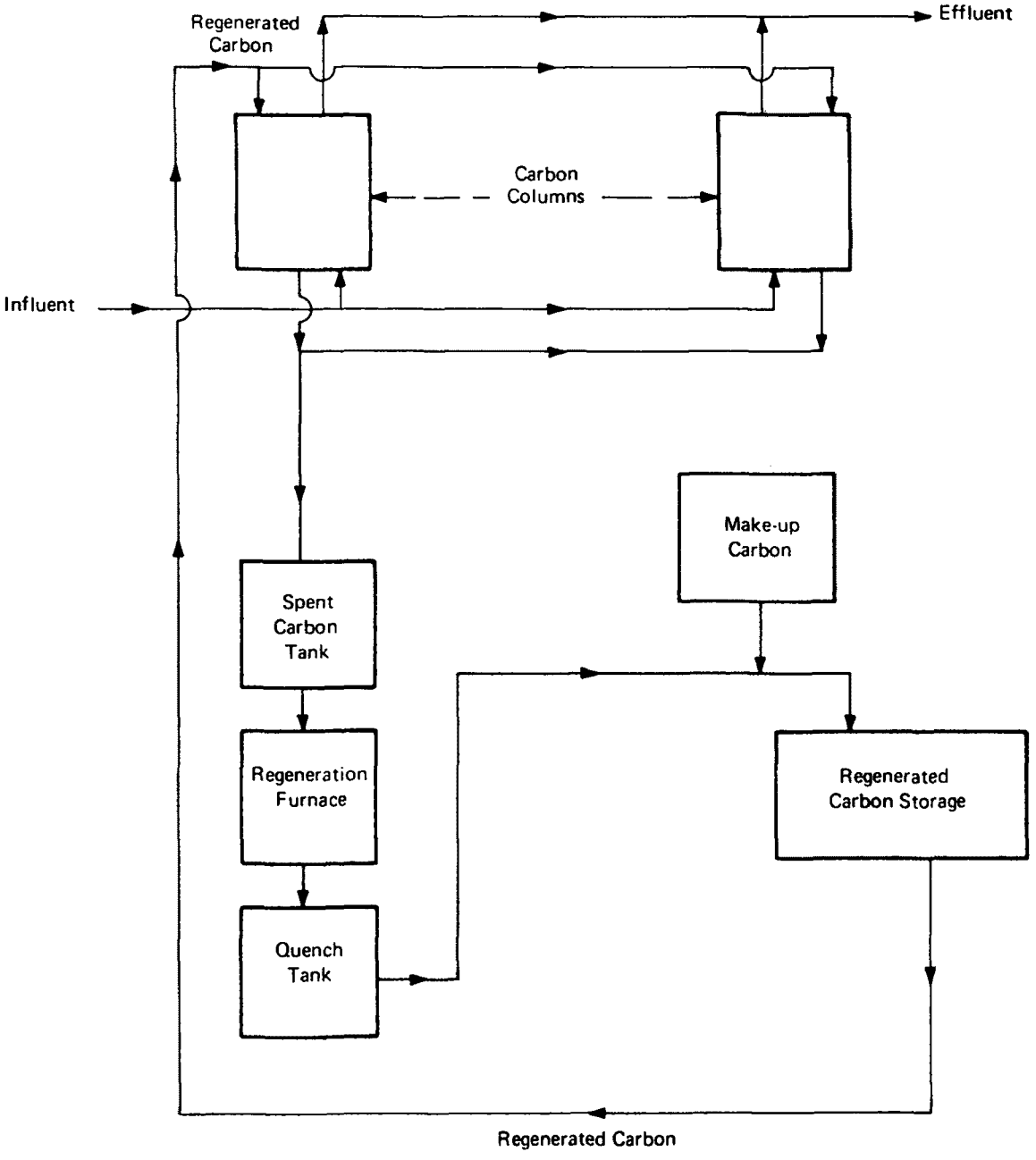

FIGURE VII-11 SCHEMATIC OF AN ACTIVATED CARBON SYSTEM INCLUDING THERMAL REGENERATION

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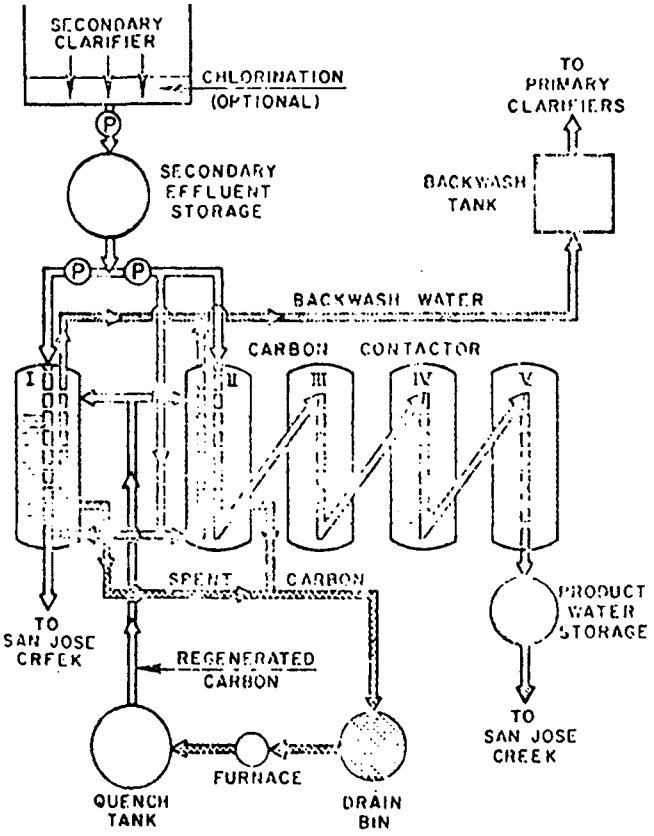

FIGURE VII-12 SCHEMATIC FLOW DIAGRAM

Table VII-2 Carbon Adsorption Pilot Plant;
Average Water Quality Characteristics
(June 1965 to July 1969)

Parameter		Influent	Effluent
Suspended solids	mg/l	9	0.6
COD	mg/l	43	10
Dissolved COD	mg/l	30	8
TOC	mg/l	12	3
Nitrate as N	mg/l	8.1	6.6
Turbidity (Jtu)		8.2	1.2
Color (Platinum-Cobalt)		28	3
Odor		12	1
CCE	mg/l	--	0.026
BOD	mg/l	3	1

Source: Reference VII 5.20.

About 75% of the influent COD is removed, and the values of most other parameters such as suspended solids, turbidity, color, odor, and BOD are reduced to insignificant levels. The effluent water had an average dissolved COD of 8 mg/l.

Another activated carbon plant studied by the EPA is part of the advanced waste treatment facility at the District of Columbia's advanced waste treatment facility (VII 5.21). Following lime precipitation, filtration and water stabilization, the secondary effluent is passed through five pressurized activated carbon columns in series at a rate of 190 cu m/day (50,000 gallons per day). When the preceding clarification was operating efficiently, up to 75 percent of the TOC was removed by the carbon adsorption system. Problems developed because the carbon entrapped grease and bacterial activity produced stemies on the carbon. (In other work, this was prevented by addition of biocides). Anaerobic conditions developed leading to hydrogen sulfide production. In addition, blinding, plugging, and channeling accompanied by severe pressure drops were experienced. The carbon had to be replaced before saturation, at a loading of only 0.133 kilograms TOC/kilogram carbon.

Two more specialized applications of activated carbon treatment of waste waters are worthy of mention. The first, moving-bed, single-stage carbone adsorption unit, was used to recondition brines used in olive processing in the Central Valley of California (VII 5.22). The unit had a capacity of 6.8 to 47.7 cu m/day (1,800 to 12,600 gallons per day). Its effectiveness is illustrated in Table VII-3.

Table VII-3. Brine Reconditioning

	Influent	Effluent
pH	4.0-4.3	4.2-8.8
Acidity	0.3	0.02-0.39
Color	75-100	70/5
NaCl	5.5	5.2-5.5
SS	200-286	164-220
COD	18,000	5,000-16,500

In the second exploratory studies (VII 5.18) in Conway, North Carolina, the feasibility of using activated carbon treatment to reduce phenol levels and coloration of a waste stream to insignificant levels was demonstrated. The influent was dark red and contained 2,500 mg/l of

Table VII-4

		Dyehouse Wastewater Influent	Treatment Plant Effluent	Reduction
COD - mg/l	at 8.5 gpm ft²	945	178	81.1
	at 15.6 gpm/ft²	550	280	49.0
TOC - mg/l	at 8.5 gpm/ft²	378	70	81.7
	at 15.6 gpm/ft²	220	115	47.8
Colour -	at 8.5 gpm/ft²	-	-	99.4
	at 15.6 gpm/ft²	-	-	99.5

phenol. The carbon was regenerated by washing with sodium hydroxide solution. Activated carbon treatment was also used successfully at Lake Tahoe to produce drinkable water from secondary effluent (VII 5.23). A 28,000 cu m/day (7.5 million gpd) unit operated at a cost of 6¢/1000 liters (23¢ per 1000 gallons).

Experience with the Use of Activated Carbon on Textile Wastes. The use of activated carbon to treat textile wastes was pioneered at the Stephen-Leedorn Carpet Mill, Southampton, Pennsylvania (formerly Hollytex Carpet Mills) in association with Calgon Corporation (VII 5.24). Of the raw waste from the dyeing and rinsing plant, 80 percent was treated and reused. The remaining 20 percent, which contained high dye concentrations, could not be treated economically, however. A schematic of this plant is given in Figure VII-13. Capacity of the system was 1900 cu m/day (500,000 gallons per day) and it utilized 22,700 kilograms (50,000 pounds) of Filtrasorb 400 granular activated carbon. The carbon was regenerated by heating it in a furnace.

The Fram Corporation, supported in part by the EPA, has done considerable work in pioneering its unique activated carbon system in which regeneration is accomplished by backwashing the absorbed organic

material into an aerobic biological treatment unit (VII 5.24-5.28), as shown schematically in Figure VII-14.

After encouraging results in a laboratory unit operating on synthetic textile waste water, a pilot system was installed at C. H. Masland and Sons carpet yarn fibre dyeing plant in Wakefield, Rhode Island. The flow diagram of the pilot system, which has a capacity of 190 cu m/day (50,000 gpd), is shown in Figure VII-15.

Three basic problems were encountered:

1. The waste was not equalized so sugrges of dye concentration sometimes overload the carbon beds.

2. Batch adsorption required acceptance of the full hydraulic load of the dye-house discharge, shortening adsorption times.

3. The biological culture was subject to er atic feeding. These difficulties forced the systems to be redesigned, as shown in Figure VII-16.

Cone Mills Corporation of Greensboro, N.C., has been conducting a range of studies on the treatment of dye waste waters (VII 5.26). The company encountered only partial success in the use of carbon for effluent polishing following biological treatment. Anthracite-based media proved unreliable in removing all types of color contamination; bone char proved successful but cost about $2.20 per kilogram ($1.00 per pound) compared to 66¢ per kilogram (30¢ per pound) for the former materials. Hecknoth reported a 50 percent reduction of organics in certain dye wastes using activated carbon.

Our field work yielded several further instances of the use of activated carbon adsorption for the treatment of textile wastes, particularly in regard to color renewal. Milo Industries, Bloomsbury, Pa., operates a closed dye cycle using alum, dicetomaceous earth, and carbon to yield a color of less than 50 units. A series of trials carried out to evaluate activated carbon adsorption for color removal (VII 5.30) gave somewhat erratic results; despite early hope only a small amount of color was removed. This has been confirmed generally throughout the industry. The consensus (VII 5.32) appears to be that while color can be removed by activated carbon, some elements (particularly the dispersed dyes) are not adsorbed. Chemical coagulation perhaps supplemented by activated carbon adsorption remains the best method.for the dispersed dyes, while carbon adsorption alone may be adequate for dissolved dyes.

To summarize, activated carbon treatment is a common technique in industrial processes, has been evaluated in some detail and has been successful in treating secondary effluent following biological treatment of

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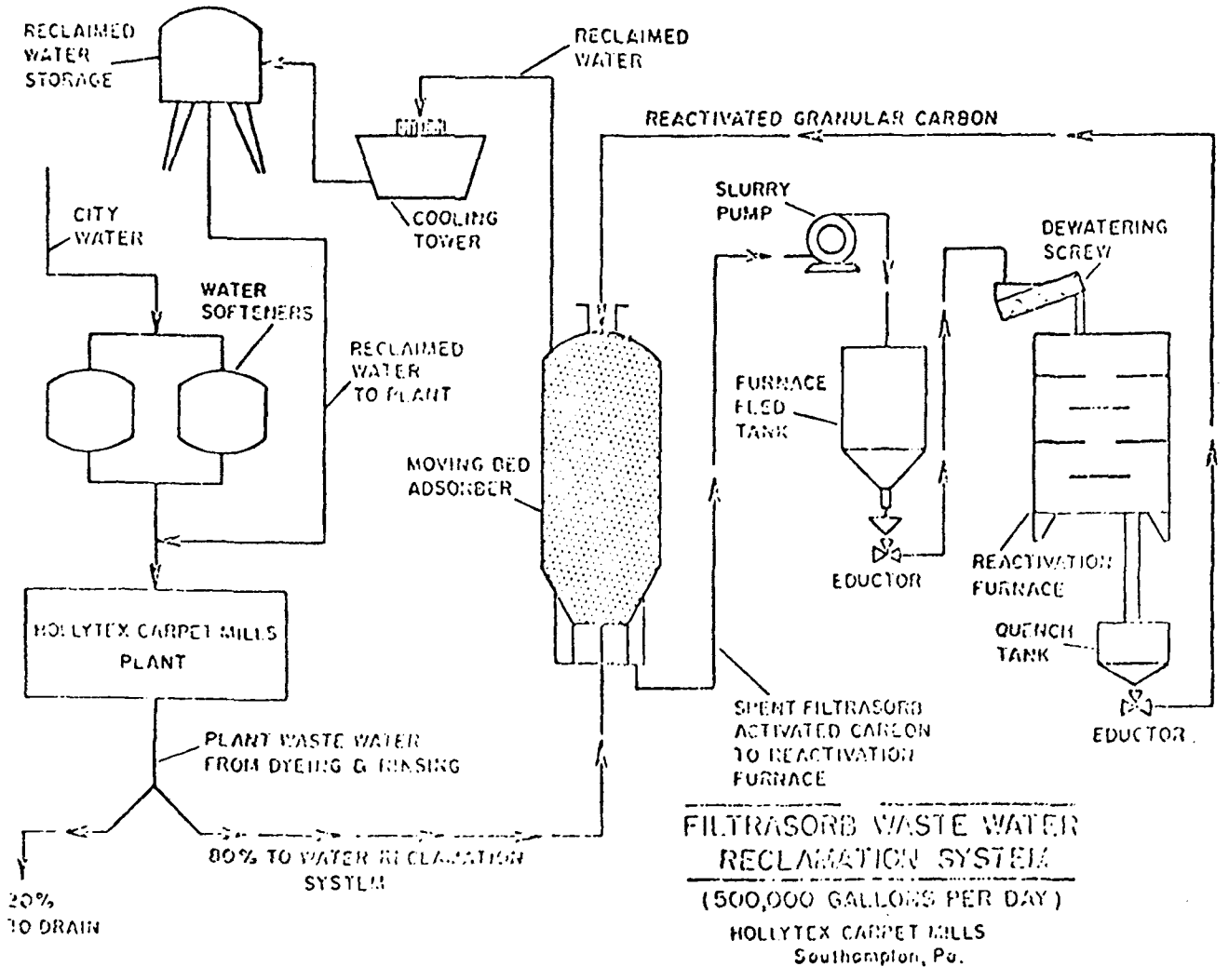

FILTRASORB WASTE WATER RECLAMATION SYSTEM
(500,000 GALLONS PER DAY)
HOLLYTEX CARPET MILLS
Southampton, Pa.

FIGURE VII - 13

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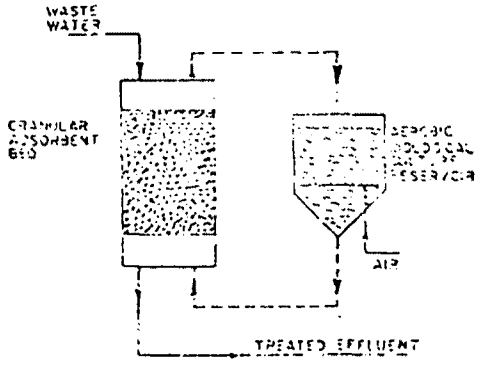

FIGURE VII - 14 SORPTION REGENERATION

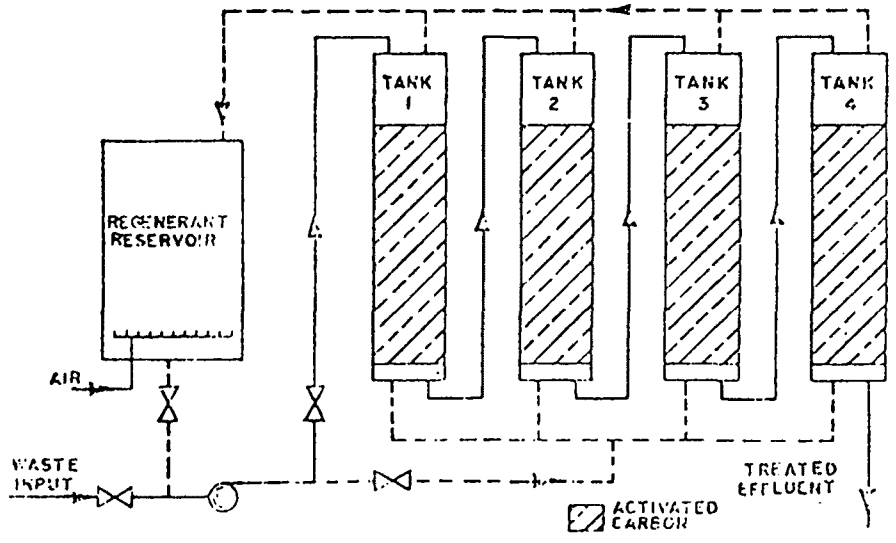

FIGURE VII-15 SCHEMATIC FLOW DIAGRAM

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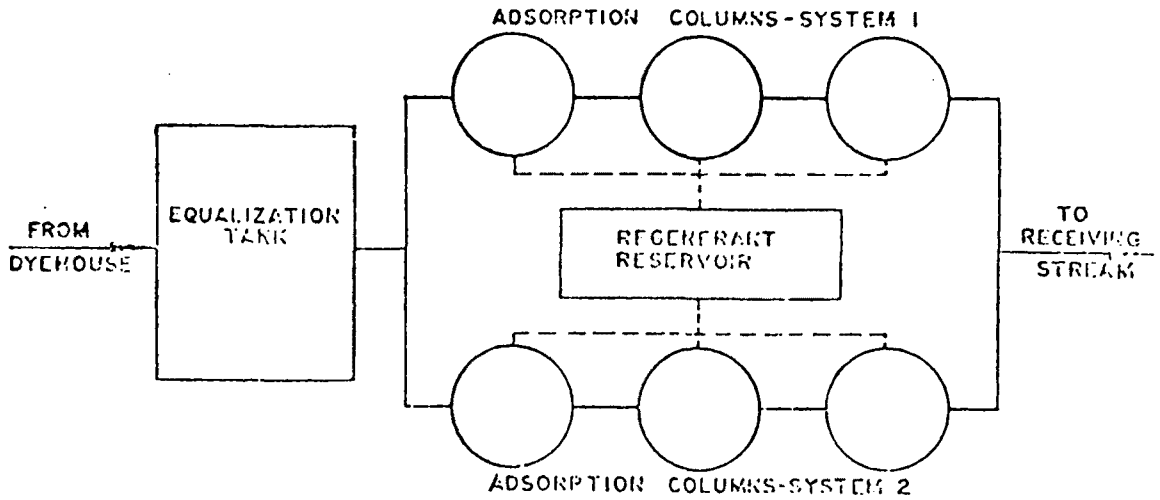

FIGURE VII-16 SECOND GENERATION SYSTEM

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municipal waste water. Some successful experience also has been accumulated in the treatment of textile wastes. Only the advanced process is suitable for reducing low-level organic contamination, but it affects the levels of dissolved ionic solids very little. Its chief difficulty concerns the removal of color; some dispersed dyes are not absorbed to any great extent. The process needs to be evaluated for any given process stream.

Ion Exchange

General Description. Ion exchangers are solid materials, insoluble in electrolyte solution, which are capable of exchanging soluble anions or cations with electrolyte solutions. For example, a cation exchanger in the sodium form, when contacted with a solution of calcium chloride, will scavenge the calcium ions from the solution and replace them with sodium ions. This provides a convenient method for removing the "hardness" from waters.

Ion exchange can also be used for total salt removal from waste streams, by employing a series of beds of exchangers followed by anion cation exchangers. The cation exchanger is used in its "acid" form, exchanging hydrogen ions for the cations in the stream. The anion exchanger is used in its "base" form, exchanging hydroxyl ions for the waste stream anions. The hydroxyl and hydrogen ions thus liberated from the ion exchanger recombine to form water, and thus replace the salts in the stream by pure water.

An example is a stream that contains sodium chloride. The reactions may be presented as follows, where RA is the solid anion exchanger, and RC is the cation exchanger:

RA-OH + NaCl RA -Cl + NaOH

RC-H + NaOh RC-NA + HOH

The exchange of ions on ion exchangers is stoichiometric and usually reversible. Thus, after the ion exchanger becomes saturated with the contaminant ion, it can usually be "regenerated" by flushing with a concentrated solution of its original ion. Therefore, in the example quoted above, the cation exchanger would be regenerated with a concentrated caustic solution (resulting in a waste regenerate stream of concentrated Na_2SO_4). The waste regenerate streams are usually quite concentrated and can be disposed of economically by simple evaporation.

Many natural and synthetic materials can act as ion exchangers (VII 5.33). Various alumosilicate minerals with cation exchange properties are known. Clays and glauconites carry exchangeable counter ions, and certain natural and modified coals have been used as ion exchangers. The most important class of ion exchangers, though, is the organic ion-exchange resins made from cross-linked polyelectrolytes. The exchanger exchanges the counter ions to the fixed charges on the polyelectrolyte. These resins are insoluble but swell to a limited degree, allowing ions from solution to penetrate into the gel matrix formed by the swollen polyelectrolyte.

They are conventionally used in particulate form in packed beds. The ion exchange behavior of the resins depneds on the nature of the fixed ionic groups, with the exchanger preferring those ions which strongly associate with the fixed (bound) ions.

One of the major advantages of the synthetic resins is the wide ranges of ion exchange properties which can be built into them, allowing considerable latitude in the designing of processes. These exchangers have the additional advantage of being capable of absorbing non-ionic organic solutes from solution (VII 5.33). This sorption is reversible in that the constituent can be removed by flushing with strong caustic. disposal of this organic-laden caustic stream then presents an additional problem which may prohibit its use.

General Applicability. In general, ion exchange processes are limited by the selectivity of the exchanger for the contaminant ion over its own counter ion. Divalent ions such as calcium and magnesium in general have high affinities for the ion exchange resins, and can therefore be removed with extremely high efficiencies. In general, also, ion exchange is less efficient than electrodialysis or reverse osmosis for high concentration streams. An upper limit frequently given for efficient removal of ions by ion exchange is 200-500 mg/l (VII 5.34), but others quote efficient cleansing of 2500 mg/l streams at costs less than that for electrodialysis or reverse osmosis (VII 5.35).

Recently, a new form of organic ion exchange resin has been developed which may allow economical de-ionization of waste streams at dissolved salt levels of 1000 to 3000 mg/l. This "Desal" process is based upon the discovery that certain weakly basic anion exchange structures can form the bicarbonate salt with solutions of carbon dioxide, and also have a favorable chloride-bicarbonate selectivity coefficient (VII 5.34). The process relies on a series of three ion exchange beds.

The first, which is the alkalization unit, consists of a weakly basic exchanger in the bicarbonate form. When it contacts an electrolyte such as NaCl, the following reaction occurs:

I $(R\text{-}NH)HCO_3 + NaCl \qquad (R\text{-}NH)Cl + NaHCO_3.$

The second bed, containing a weak acid cation exchange resin, acts as the "dealkylization" unit:

II $R\text{-}COOH + NaHCO_3 \qquad R\text{-}COONa + CO_2 + H_2O.$

The third unit, which is the carbonate unit, contains a weakly basic anion exchanger, similar to the exchanger in the first unit, but in the free base form, and acts as the carbonic acid absorber, resulting in an effluent free salt:

III $R\text{-}N + H_2O + CO_2 \qquad (R\text{-}NH)HCO_3.$

Upon completion of the above cleansing cycle, the alkylization unit (Unit I) is regenerated to the free base form with ammonia, caustic or lime. The dealkylization unit (II) is converted back to the hydrogen form by regeneration with inexpensive mineral acids. Since the carbonation unit is already in the bicarbonate form, the flow pattern is reversed for the next cycle, and the process repeated. A flow sheet illustrating the process is shown in Figure VII-17.

Typical experimental data from such a process are shown in Tables VII-5 to VII-8 for a number of different waste streams. This process has also been operated successfully at the polot plant scale on brackish water of 100 mg/l; the concentration was reduced to a final effluent of 20 to 30 mg/l, at an operating cost estimated to be equivalent to a cost of a 3785 cw m/day (1-mgd) plant of 5.3¢/1000 liters (20¢/ 1000 gallon) (1970) and a total capital investment for a 3785 cu m/day (1-mgd) plant of about $250,000 (again in 1970). A commercial plant achieving similar results was operating in the United STates for several years.

The major problem with this process appears to be the irreversible degradation of the weak base resins, which may limit their long-term stability and the ultimate economics of the process.

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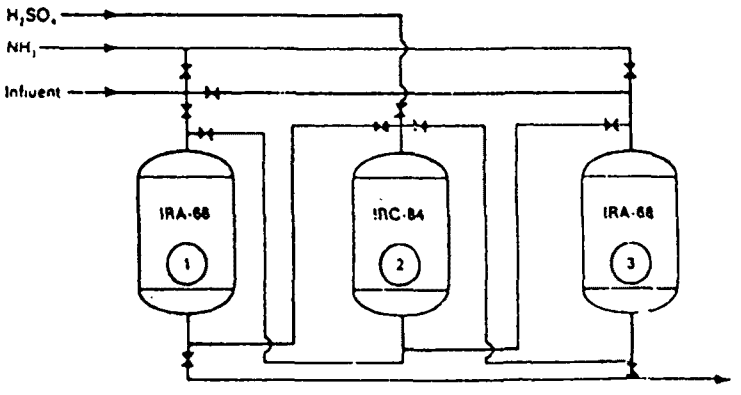

OPERATING SEQUENCE	CHEMICAL REACTION IN UNIT NO 1	2	3
1	$HCO_3 \rightarrow Cl$	$H \rightarrow Na$	$OH \rightarrow HCO_3$
2	$Cl \rightarrow OH$	$Na \rightarrow H$	HCO_3
3	$OH \rightarrow HCO_3$	$H \rightarrow Na$	$HCO_3 \rightarrow Cl$

The chemical symbols refer to the change in ionic form of the resins which is occurring

FIGURE VII-17 THREE-UNIT DESIGN

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Table VI-5 Composition of Untreated and Desal Ion-Exchange Treated Acid Mine Water

Constituent	Concentration (mg/l as $CaCO_3$)	
	Untreated	Treated
pH	3.1	8.5
Ca	964	290
Mg	480	10
Fe	895	0.1
Al	556	0.1
Mn	91	0.1
$SO_4^{=}$	3,104	100
HCO_3^-	.....	200

Source: Reference VII 5.34.

Table VII-6 Modified Desal Process for Renovation of Steel Mill Pickle Rinse Wastes

Constituent	Wastewater	Modified DESAL treated waste mg/l as $CaCO_3$
Na	42	35
K	4	4
Ca	73	11
Mg	35	22
Fe	122	0.1
Al	1	1
Mn	2	0.1
Acidity (H_2SO_4)	1,160	None
pH	1.6	8.0
Electrical resist., ohm. cm.	175	4,000

Source: Reference VII 5.34.

Table VII-7 Modified Desal Process for Renovation of Tin Plating Rinse Water

Constituent	Wastewater	Treated Water After Amberlite IRA-68 (mg/l as $CaCO_3$)	Treated Water After Amberlite IRC-84 (mg/l as $CaCO_3$)
TDS	2,350	875	50
Na	893	872	50
K	1	1	0
Ca	7	2	0
Mg	3		0
Fe	15	<1	<0.1
Al	6	<1	<0.1
Mn	<1	<1	<0.1
Sn	1,180	<1	<0.1
Cu	<1	<1	<0.1
HCO_3	0	875	50
pH	3	8.5	6.5

Source: Reference VII 5.34.

Table VII-8
Typical Results Achieved with Counter
Current Ion Exchange

Water analysis, mg/l

Calcium, mg/l as $CaCO_3$	92
Magnesium mg/l as $CaCO_3$	10
Sodium, mg/l as $CaCO_3$	146
Bicarbonate, mg/l as $CaCO_3$	191
Chloride, mg/l as $CaCO_3$	55
Sulfate, mg/l as $CaCO_3$	2
SiO_2, mg/l as SiO_2	45

Deionization Results

	Cation Exchanger	Anion Exchanger
Resin	Duolite C-20	Duolite A-104
Regenerant	H_2SO_4	NaOH (amb3 temp.)
Regenerant dosage	36.4 kg/m³ (2.25 lb/cu ft)	36.4 kg/m³ (2.25 lb/cu ft)
Service flow rate	19 l/sec/m² (28 gpm/sq ft)	19 l/sec/m² (28 gpm/sq ft)
Effluent TDS	--	0.2 mg/l
Effluent SiO_2	--	5 mg/l
Operating capacity	11.0 kgr/cu ft (as $CaCO_3$)	11.5 kg/cu ft (as $CaCO_3$)

Source: Reference VII 5.35.

More conventional ion exchange resins have been used for the desalination of brackish water. A polot plant operation at Pomona, California has reduced the salinity of tertiary sewage from 1500 to 250 mg/l with an estimated cost (based on a 37850 cu m/day or 10-mgd plant) reported to be 2.6 to 6.1¢/1000 liters (10-23¢/1000 gallons). (The former figure is probably unrealistically low, since the cost of regeneration chemicals alone, based on 100 percent efficiency of utilization of ammonia and sulfuric acid is over 4¢/1000 liters or 15¢/1000 gallons).

The National Cannera Association ran another pilot plant study for the EPA on reducing the salinity of food processing waste water by ion exchange (VII 5.36). It was found possible to reduce the salinity of process streams from 600-6000 mg/l NaCl to an ultimate salinity of 100-200 mg/l for a cost estimated to be (26¢/1000 gallons) (1970). The resins were regenerated with calcium hydroxide. It was estimated that the waste regenerate solution could be made at least 1000 times more concentrated than the feed solution.

Recently, countercurrent ion exchange (in which regenerate flow is in the opposite direction from feed water flow, see Figure VII-18) has begun to make an impact on American ion exchange technology (VII 5.35). This
process allows more efficient use of regeneration chemicals, and therefore significantly reduces cost and pollution by regeneration waste streams. Apparently, European manufacturers of ion exchange equipment have recognized the savings for some years and have incorporated the new technology into their systems. It has been predicted that this technology whose success relies upon novel methods of preventing fluidization of the ion exchange resin particles during back flow, will soon become dominant in U.S. markets also, and will lower the cost of ion exchange use. Typical operating data on such a system are shown in Table 4. It is predicted that the cost of reducing the salinity of waste water containing 1000 mg/l NaCl to 250 mg/l will be 10 to 12¢/1000 liters (40-45¢/1000 gallons), including amortization of equipment, labor costs, chemicals, etc.

Applicability to Textile Wastes. Direct data on the applicability of ion exchange to textile wastes is scarce. Extrapolation of data from other waste streams is therefore necessary. It would appear that the major application of ion exchange to textile waste treatment would be to reduce the dissolved solids level of the effluent from the secondary treatment plants or the effluent from other operations such as electrodialysis or reverse osmosis. (Synthetic organic ion exchange resins have also been used as absorbers for non-ionic dyes, but the process is inefficient, and the cost $5/1000 liters over ($20/1000 gallons) impractically high). The dissolved solids levels of the secondary sewage effluents (ca. 1000 mg/l) would appear to be in the proper range for effective use of ion exchange. Costs for a 500 percent reduction of this salinity, assuming no other complications, would be expected to be about 12¢/1000 liters (45¢/1000 gallons) of product water, not including the cost of evaporating the concentrated regenerate waste stream. This latter is estimated to be of the order of 3 to 5 liters of concentrated waste saline per 1000 liters of feed water.

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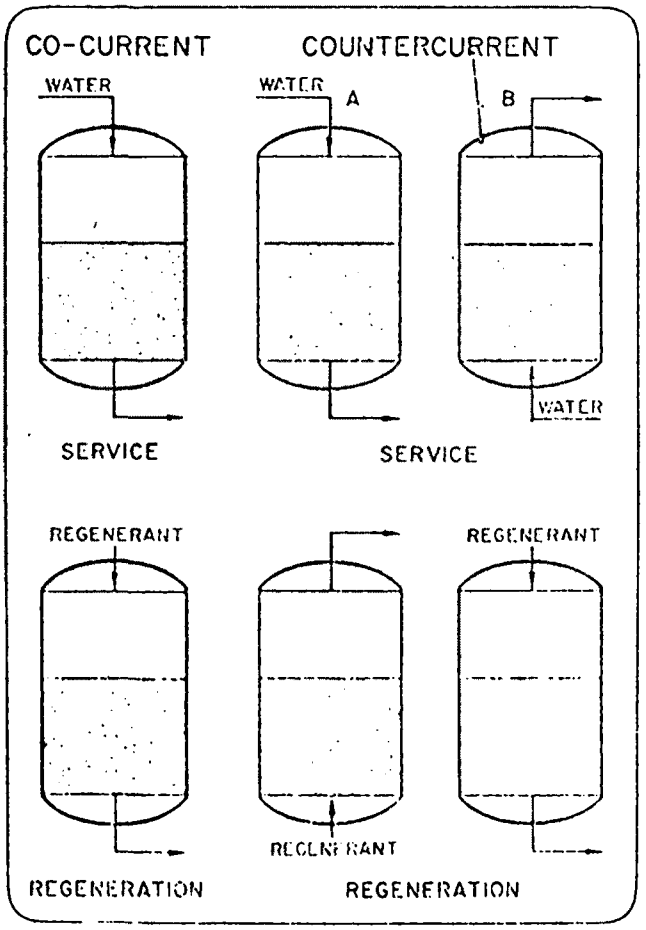

FIGURE VII-18 CO-CURRENT AND COUNTER-CURRENT OPERATION IMPLIES SERVICE IN ONE DIRECTION AND REGENERATION IN THE OPPOSITE DIRECTION. SERVICE CAN BE DOWNFLOW AS IN (A) OR UPFLOW AS IN (B).

One additional advantage of ion exchange is applicable to highly alkaline textile waste streams: neutralization combined with ion removal. For example, if the effluent is sodium hydroxide instead of the sodium chloride effluent quoted in the original example in this article, the cation exchanger alone may be used, resulting in the process:

$$RC - H + NaOH \qquad RC - Na + H20$$

Thus it may be advantageous, where possible, to leave the alkalinity in the hydroxide form (rather than carbonating it), and removing it by ion exchange.

Several unknowns complicate the application of ion exchange to textile waste streams. A major limitation is that ion exchange is effective only in the removal of dissolved ions from the solution. Thus, many other waste treatment procedures (such as reverse osmosis) may remove the ions in the process of removing other materials such as suspended solids, rendering ion exchange necessary.

The quality of the waste stream necessary to make ion exchange feasible is also a major factor in its usefulness. The level of suspended solids in the waste stream can have a considerable deleterious effect on the long-term operation of the ion exchange columns. It will therefore probably be necessary to pre-filter suspended solids down to a level of 20-50 mg/l before allowing the water to enter the ion exchange columns. Any oxidizing agents in the waste stream (e.g., hydrogen sulfide) will have an adverse effect on the life of the cation exchangers, while organic constituents may shorten the life of the anion exchange resins.

It appears, however, that the projected costs of ion exchange for textile waste clean-up are sufficiently low to justify a study of the parameters to determine long-term applicability.

Chemical Clarification

Suspended solids are a significant element of raw textile mill waste water. The larger components such as lint are readily removed by screens prior to entering a waste water treatment process. Residence in a clarifier permits other smaller yet macroscopic particles to settle as a sludge. Following activated sludge treatment and sludge removal in a further clarifier, the waste water still contains a variety of microscopic suspended solids. These may be removed by chemical clarification methods, which, in addition, have been found to be effec-

tive for color removal. Chemical clarification is rarely used prior to activated sludge treatment.

Physical Principles. Textile wastes typically contain a complex mixture of suspended solids, mostly of organic composition, with particles ranging from 0.01 m up to filterable sizes. They include color bodies, proteins soaps, fibers, mineral fines, oil and grease. These suspended solids have deleterious effects on the other advanced waste treatment processes used in tertiary treatment of waste streams; they load secondary treatment plants, blind sorbent beds and deposit on membrane surfaces. In themselves, they contribute undesirable properties to the waste water -- suspended COD, turbidity, color, etc. The smaller particles are virtually ulfilterable except by expensive and complex procedures and cannot be settled. (A 1-micron particle takes one hour to fall 1 mm in solution; a 0.01-micron particles takes more than one year.)

In addition to the obvious difficulty of removing small particles, the suspensions are stabilized by two effects: hydration and electrostatic charge. Most such particles adopt a negative charge and are prevented from coalescing to the larger, more easily removed particles by electrostatic repulsion. Neutralization of these charges destabilizes the system and leads to coagulation and precipitation or easier filtration. This process is the basis for chemical clarification.

Neutralization and electrostatic charge are generally accomplished by adding coagulants that contain multivalent cations. These include:

aluminum sulfate
ferric chloride
copperas (a mixture of ferric chloride and ferric sulfate prepared by chlorinating ferrous sulfate)
ferrous sulfate
ferric sulfate
sodium aluminate

The multivalent cations Al^{+++}, Fe^{+++} and Fe^{++} are strongly hydrated and hydrolyzed, forming acidic solutions that contain hydroxylated positive ionic pieces. Sodium aluminate, on the other hand, forms a strongly alkaline solution and is sometimes used in combination with aluminum sulfate to improve the resulting floc.

A subsidiary mechanism which operates during flocculation in waste water may also remove certain polluting species: the formation and settling of the precipitate may absorb and sweep out other water components

responsible for color, COD, turbidity, BOD, etc. In addition to the reagents listed abobe, lime has been used for this purpose.

Addition of these coagulants to the suspended solids and colloidal substances produces a floc which is allowed to settle in a clarifier using gentle agitation. It is important to dissipate the coagulant throughout the waste water as fast as possible; flash mixing at point of entry to the clarifier is normally used.

The correct coagulant dose for a specific waste water and particularly the precise pH for maximum effectiveness must be determined experimentaly for a given waste water. Unfortunately, the optimum values of these parameters may not be the same for different components of the waste water; thus turbidity removal mayddemand an operating pH different from that needed for color removal.

A second step in chemical clarification may be needed to satisfactorily separate the suspended floc from the clear supernatant liquor. This involves the addition of coagulant aids which act to create larger, tougher flocs that are more amenable to sedimentation or filtration. Activated silica has been used for many years; more recently, water soluble polymers, usually polyelectrolytes, have been used successfully for this purpose. They are available in anionic, cationic, or neutral form to treat flocs of differing electrostatic charac eristics.

Experience in General Waste Water Treatment. Coagulation and flocculation is a widely used technique in waste water treatment and in the preparation of potable water. Costs typically range from 1-5¢/ 1000 liters (5 to 20¢/1000 gallons).

Experience in the Textile Industry. Chemical clarification has frequently been used in the treatment of textile waste (VII 5.32, VII 5.38-5.42). Apart from its use to remove suspended solids, it has found particular promise in the removal of troublesome disperse dye particles which are generally not absorbed by activated carbon. A description of some typical experience in the textile industry will illustrate the usefulness of the process.

In 1949, a two-stage flocculation process using ferric sulfate as a coagulant was used to treat the combined wastes of a wool scouring and dyeing plant in Glasgow, Virginia (VII 5.43). A total of 950 cu m/day (250,000 gpd) was treated at a capital cost of $380 (1949 dollars) per 1000 liters ($1,450 (1949 dollars) per 1000 gallons). No operating costs are given. BOD of the combined wastes was reduced by 60 percent and suspended solids by over 90 percent.

Coagulation was also used successfully in waste water treatment at a Dow Chemical Company acrylic fiber plant in Williamsburg, Virginia (VII 5.44). The capacity of the plant was 1840 cw m/day (486,000 gpd). After primary clarification, the waste is treated with copperas coagulant with pH adjustment. (The wastes contained zinc, which was precipitated as hydroxide at these high pH levels.) Zinc removal was consistently above 99 percent so effluent levels were below 1 mg/l.

In Israel, experimental results showed (VII 5.48) that flocculation with alum and filtration would reduce color by 95% and turbidity by 97% in a highly colored simulated waste water. Performance was shown to be a strong function of pH and alum dosage; maximum reduction of color levels and turbidity did not necessarily occur at the same pH value. The dependence of color removal on pH is shown in Figure VII-19. Cationic poly
electrolytes were found to be effective coagulant aids, but only at very high doses (about 30 mg/l).

The treatment of wool processing effluent using coagulants has been discussed by Stewart (VII 5.49). Calcium chloride coagulation was used in a plant of Patens and Baldwins Ltd, Darlington, England. Addition of 2,000 mg/l of calcium chloride followed by filtration reduced a BOD of 15,000 to 30,000 mg/l to 2,700 to 3,800 mg/l, suspended solids of 20,000 to 32,000 mg/l to 1,000 mg/l and grease levels of 17,000 to 20,000 mg/l to 50 mg/l. But the cost was over $1.30 per 1000 liters ($5 per 1,000 gallons) in 1964.

The Wool Industries Research Association in Leeds, England, developed evidence that copperas coagulation could be used in combination with lime followed by filtration to achieve almost as good results as calcium chloride coagulation. A 1971 estimate of the cost of this process yields a value of over $1.80 per 1000 liters ($7 per 1000 gallons) including plant, chemical and operating factors.

The cost of ferric chloride used as a coagulant has been estimated as 0.8¢/1000 liters (3¢/1,000 gallons) (VII 5.24) to reduce COD by 70 to 90% and to remove 99.9 percent of bacteria and 70 percent of the turbidity.

In a review of treatment methods for dye waste waters (VII 5.26), it was reported that the most successful coagulation technique for color removal consisted of the use of alum or a combination of alum and a

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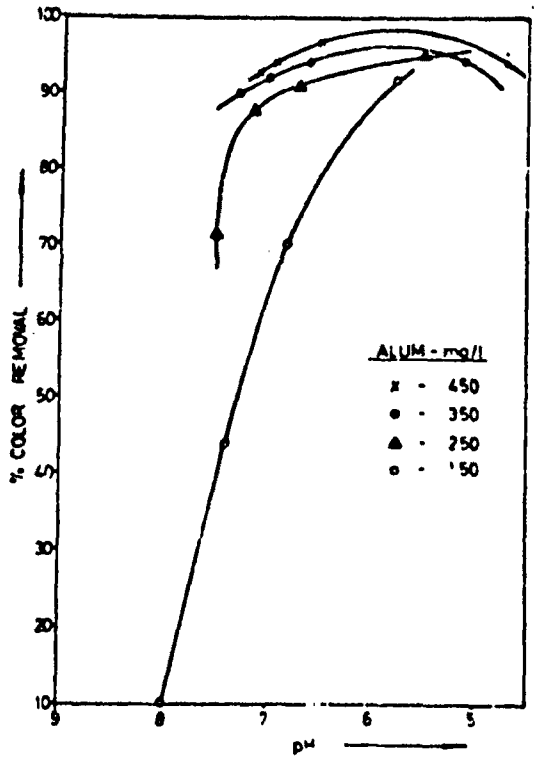

FIGURE VII-19 REMOVAL OF COLOR FROM AERATED WASTES AS A FUNCTION OF pH AFTER FLOCCULATION

cationic polyelectrolyte. Treatment of wastes before and after activated sludge treatment was studied; in general, less chemical requirement was found prior to biological treatment. Mixed liquor treated with 150 to 250 mg/l alum, 10 mg/l lime and 20 mg/l cationic polymer produced an effluent color g 15 (pt/Co scale) wwith zero suspended solids, but the chemical cost alone was 2.1 to 2.6¢/1000 liters (8 to 10¢/1000 gallons). If chemical clarification must follow biological treatment, 200 to 400 mg/l alum and no coagulant aid may be used. Color removals of about 95 percent can be expected.

The use of a polyelectrolyte has been found to be a useful aid to alum dewatering in other work (VII 5.50).

Milco Industries of Bloomsbury, Pa., report successful color removal of a closed dye cycle water using a combination of alum treatment, diatomaceous earth filtration and carbon adsorption.

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SECTION VIII
Cost, Energy, and Nonwater Quality Aspects

BEST PRACTICABLE TREATMENT TECHNOLOGY (Level I)

This chapter summarized the costs (necessarily generalized) and effectiveness of end-of-pipe treatment systems either currently in use or recommended for future use in the textile industry. More detailed analyses for industry categories have been presented in Supplement A of this report. In order to reflect the very different treatment economics between existing and new plants or between small and large ones, costs have been developed in Supplement A for, typically, two plant sizes in each industry category. The purpose of this discussion is to describe the basic cost analyses upon which the product-specific estimates are based.

Supplement A also includes updated inputs for EPA's Industrial Waste Treatment Model. The estimated total volume of wastewaters discharged for industry categories has been provided for 1972 and 1977. Also, general estimates of the current level of treatment in different industry segments have been made.

The best practicable treatment technology in this industry is considered as the end-of-pipe treatment steps shown in Figure VIII-1.

> Primary Treatment: For removal of suspended solids. Includes equalization, screening and chemical coagulation or precipitation (to remove heavy metals where required).
>
> Secondary Treatment: Primarily for removal of BOD5. Includes aerated stabilization basins, sludge recycle and disposal, and final clarification with a long-duration polishing lagoon. (Land and land-fill requirements are very small.)

Information on actual treatment cost experience in the textile industry was available in varying degrees of completeness from the exemplary plants visited. To verify the quality of the data received and to provide a broader basis for estimation, a costing model was developed based on standard wastewater treatment practice. This model covers both capital and operating costs for the equivalent of what appears to be the best technology currently practiced by the industry: essentially primary and secondary treatment as extended aeration with stabilization ponds. Over a plant size range of 400-12,000 cubic meters per day (0.1

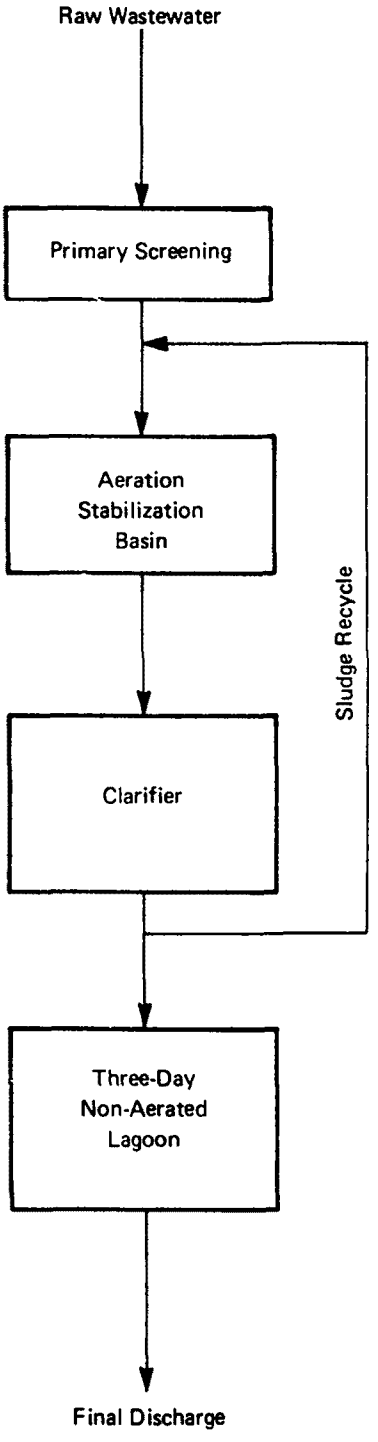

FIGURE VIII-1 SCHEMATIC FLOW DIAGRAM OF PROCESS STEPS AND COST CENTERS FOR LEVEL I TREATMENT

to 3.0), the cost experience data from the plants visited came within 30 percent of that predicted by the cost model, as shown by the examples in Table VIII-1. The costs calculated from the model, therefore, are believed to be realistic bases for estimating the (replacemfent) value of existing facilities and the economic impact of further secondary-type treatment requirements.

Cost curves developed from the cost model are presented in Figures VIII-2 to VIII-10. (For very small plants (about 110 cu m/day or 30,000 gpd),

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Table VIII-1
Accuracy of Standardized Costing Methodology

Example Plant	ADL std cost estimate	Company reported cost for actual plant	Ratio ADL reported refined
Plant A (0.394 mgd)			
Category 1			
Aeration basin	$ 27,000		
Aeration equipment	136,900		
Clarifier	35,600		
3 day lagoon	12,500		
	$212,000		
yard work (15% const)	31,800		
engineering	42,400		
	$286,200	$210,000	1.36
Plant Q (2.5 mm gal/day)			
Category 4			
Aeration	$ 59,000		
Aeration equipment	123,400		
Clarifier	116,400		
3 day lagoon	3,200		
	$330,800b		
yard work (15% const)	49,600		
engineering	60,000		
	$440,400	$554,000	0.79
Plant X (1.7 mm gal/day)			
Category 5			
Aeration basin	$ 57,000		
Aeration equipment	23,600		
Clarifier	98,800		
3 day lagoon	27,000		
	$206,400		
yard work (15% const)	31,000		
engineering	47,000		
	$284,400	$335,400	.85

[Land cost left off these estimates in order to compare with plant reported

cost -- maximum land cost, plant Q, is $6000.]

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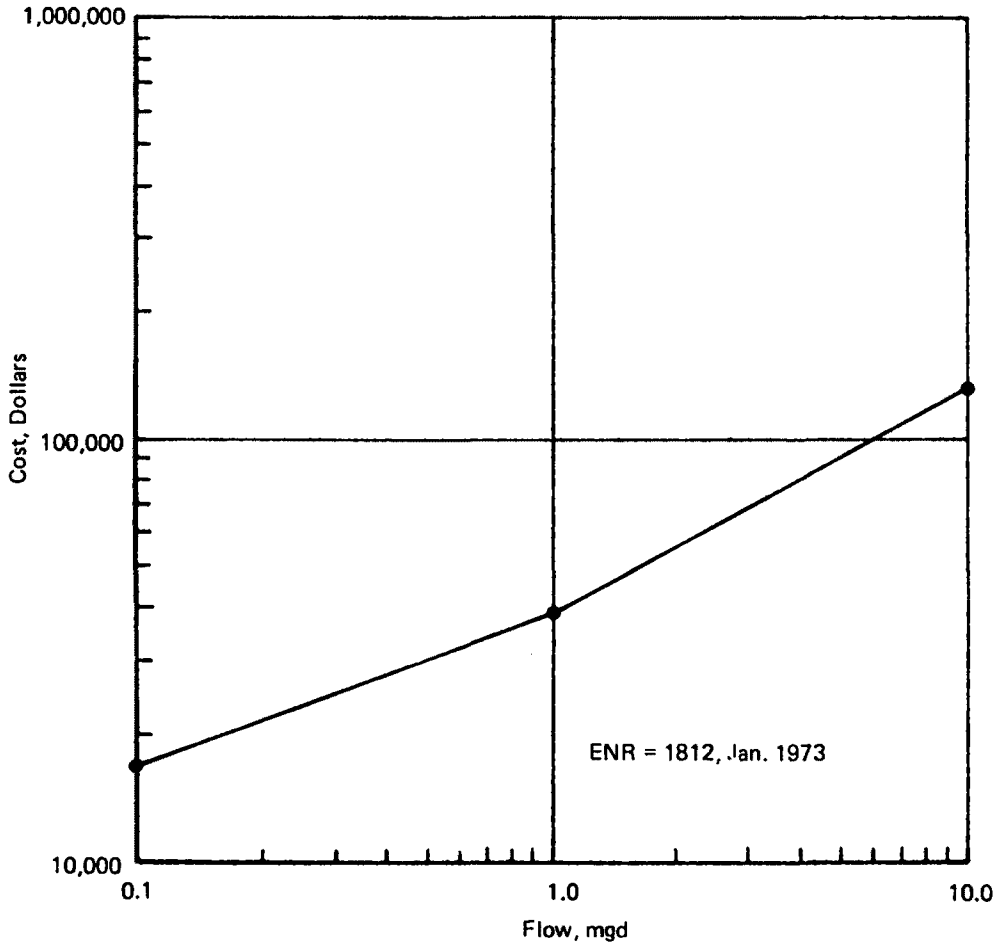

FIGURE VIII–2 AERATED STABILIZATION BASIN CONSTRUCTION COST

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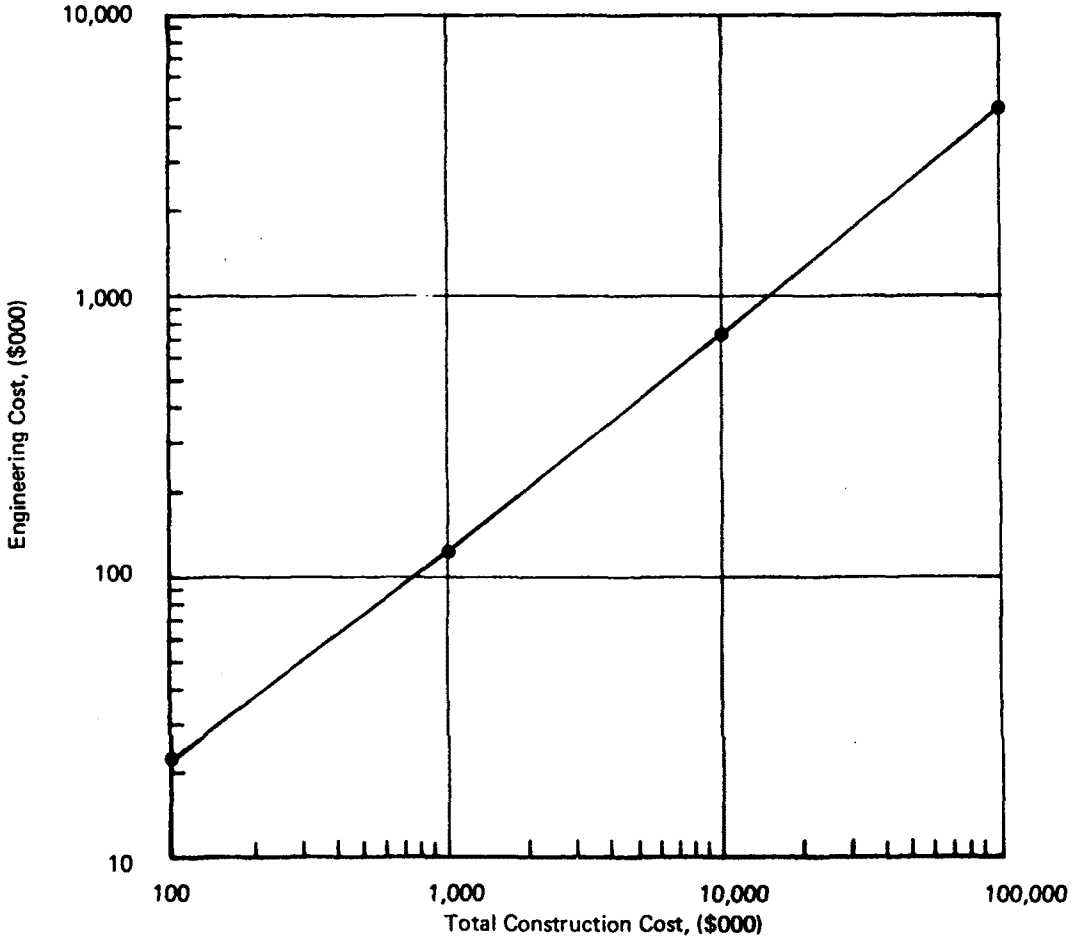

FIGURE VIII–3 ENGINEERING COSTS

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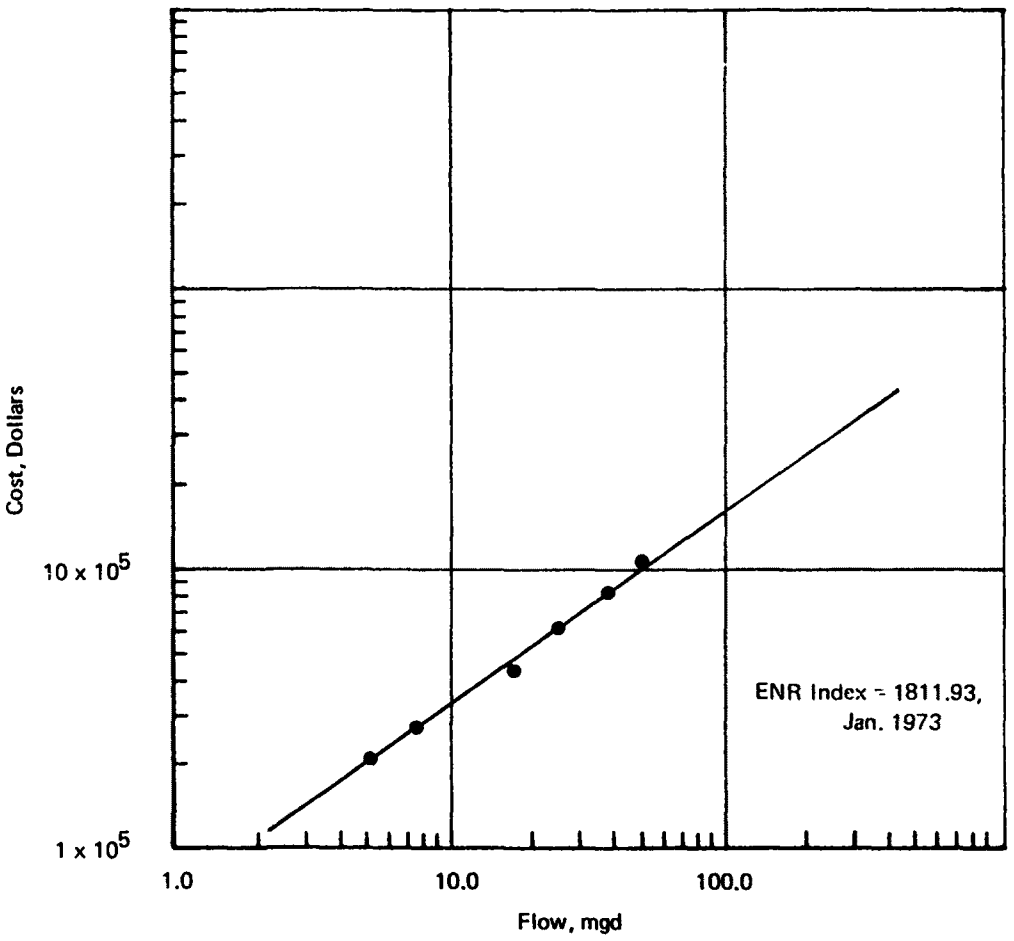

FIGURE VIII–4 CLARIFIER CAPITAL COST

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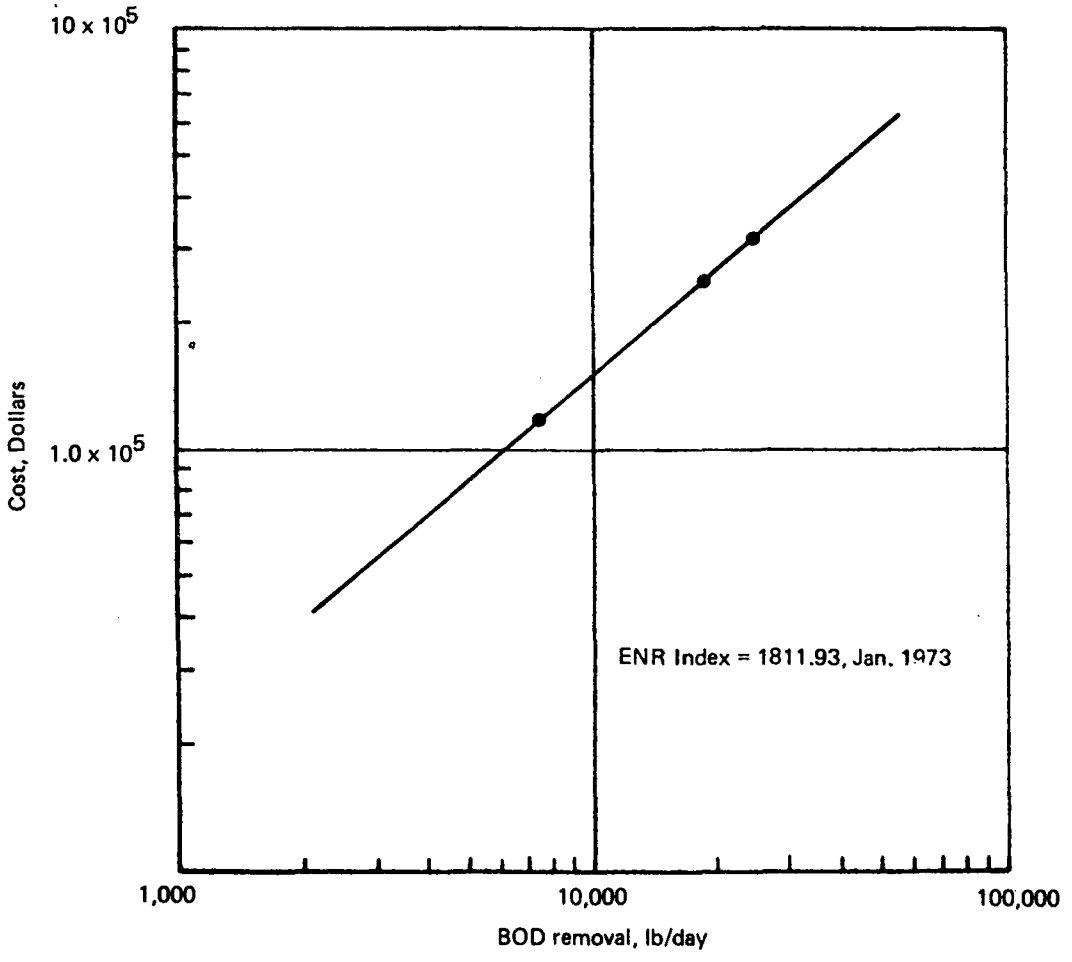

FIGURE VIII–5 AERATED STABILIZATION BASIN
(Aeration Equipment Only)

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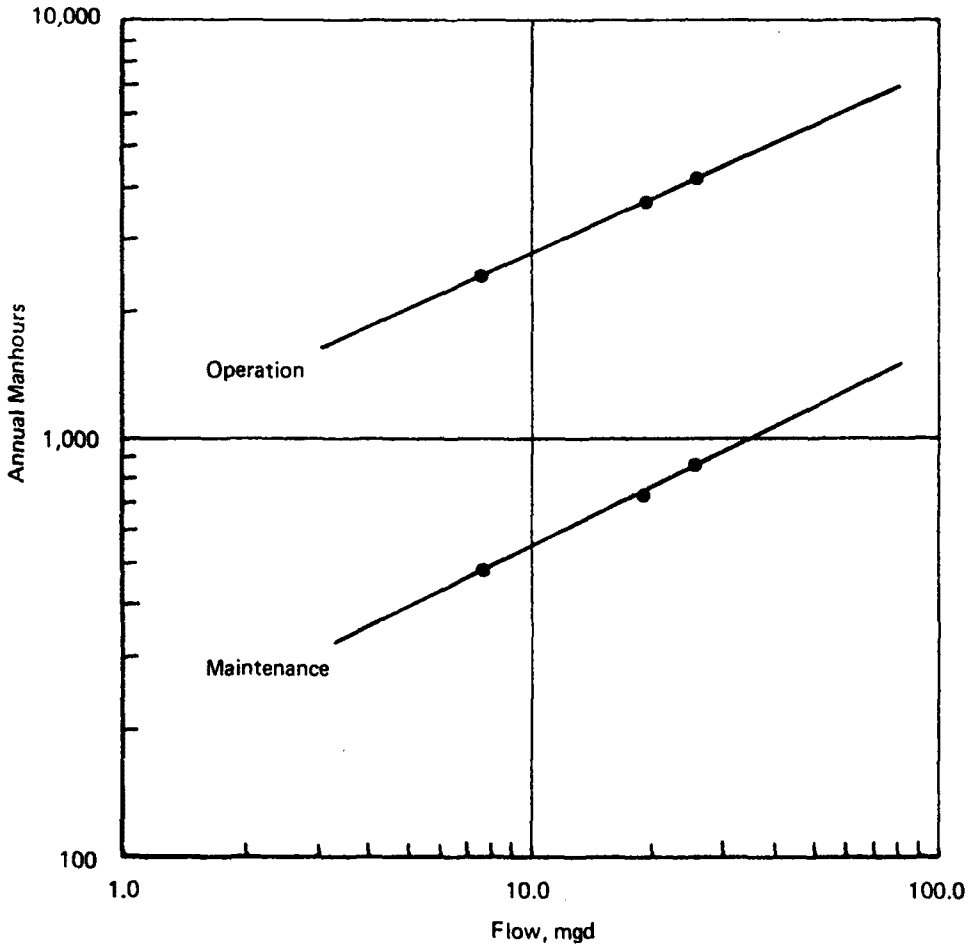

FIGURE VIII–6 AERATED STABILIZATION BASIN ANNUAL OPERATION AND MAINTENANCE LABOR

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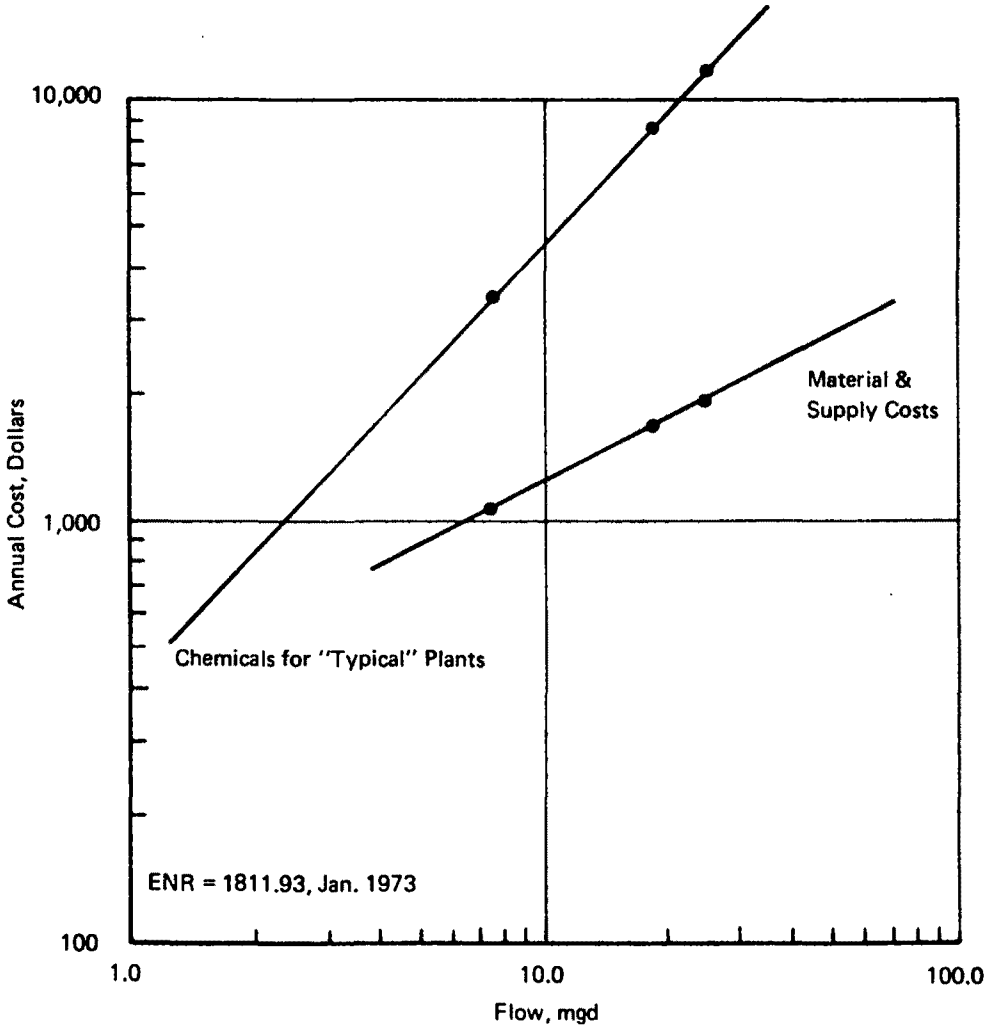

FIGURE VIII–7 AERATED STABILIZATION BASIN
1. Material and Supply Costs, Annually
2. Chemical Costs

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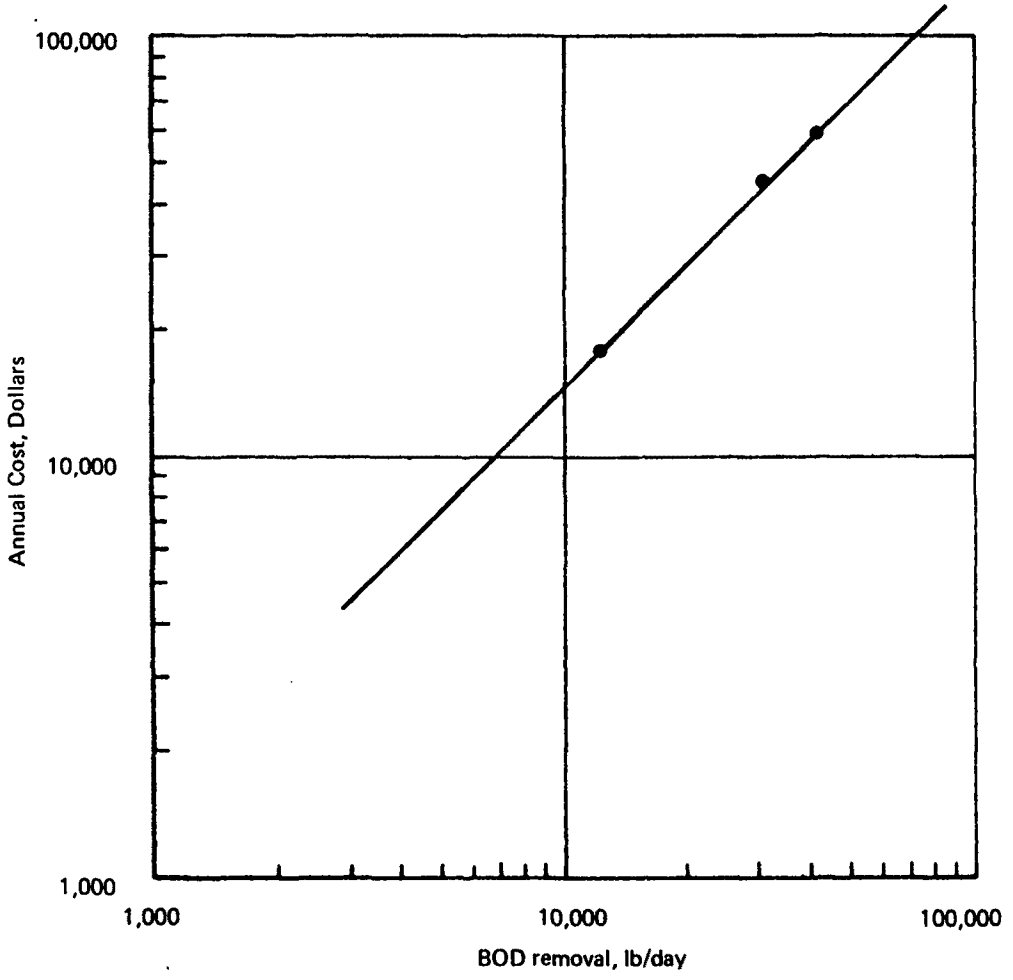

FIGURE VIII–8 AERATION EQUIPMENT ANNUAL POWER COSTS
Aerated Stabilization Basin

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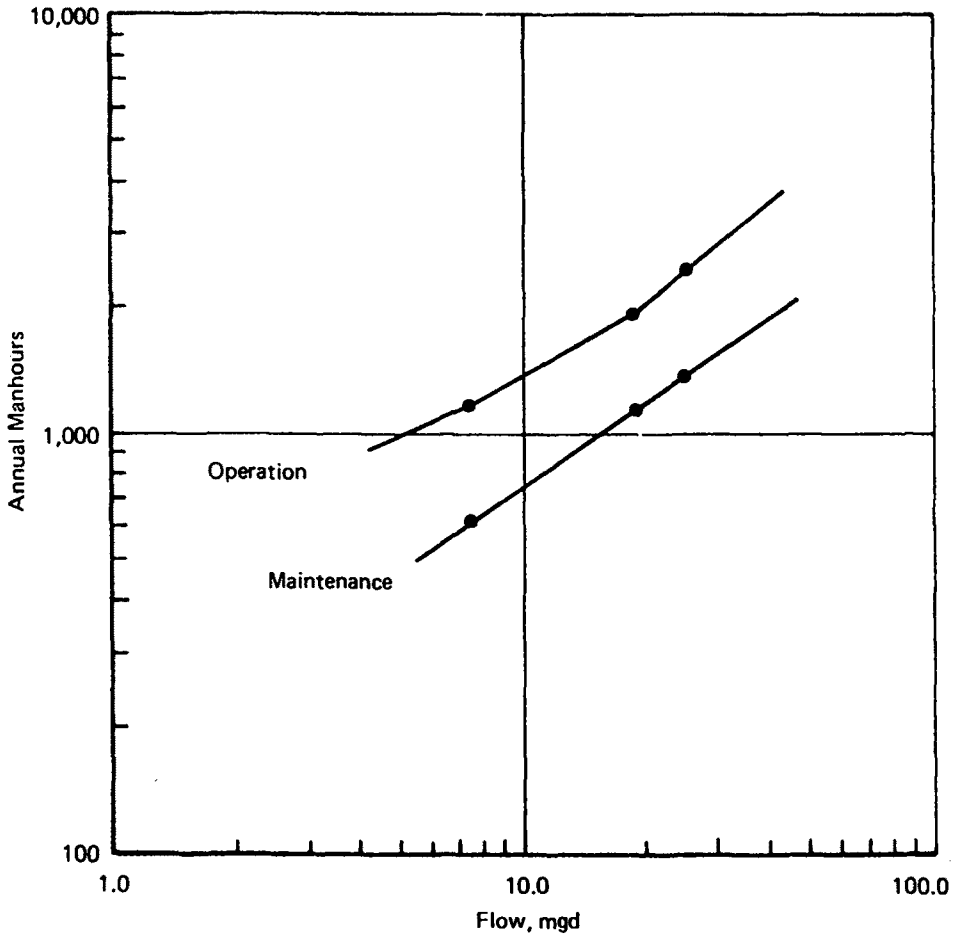

FIGURE VIII–9 CLARIFIER, ANNUAL OPERATION AND MAINTENANCE LABOR

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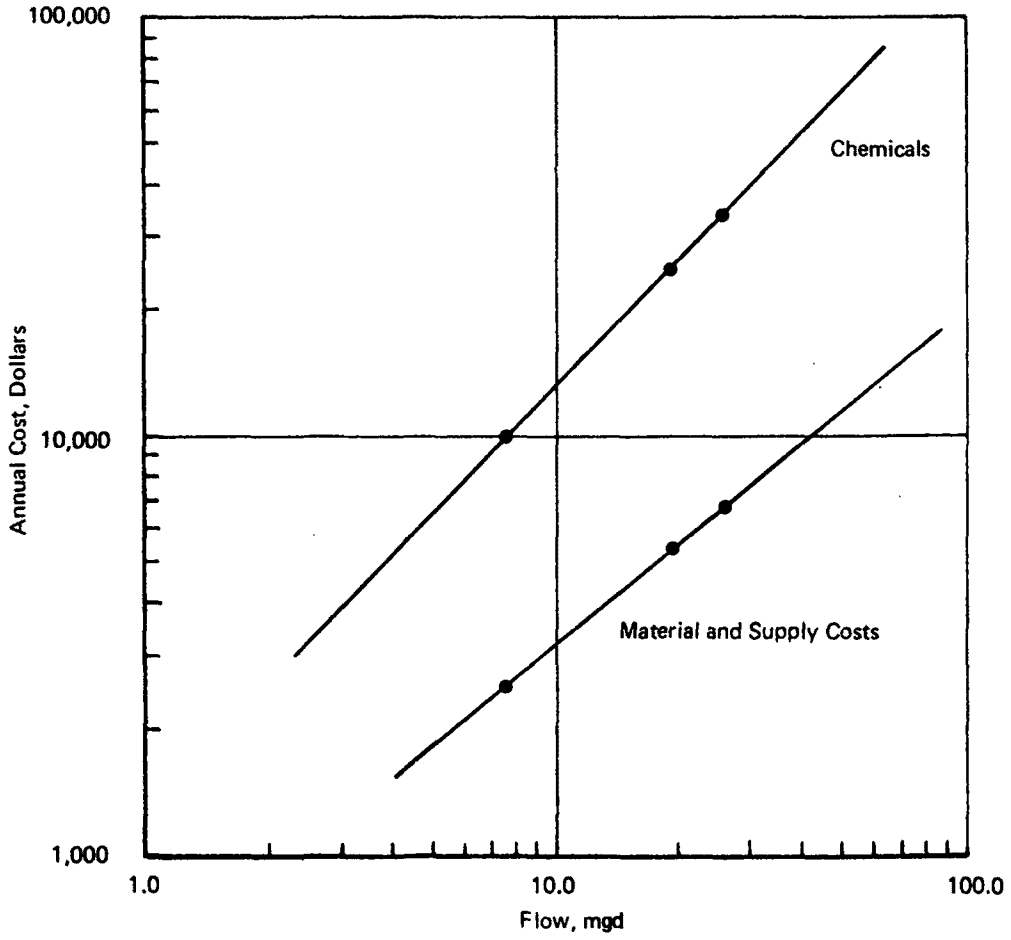

FIGURE VIII–10 CLARIFIER

1. Material and Supply Costs, Annually
2. Major Chemical Costs

an overall cost figure of $264 for 1 cu m/day or $1.00 for 1 gpd was assumed.) Figures VIII-6 to VIII-10 present the operating and maintenance costs over the ranges of production found. The initial capital cost of biological treatment systems depends mainly upon (and here is related to) the hydraulic load, the other factors making only minor variations in the total cost. Operating costs, on the other hand, have been viewed as dependent on pollutant as well as hydraulic loads.

Costs for representative large plants in industry categories were developed using these curves and assuming an aerated stabilization basin, which is widely used by the industry when land is readily available. The following items were determined for the individual treatment steps:

(1) Construction cost as a function of hydraulic load at a given pollutant level;

(2) Operating and maintenance labor as a function of hydraulic load;

(3) Chemical requirements as a function of hydraulic and pollutant load;

(4) Power requirements as a function of hydraulic and pollutant load;

(5) Additional material and supply cost as a function of hydraulic load.

The cost data used were derived from varied industrial and municipal applications. They are adjusted where possible to reflect specific changes necessary for the textile industry. Costs have been adjusted to a national average cost level of January 1973 using the ENR Construction Cost Index. The estimated cost curves have been adjusted to exclude unusual construction or site-specific requirements. The curves include all elements of construction cost which a contract bidder would normally encounter in completing the wastewater treatment. Included are building materials, labor, equipment, electrical, heating and ventilation, normal excavation and other similar items. Also included are the engineering costs. The annual operating costs include operation and maintenance labor, chemicals, power, material and supplies, and depreciation.

BEST AVAILABLE TREATMENT TECHNOLOGY (LEVEL II)

Zero Discharge

From a consideration of the data on advanced treatment technology given in Chapter VII, reverse osmosis or evaporation followed by incineration appears to show the most promise for achieving zero discharge. The flow diagram for a zero discharge system is shown in Figure VIII-11.

We have carried out detailed costing of this technology for two categories in the textile industry--4, Woven Fabric Finishing, and 5, Knit Fabric Finishing--because these two segments contributed the major waste loads in the industry. To compute the total costs, we have assumed water economy and reuse within the process, and for Category 4 show some of the ways this might be achieved.

The continuous wet processing of woven 100 percent cotton cloth is carried out in a series of baths, saturators, and/or holding devices. The unit operations making up the over-all process vary from plant-to-plant and line-to-line and depend on the product and on individual company preferences. It is, therefore, impossible to pick a standard process that characterizes the industry, and also provides an example of exemplary operations.

After review of the literature, field interviews and discussions amongst consultants and industry experts, the process, as outlined in Figure VIII-12, was decided on as the most extensive representative that may be encountered for category 4. This processing consists of taking 100 kg/1000 kg of PVA sized greige goods through water desizing, caustic scouring, two stages of peroxide bleaching, followed by mercerizing and dyeing.

At the given production rate, the water balance for this series of unit operation shows 2020 gpm of water going to the sewer or a discharge of 22.3 gallons of water per pound of cloth produced.

The present state of technology, as represented by Figure VIII-12, shows the complex nature of wet processing being practiced today. In attempting to reach a water usage for Level II application, a two-step recycle approach is hypotehsized. The first step is represented by Figure VIII-13. To reduce the water consumption counter-current processing was imposed on the process as follows. The wash effluent from the second stage peroxide bleaching is introduced as wash water to the first stage, and effluent from this wash is used one step further back in the scouring wash. Because of the nature of the process, this is probably the extent to which counter-current processing can be utilized. However, there is no apparent reason why the desizing waste stream, which consists of PVA and/or PVA-starch blends cannot be introduced as a

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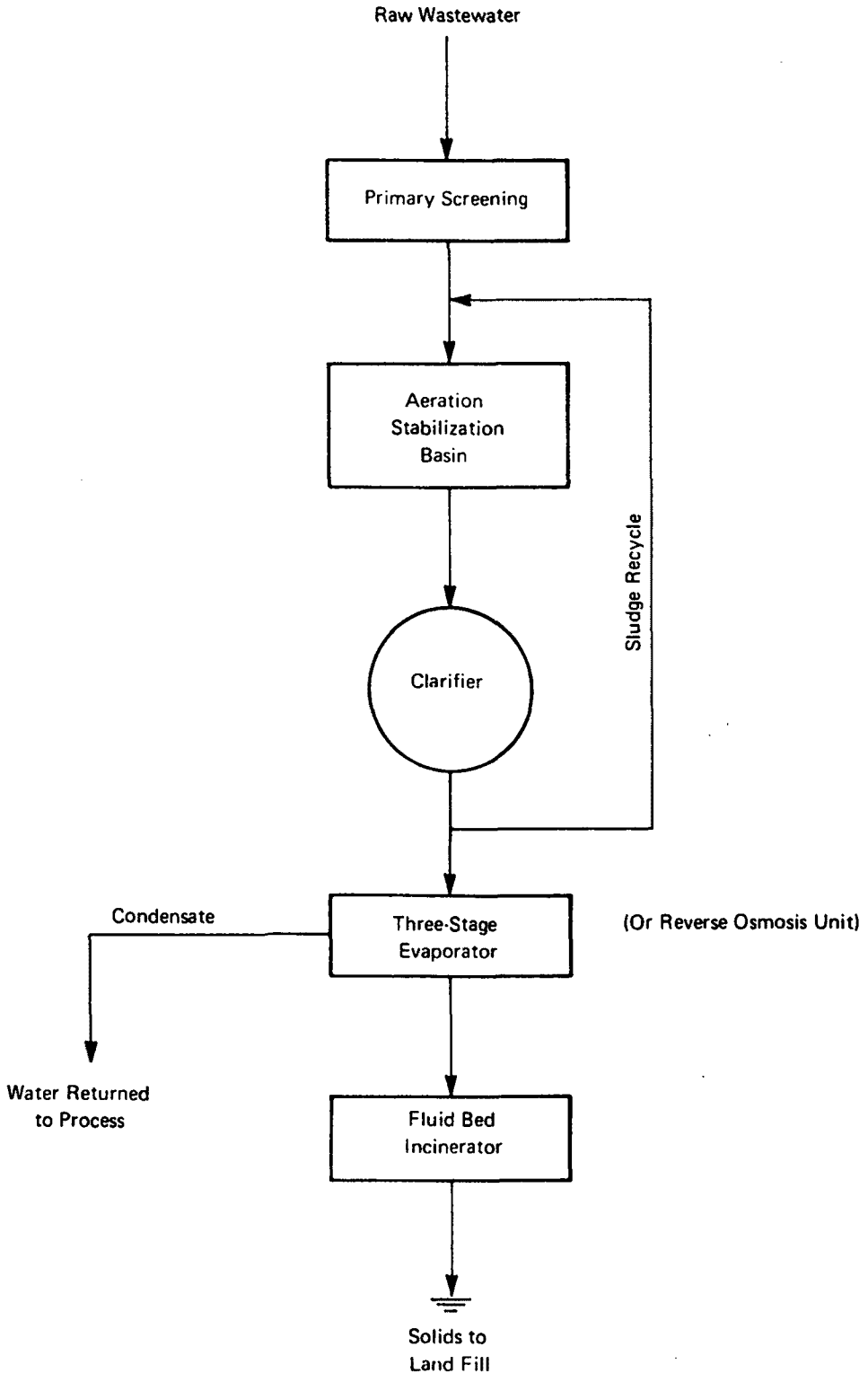

VIII-11 SCHEMATIC FLOW DIAGRAM OF PROCESS STEPS AND COST CENTERS FOR ZERO DISCHARGE TREATMENT

first-stage scouring wash, as shown in Figure VIII-13. The dilution factor in the wash stream from desizing should minimize the problems of starch-caustic reactions in this processing step. Also, the concentrations of caustic (20%) used in mercerizing should allow for evaporation and reuse.

The second step is shown in Figure VIII-14. The major difference rep

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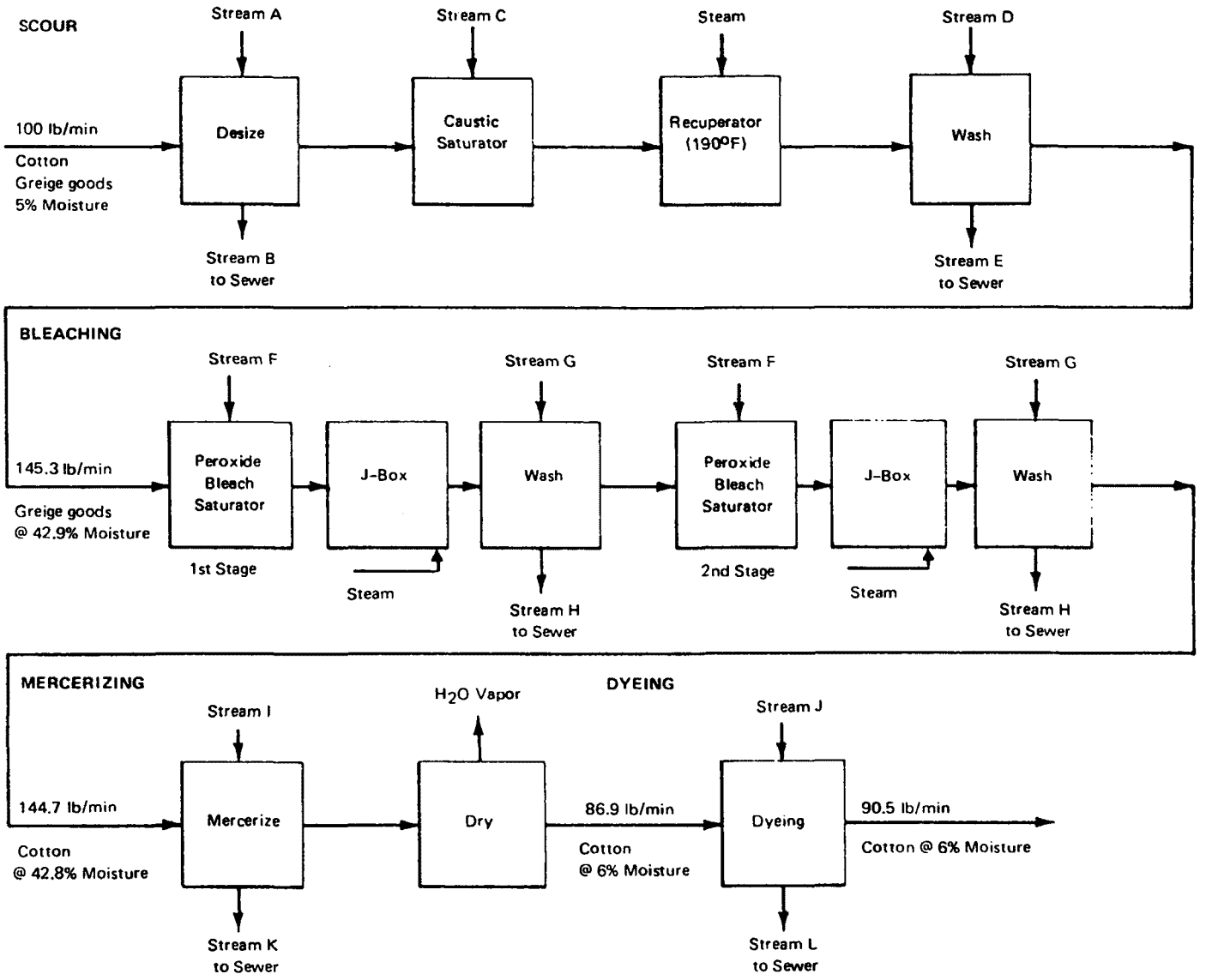

FIGURE VIII-12 1000% COTTON-ROPE CONTINUOUS WET PROCESSING (present practice)

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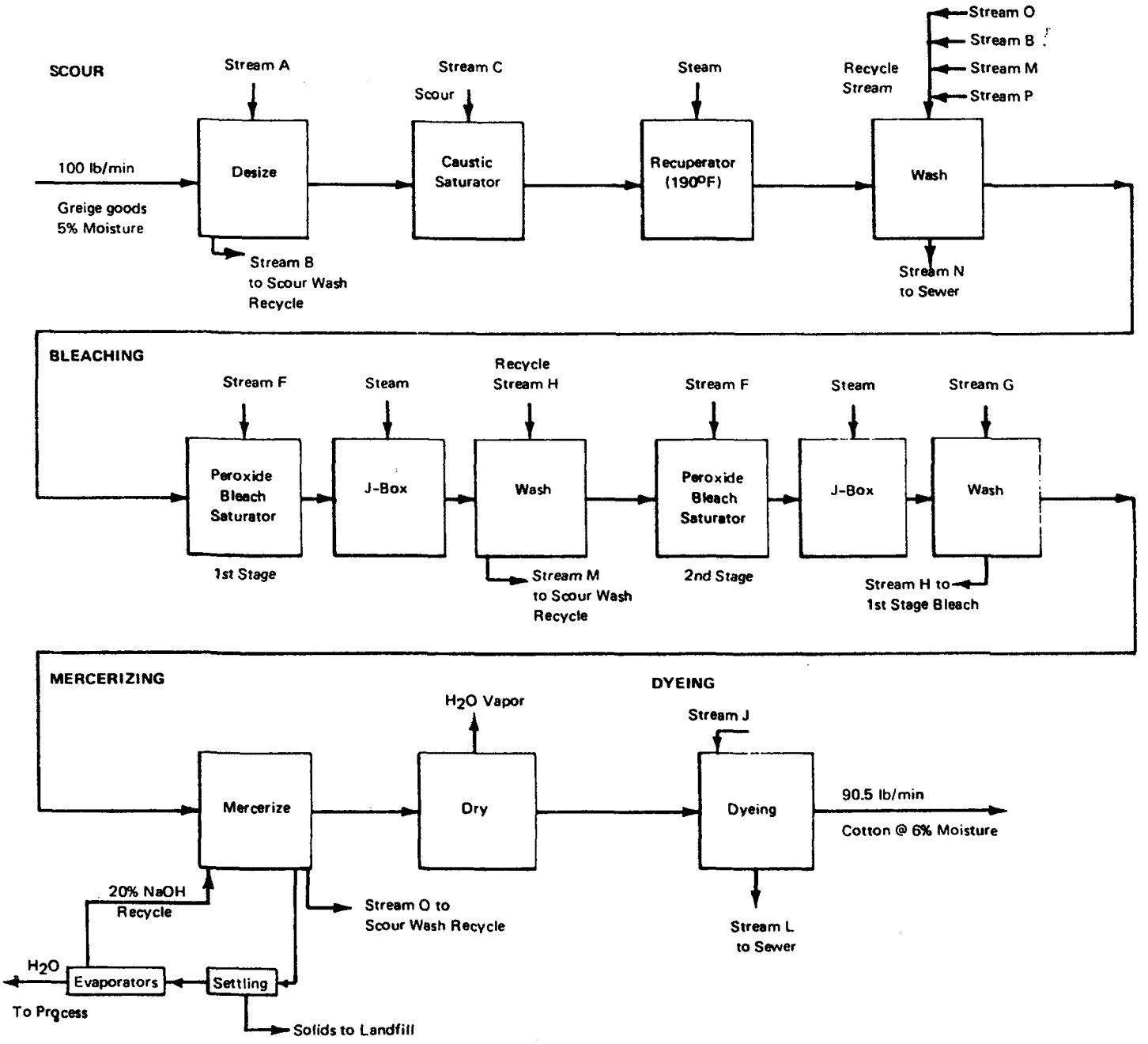

FIGURE VIII-13 100% COTTON-ROPE CONTINUOUS WET PROCESSING (1st pass recycle)

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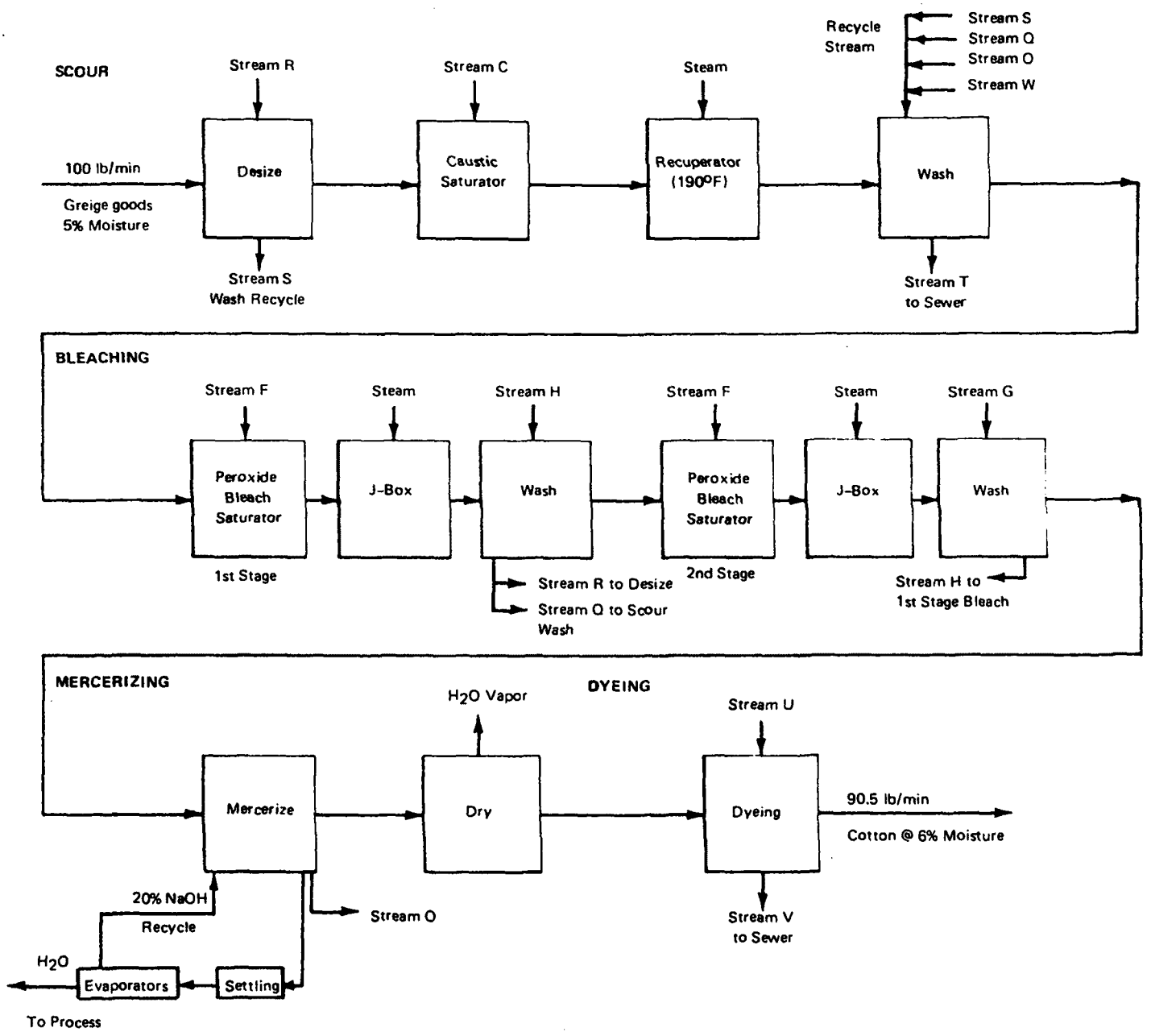

FIGURE VIII-14 100% COTTON-ROPE CONTINUOUS WET PROCESS (2nd pass recycle)

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resented in this figure is the use of full counter-flow washing in each process step. As a result, water consumption for the outlined process is projected at 805 gpm or 8.9 gallons per pound of cloth produced. Further in-process recycling of water shows diminishing returns, therefore, the next logical step is treatment of the wash stream to provide zero discharge of water pollutants. Although it might be possible to treat waste streams from the individual process steps, because of scale of operations and lack of proven technology, only the cost of treating the final effluent can be realistically estimated.*

Two processes were evaluated as the most applicable for reaching zero discharge: (1) multi-stage flash evaporation followed by incineration; and (2) reverse osmosis followed by incineration. Evaporation represents proven technology and reverse osmosis unproven technology in this industry. Tables VIII-2 through VIII-5 show the cost calculations as applied to these to treat the waste streams for the outlined process.

The information as summarized in Table VIII-2 shows that the cost of evaporation varies from $0.77 to $0.94/1000 liters ($2.90 to $3.56/1000 gallons) and for reverse osmosis from $0.94 to $1.06/1000 liters ($3.56 to $4.02/1000 gallons), as concentration increases and flow rate decreases. With a credit of 4¢/1000 liters (15¢/1000 gallons), assuming that the water can be recycled to the process, these costs reduce to $0.76 to $0.93/1000 liters ($2.88 to $3.54/1000 gallons) for evaporation and $0.93 to $1.05/ 1000 liters ($3.54 to $4.00/1000 gallons) for reverse osmosis. Economic differences between the two processes appear to be small and within the error of estimation.

The wet processing of nylon and/or acetate knit goods normally consists of dyeing with dispersed systems, followed by treating with resins for shrinkage resistance, usually in a batch system. A unique feature of

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TABLE VIII-2 "ZERO" DISCHARGE COSTS 100% COTTON - ROPE

	1st Pass Recycle (figure VIII-22)		2nd Pass Recycle (figure VIII-23)	
Flow.	(1.87 MGD, 14.4 gal/lb)		(1.16 MGD, 8.9 gal/lb)	
Solids (TDS)	N 2000 mg/l		N 4000 mg/l	
	Multi-Flash Evaporation	Reverse Osmosis	Multi-Flash Evaporation	Reverse Osmosis
Total Cap. Employed	$ 4,232,000	$3,427,000	$3,151,000	$2,323,000
Annual Oper. Cost	1,151,000	1,759.900	892,700	1,249,000
Indirect Oper. Cost	825,300	668,300	614,500	453,000
Total Costs/Year	1,976,300	2,428,200	1,507,200	1,702,000
$/day	5,414.52	6,652.60	4,129.32	4,663.01
$/1000 gallons	2.90	3.56	3.56	4.02
Secondary Treatment Cost @ $/1000 gallons	.13	.13	.13	.13
Credit for Water Saved @ $15/1000 gallons	.15	.15	.15	.15
Net Final Cost				
$/1000 liters	.76	.93	.93	1.05
$/1000 gallons	2.88	3.54	3.54	4.00
Net Final Cost				
¢/kg of cloth	9.1	11.2	6.9	7.8
¢/lb of cloth	4.1	5.1	3.2	3.6

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TABLE VIII-3 FLOW AND SOLID CALCULATIONS

1st Pass Recycle (figure VIII-22)

Water to sewer:
Flow - 1300.1 gpm or 1.87 MGD
Solids - 34.45 lb/min or 49608 lb/day

$$\frac{34.45 \text{ lb/min}}{1300.1 \text{ gpm}} \quad \frac{453.6 \text{ mg/lb}}{3.79 \text{ liter/gal}} \quad 10000 \text{ mg/gm} =$$

3171 mg/liter Total Solids.

$$3171 \text{ mg/liter} \times \frac{26.5 \text{ lb/dissolved solids}}{34.45 \text{ lb/total solids}} =$$

2434 mg/l dissolved solids.

Therefore use 2000 mg/l.

2nd Pass Recycle (figure VIII-23)

Water to Sewer:
Flow - 805 gpm or 1.16 MGD
Solids - 34.45 lb/min
Concentration is 3834.2 mg/l Dissolved Solids or approx. 4000 mg/l

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TABLE VIII-4 MULTI-STAGE FLASH INCINERATION

	1st Pass Recycling (1.87 MGD) 2000 Mg/l TDS	2nd Pass Recycling (1.16 MGD) 4000 Mg/l TDS
Capital Employed		
Multi-Stage Evap.	$2,850,000	$1,950,000
Crystallization	270,000	270,000
Land fill	240,000	240,000
	$3,360,000	$2,460,000
Engineering	320,000	280,000
Contingency (15% of above)	552,000	411,000
Total Capital Employed	$4,232,000	$3,151,000
Annual Oper. Costs		
Labor Oper. $5/hr x 19500 hr	97,500	97,500
Main. $5.5/hr x 6400 hr	35,200	35,200
Fringe (25%)	33,200	33,200
Total Labor	$ 165,900	$ 165,900
Electric Power	143,800	89,200
Fuel	551,500	403,100
Solids Disposal	92,500	92,500
Maintenance Mat. (4%)	169,300	126,000
Chemical & Oper. Suppl.	28,000	16,000
Total Oper. Costs	$1,151,000	$ 892,700
Indirect Oper. Costs		
Taxes & Ins. (@ 1 1/2% cap)	63,500	47,300
Cost of Capital (@ 8%)	338,600	252,400
Depreciation (@ 10%)	423,300	315,400
Total Costs	$1,976,300	$ 614,500
$/day	5,414.52	4,129.32
	$0.77/1000 liters ($2.90/1000 gal)	$0.94/1000 liters ($3.56/1000 gal)

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TABLE VIII-5 REVERSE OSMOSIS, EVAPORATION INCINERATION

	Reverse Osmosis Evaporator-Crystallizer		
	1st Pass Recycle (1.87 MGD) 2000 Mg/l TDS		2nd Pass Recycle (1.10 MGD) 4000 Mg/l TDS
Capital Employes			
Reverse Osmosis	$1,900,000		$1,020,000
Crystallizer	560,000		560,000
Land Fill	240,000		240,000
	2,700,000		1,820,000
Engineering	280,000		200,000
Contingency (15% of above)	447,000		303,000
Total Capital Employed	$3,427,000		$2,323,000
Annual Oper. Costs			
Labor: Oper. $5/hr 12,000	60,000	7200	36,000
Main. $5.5/hr 5,000	27,500	3100	17,100
Fringes 25%	21,900		13,300
Total Labor	$ 109,400		$ 66,400
Electric Power 1405 kwh/dy/mgd	1,136,400		705,000
Fuel	180,200		220,168
Solids Disposal	92,500		92,500
Maint, Mat. & Supply (1 1/2%)	51,400		34,900
Chemical & Membranes	190,000		130,000
Total Oper.	$1,759,900		$1,249,000
Indirect OPer. Cost			
Taxes & Insur. (1 1/2%)	51,400		34,900
Cost of Capital (8%)	274,200		185,800
Deprec. (10%)	342,700		232,300
Total Costs	$2,428,200		$1,702,000
$/day	6,652.60		4,663.01
	$0.94/1000 liters ($3.56/1000 gal)		$1.06/1000 liters ($4.02/1000 gal)

dispersed dyes is that they do not require the use of salts in the dyeing The high use of soluble salts in dye plants is a principal factor militating against extensive re-use of process water in the textile industry. The two knit mills considered here do not utilize salt to any great extent in their dyeing and indeed this is a fundamental reason these are among the first types of plants to consider recycling dye waters.

In our examination of this segment of the knit industry we focused on two exemplary mills, one making nylon acetate lingerie and one making nylon hosiery. The water usage for dyeing in the lingerie plant is 25-33 l/kg (3 to 4 gal/lb) of cloth and in the panty hose mill (8.1 gal/lb) 68 l/kg of cloth.

Process flow sheets for the two plants are shown in Figures VIII-15 and

VIII-16. These flow sheets show the sources of the waste stream and the total flow from the dye house to the sewer or treatment plant.

Figure VIII-17 is based on a water treatment system that is in start-up phases at Plant HH. This system is designed to treat dispersed dye wastes and is applicable to similar wastes in considering Level II guidelines. The process, as described, flocculates, filters, and de-ionizes the water, removing enough impurities to allow for recycling.

The only liquid waste system from the process is the de-ionizer regeneration stream. This amounts to 23 to 32 kilograms (50 to 70 pounds) of salts (Mg and Ca) dissolved in 10200 liters (2700 gallons) of H20 every two days, which is currently discharged to municipal treatment plants. For zero discharge, these salts could be disposed of via an evaporative type process.

The estimated costs of treating the wastes, via the process outlined in Figure VIII-26 for zero discharge are shown in Table VIII-6. Treatment costs are approximately $0.42/1000 liters ($1.60/1000 gal) or $0.02/kg ($0.01/lb) of product, including evaporation of de-ionizer regenerative waste. After taking credit for the recycled water the net cost comes to $0.38/1000 liters ($1.45/1000 gal).

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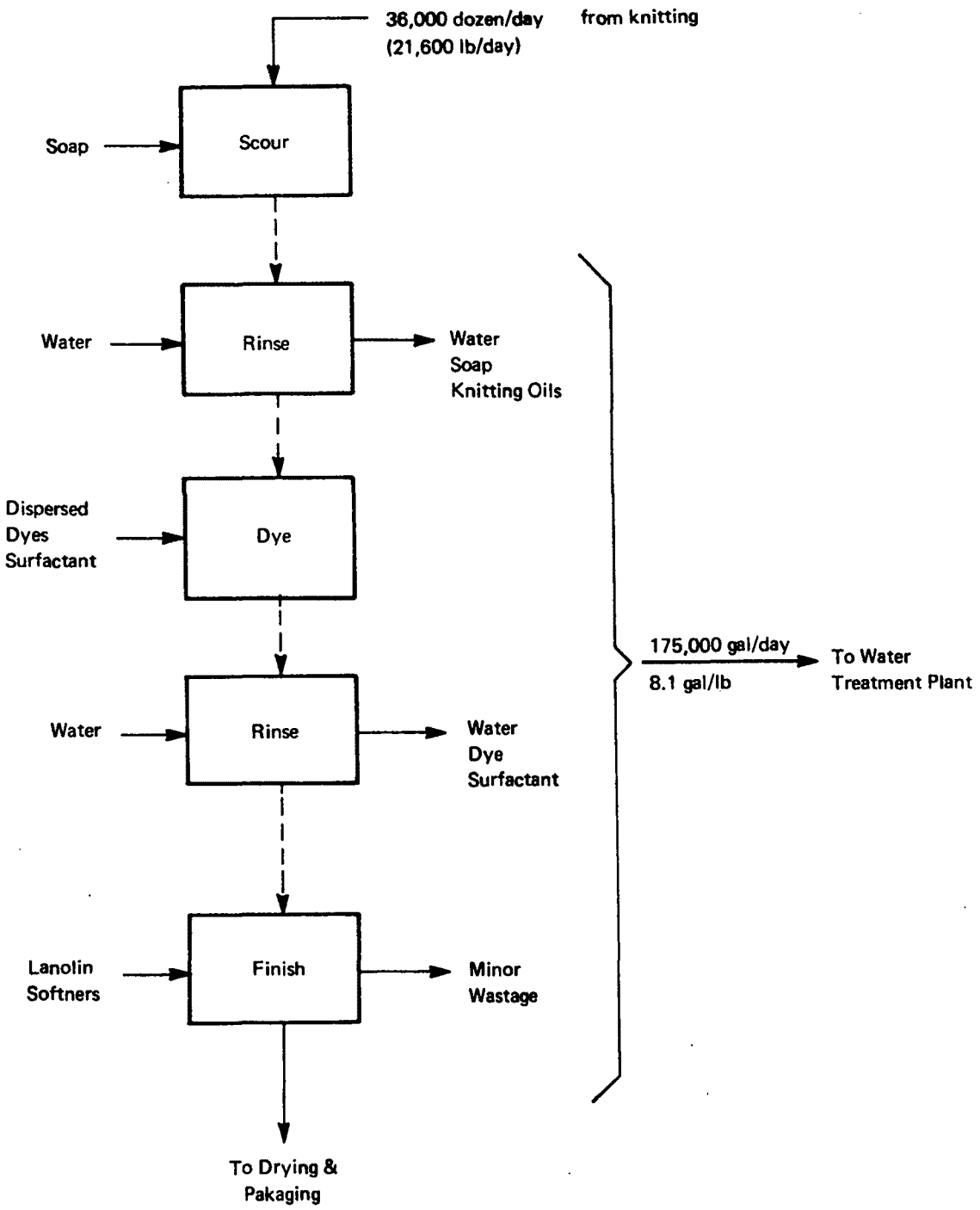

FIGURE VIII-15 WOMENS' NYLON PANTY HOISERY BATCH

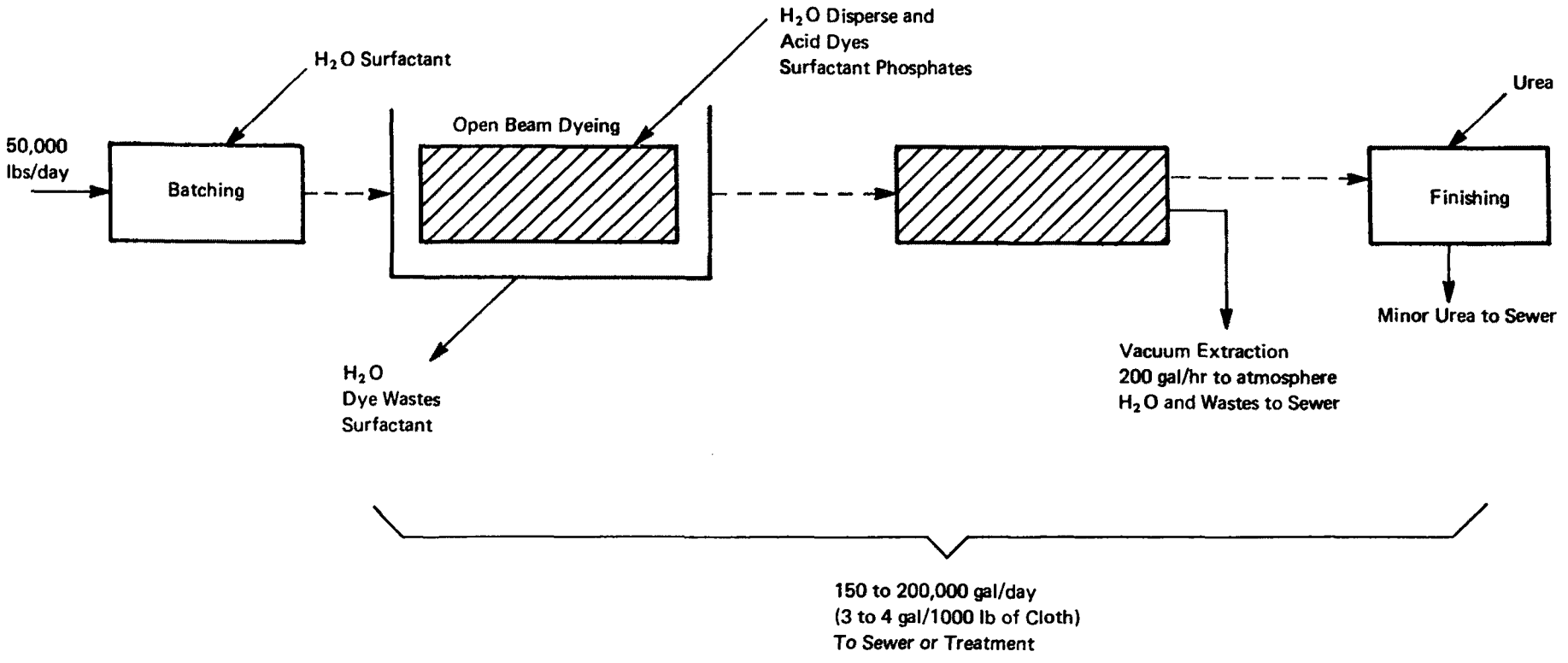

FIGURE VIII-16 NYLON/ACETATE KNIT GOODS BATCH

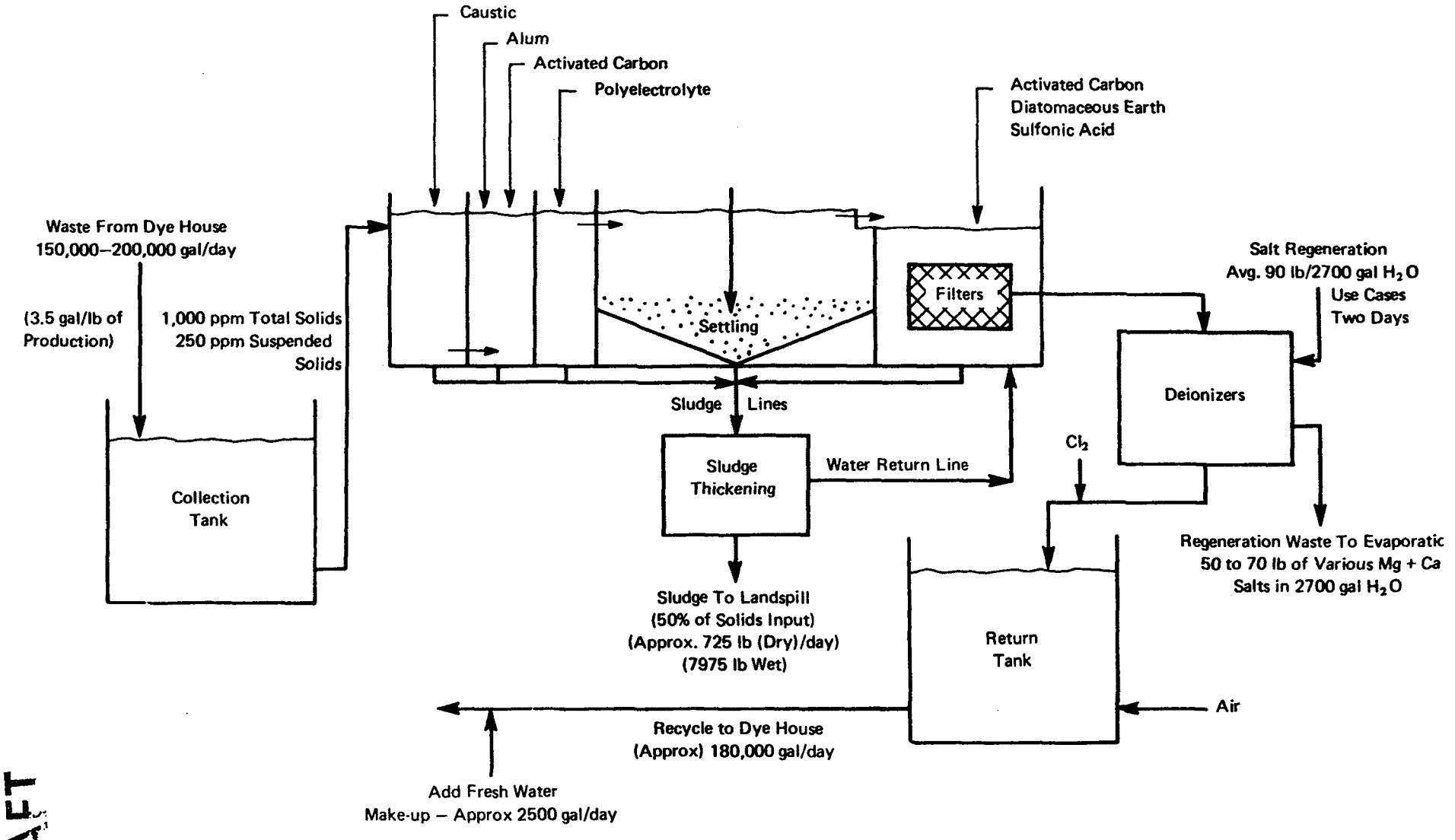

FIGURE VIII-17 NYLON/ACETATE KNIT WATER TREATMENT PLANT DISPERSED OR ACID DYES

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TABLE VIII-6

ESTIMATED COSTS OF WATER TREATMENT (ZERO DISCHARGE) FOR NYLON/ACETATE KNIT GOODS*

Capital Employed		
Treatment Plant (including Eng., etc)		$ 120,000
Evaporator (De-ionizer Regeneration Wash)		25,000
		$145,000
Annual Oper. Costs		
Chemical	$10,000 - 15,000	
Labor (includingffringe)		30,000
Maintenance & Related (5% of capital)		7,250
Steam & Power		3,300
Make up Water ($.20/1000 gal, 25,000 gpd)		1,500
Total Oper. Costs		$57,050
Indirect Oper. Costs		
Taxes & Insurance (1 1/2% of Cap.)		2,180
Cost of Capital (@ 10%)		14,500
Depreciation (@ 7%)		10,150
Total Indirect Costs		$26,830
Total Costs		$83,880
$/day		293.29
$/1000 liters		0.42
$/1000 gallons		1.60
Credit for recycled water @ 15¢/1000 gal		0.15
Net water cost		1.45/1000
		0.38/1000 1

*Basis: Plant described in Figure VIII-26

Ref: Plant HH and ADL Estimates

SECTION IX - Best Practicable Control Technology Currently Available

INTRODUCTION

The best practicable control technology currently available has been found to be comparable to the primary and secondary treatment of municipal sewage.

Level I guidelines are based essentially on well-operated activated sludge plants or extended aeration lagoons, along with chemical separation of heavy metals in some of the industry categories. The not-to-exceed guidelines that are recommended will require 93 percent or more BOD removal in four of the six categories that have significant pollution.

This technology has proved to be applicable regardless of the age or size of the plant. It is capable of reducing concentrations of oxygen demanding substances in the effluent stream to reasonable limits, depending upon the treatability of the wastes. However, variations due to the vagaries of the microorganisms as well as process and climatic conditions are normal for any well-designed biological waste water treatment plant.

An activated sludge system which is permitted to operate at a constant F:M ratio all year round and with minimum operational changes would have a natural variation as shown by the solid line in Figure IX-1.
A similar system with careful operational control would have a controlled monthly average variation as shown by the points. Although the mean value is the same, the amount of natural variation is controlled by the operator through aeration rate control, sludge recycling and F:M ratio adjustments. These adjustments can be made daily so that monthly averages can be held within the desired limits.

Although a well-operated facility (properly designed) can be controlled within ±25 percent of the average on a monthly operating basis, an allowance of 50% deviation from the average will be used to calculate the maximum monthly effluent limitation.

The results of this work show that exemplary waste water treatment plants are presently in operation, that their operations are compatible with widely accepted and achievable operational guidelines for biologically-active substances, and that the most significant factors in establishing guidelines and limitations are the pollutants unique to the manufacturing processes.

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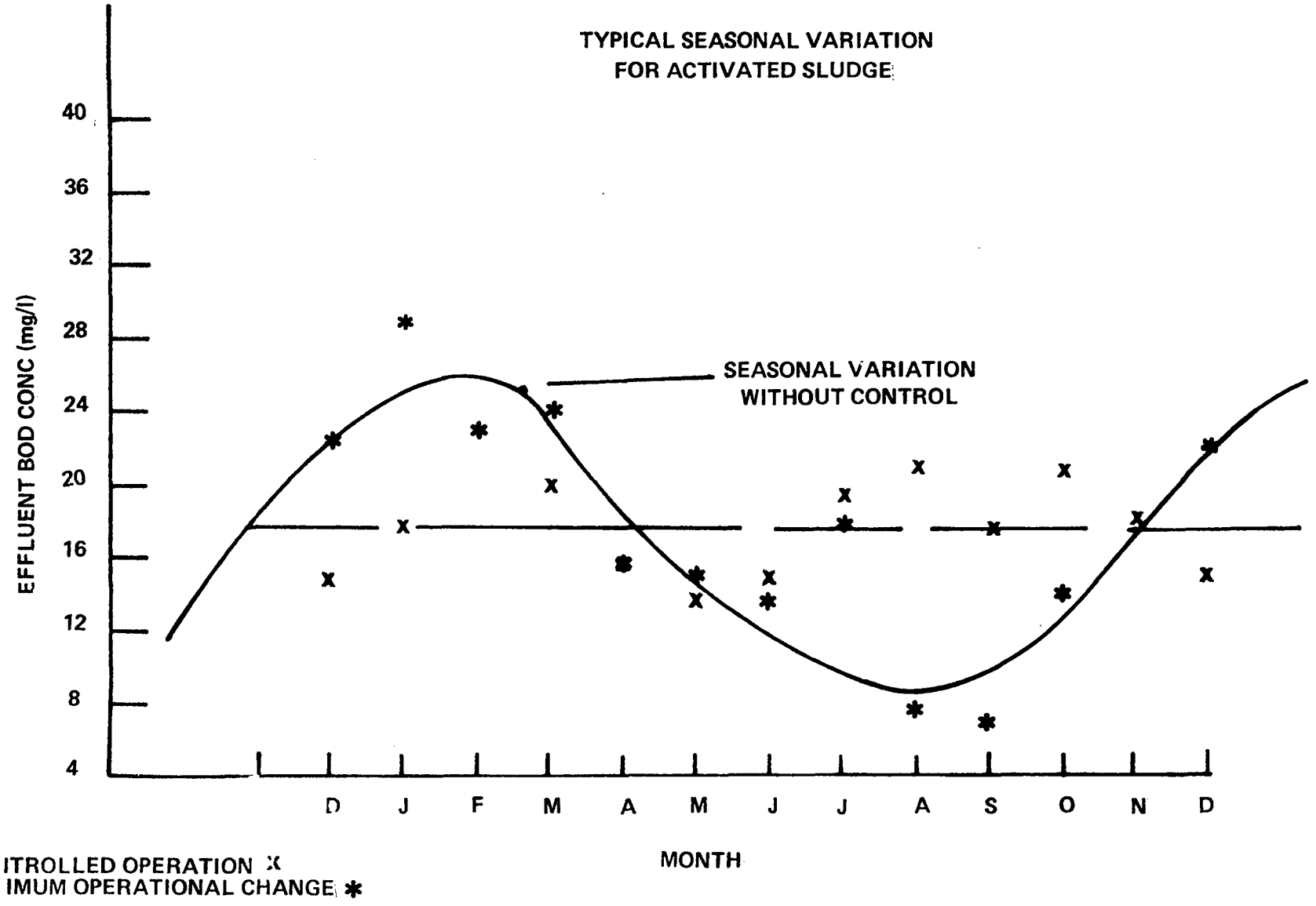

FIGURE IX-1

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EPA and the textile industry desire to simplify the approach to Federal pollution abatement guidelines by using simple subcategories within the industry. It should be understood that decreasing the number of categories makes each less homogeneous and therefore more susceptible to larger variations in waste effluent. Moreover, as discussed in Chapter IV, no simple means of subcategorizing the industry further to take into account varying loads have been found.

These concerns are particularly valid for categories 2 and 7, wool finishing, and stock and yarn dyeing respectively, both of which are on the lower end of the treatability scale (90 percent BOD removal) and categories 1 and 4, wool scouring and broad woven finish, both of which have high raw waste loads.

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CONTROL TECHNOLOGY

The engineering aspects of applying best practicable technology are well understood once the treatability of waste water streams has been established. This treatability can be tested on a laboratory scale or on a pilot plant scale. Scale-up of the test results by the application of techniques widely-used throughout the waste water treatment industry should be relatively straightforward. However, it must be recognized that appropriate safety factors are required in designs and that short-circuiting these factors in order to minimize capital investment may mean the difference between a marginally-performing waste water treatment plant and one performing at achievable efficiencies.

The availability of practicable technology for removal of biologically-active substances means that reduction in the concentration of these substances, as measured by BOD_5 tests, should be achievable within acceptable limits. The cost of achievement and its impact will be a function of the specific plant and its location.

Since biologically active substances in the waste waters have been shown to be removable to degrees commensurate with well-known waste water treatment technology, the development of industry guidelines and limitations must focus on the specific conditions encountered at each operating plant. As has been seen, the conditions depend upon a large number of factors, the most important of which are the following:

1. The water usage rates at the plant. These may vary for a number of reasons, some peculiar to the process, some dependent upon the type and age of equipment, some dependent upon nonprocess practices or requirements, and some upon the age and configuration of the plant.

2. The nature and amounts of pollutants generated per unit of product. The pollutant load per unit of production for similar processes at different locations or between different equipment will vary because it is inherently impossible to control precisely all the physical and chemical variables required to produce a highly-uniform flow of waste water with relatively constant compositions.

3. Segregating and preventing pollutants from entering waste water streams. The in-plant housekeeping practices and process designs that prevent pollution by preventing or minimizing spills, drips and leaks from equipment from entering the waste water system can affect both the raw and treated waste loads.

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4. The relationship between the pollutant-removal capabilities of the end-of-pipe treatment systems and the pollutant levels applied, especially as these may be affected by operational upsets, changes in process operating conditions, or changes in plant production rates.

The limitations that these factors set upon establishing guidelines for best practicable control technology are discussed below.

Biological Oxygen Demand

Using best practicable control technology currently available, industry is capable of attaining and maintaining a BOD_5 level in the effluent within limits imposed usually by the characteristics of the biological treatment system and not by the characteristics of the process. Since it is necessary to consider concentration units, the effects of unusually-high concentration of BOD_5 in the influent to the waste water treatment plant must be given due consideration.

Chemical Oxygen Demand

Measurements of chemical oxygen demand (COD) substituents in the waste water by COD test, or measurement of organic carbon by the TOC test, vary widely because of differences in organic chemical species as well as the influence of oxygen demand by inorganic species. The measurement of COD includes not only substances subject to biological oxidation, but many substances not biologically oxidizable as well. The measured COD content of the treated waste will be expected to vary more widely than the BOD since little or none of the contributing species -- which vary in type and quantity with time -- may be removed. Whereas, biological oxygen demanding substances may be expected to be removed to similar concentration levels in the treated effluent in spite of significant influent variations, that portion of the incoming COD which is non-degradable by biological means will result in the same concentration in the effluent.

Suspended Solids

Gravity sedimentation is the best practicable control technology currently available and is typical of biological waste water treatment processes. The separation of suspended solids by gravity methods is dependent on a number of important operational variables, such as the overflow rates in the sedimentation tanks, the nature of the microorganisms, the effects of climatic conditions on settling lagoons, the effects of temperature variations in the waste water flows, the presence of colloidal particulates from the process operations, and the effectiveness of such sedimentation aids as polyelectrolytes or

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adsorptive flocs. Other methods for separation of suspended solids are available, such as dissolved air flotation or in-depth media filtration.

In general the problem of suspended solids removal in this industry is analogous to that of municipal sewage treatment plants except for a small number of unique considerations. The limitations of best practicable control technology currently available for removal of suspended solids are due to the nature of the colloidal substances produced in the process or in the waste water treatment system where soluble substances are converted into insoluble solids. Consequently, variability in the concentration of suspended solids from a well-designed and operated waste water treatment plant can be attributable to both process and waste water treatment plant operations, and not predominantly to one or the other, as in the case of BOD and COD. The removal of suspended solids requires conscientious and capable operation of well-designed waste water treatment plants operating within practicable parameters.

Heavy Metals

Except for chromium used in dyeing and as a rust inhibitor in cooling water systems, heavy metals are not a significant problem in the textile industry. The removal of chromium from cooling system blowdown is a well-established technology that is currently available from other industries, equipment suppliers, or consultants.

Phenols

Phenolics generally are present in textile waste waters in concentrations where biological treatment is the best practical control technology. Activated carbon absorption has been used for removal from both high concentration and low concentration wastes. The limits that are proposed from this study are based on industry experience with respect to effluent phenol concentrations achieved by activated sludge plants, rather than on specific processes for removing phenols.

Color

The technologies for color removal have been studies to great degree both by private and EPA funded research. Many technologies are available for color removal. However, there is some controversy over analytical measurement techniques proposed for the industry.

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Since color is an aesthetic problem and the technologies are available for its removal, a relatively lenient requirement will be established until sufficient data and agreement can be made on analytical technique.

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Category I: Wool Scouring

Table IX-1 summarizes the effluent characteristics of three mills in this industry subcategory that have waste treatment, one of these is a pilot plant. Plant A is a Southern mill with a waste treatment facility a little over one year old; plant B represents the pilot plant project sponsored by EPA at Barre Wool in Massachusetts; and plant B[1] is a central Texas mill.

A number of wool scouring mills were investigated to determine a range of water use for this subcategory. The values ranged from 0.2 to 4.0 gal/lb of raw grease wool with a median water use of 1.5 gal/lb. A scouring bowl train designed for complete counter current operation which is normal practice in the industry uses 0.5 gal/lb, however, there are variations from plant to plant. Water use value per unit of material of exemplary plant A is influenced to an unknown extent by cooling water. Plant B could reduce its water use by about 35-40 percent if it were to employ a complete counter current operation.

Another plant contacted indicated a present water usage of 0.7 to 1.0 gal/lb with intentions of future water reduction to 0.5 gal/lb.

The water use for wool scouring should not exceed 1.5 gal/lb when normal operating procedures are employed.

Although Plant A appears to be performing well, it has had a history of failures. There is indication based on several months data that the plant can operate at a much higher efficiency. Four monthly averages for BOD_5 from 1972 are 150, 100, 15 and 22 mg/l. The last value, 22 mg/l, was the value indicated on the permit application as being the average concentration in the effluent.

Two methods are available for no discharge of pollutants. One is total containment as exemplified by exemplary plant B[1]. The other is direct incineration. The high concentration of BOD_5, COD and grease makes this an excellent candidate for incineration. This coupled with the difficulty of waste treatment, either chemically or biologically, makes it even more attractive. Looking at the 1985 goal of no discharge; incineration, where land is unavailable, should be of serious interest for a mill considering substantial treatment plant investment at the present. Nevertheless, a biological treatment plant can reduce BOD_5 to an effluent concentration less than 150 mg/l. Other than total containment, present treatment of wool scouring wastes are uniformly inadequate. Therefore, a water use of 1.5 gal/lb (normal practice)

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TABLE IX-1

PERFORMANCE OF MILLS WITH TREATMENT
Category 1: Wool Scouring

Mill	Raw BOD mg/l	Raw BOD kg(lb)/1000 kg(lb)	Treated BOD mg/l	Treated BOD kg(lb)/1000 kg(lb) prod.	BOD Removal Efficiency (%)	Production kg(lb)/d	Water Use l/kg(gal/lb)
A	2500	135	100-200	8	90-95	19,666* (40,000-65,000)	33.4-75.4 (4)
B	2700	90	200-300	8.1	90	29,510 170 (65,000) (375)*	25-29.3 (3-3.5)
B'			No Discharge (total containment)			45,000 (100,000)	18 (1.5)

* Pilot plant capacity 4920 l (1300 gallons) H_2O/day $\frac{4920}{28.8}$ = 170 kg ($\frac{1300}{3.46}$ = 375 lb) equivalent production.

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coupled with an effluent concentration of 150 mg/l results in an effluent limitation of 1.9 lb/1000 lbs.

COD

Much of the COD in the effluent from treatment systems A and B is associated with the suspended solids in the effluent. For biological systems efficient removal of suspended solids will result in maximum removal of COD. The pilot plant at Barre approaches 1500 mg/l COD in the effluent. Although suspended solids removal through the system is not high and the efficiency could be improved, a value of 1500 mg/l COD in the effluent will be employed. The effluent guideline for COD is 19 lb/1000 lbs.

Suspended Solids

Data from the two treatment facilities with effluent indicate that suspended solids can be reduced to below 100 mg/l. The guideline based on this information is 1.3 lb/1000 lbs.

Grease

Grease is a serious problem in the wool scouring subcategory. It has been shown to be recoverable and treatable. Effluent levels observed at Barre Wool indicate less than 100 mg/l in the final effluent. The guideline based on this information is 1.3 lb/1000 lbs.

The guidelines for the wool scouring category are based on pounds of grease wool as received and weighed at the plant.

NOTICE: These are tentative recommendations based upon information in this report and are subject to change based upon comments received and further review by EPA.

Category 2: Wool Finishing

BOD Guidelines

No truely exemplary plants were found from which to draw data for establishing Level I guidelines. Water use for normal practice in this industry subcategory falls in the range of 10 to 40 gal/lb, the latter figure being influenced to an unknown extent by cooling water. For processes considered to be normal for wool finishing, a reasonable water use is 20 gal/lb. Waste water treatment facilities treating waste partially composed of wool finishing wastes have shown consistent reduction of BOD_5 to below 20 mg/l. Combination of these values results in an effluent guideline of 3.4 lb/1000 lbs.

COD

Reduction of COD to values below 200 mg/l has been demonstrated. This coupled with reasonable flow rate results in an effluent limitation of 34 lb/1000 lbs.

Suspended Solids

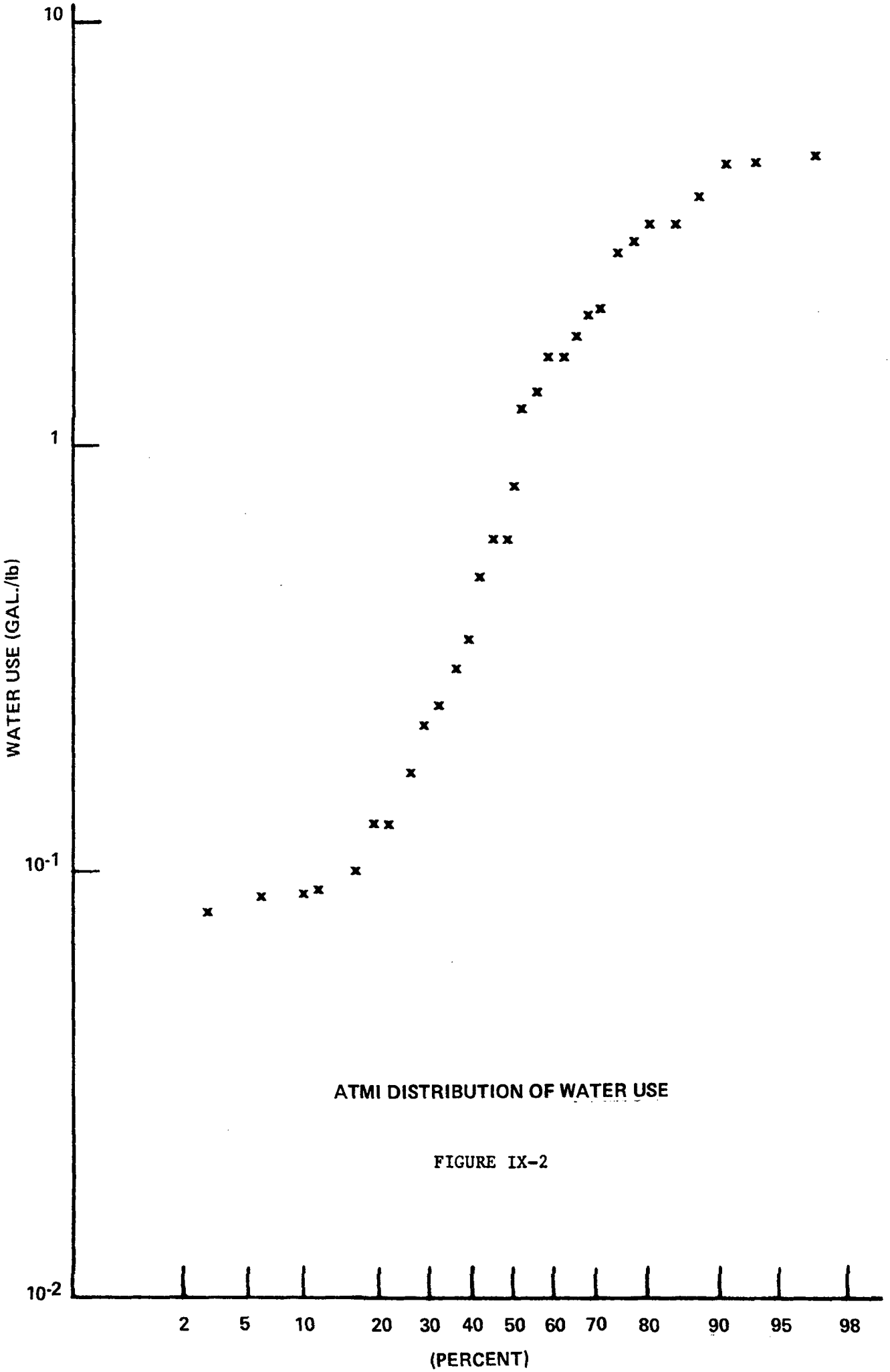
Plants attaining a high level of BOD_5 and COD reduction will also by necessity attain high reduction of suspended solids. Effluent concentration of 30 mg/l results in an effluent guideline of 5.1 lb/1000 lbs.

Category 3: Greige Mills

As described in Section IV, plants of this type are essentially a dry operation. Most Greige goods mills discharge their waste to sanitary systems. Of the mills that treat their own waste most combine their sanitary and industrial waste loads; the respondees to the ATMI questionnaire indicated that 70 to 90 percent of the load was sanitary.

The only current compilation of water use figures for various textile subcategories is that presented to EPA by the American Textile Manufacturers Institute and the Carpet and Rug Institute. Although it has not as yet been completely verified, it appears to present the full range of water uses to be expected for each subcategory. Water use distribution for greige mills as shown in Figure IX-2 illustrate an extremely wide variation. This can be explained by the overriding influences of nonprocess water such as boiler water, cooling water and sanitary wastes which are very significant in some cases and less significant in others.

NOTICE: These are tentative recommendations based upon information in this report and are subject to change based upon comments received and further review by EPA.



ATMI DISTRIBUTION OF WATER USE

FIGURE IX-2

Because of the extreme influence of nonprocess waste water on greige mill wastes and the difficulty of relating the true industrial waste to production it is recommended that some flexibility be permitted. Calculations for permit conditions may need to be based on an effluent concentration until such time as the true industrial waste is identified.

BOD

It has been demonstrated that BOD can be removed to a level below 20 mg/l consistently for a greige mill waste. From the water usage distribution presented, it can be seen that the apparent median value is extremely sensitive to the number of samples selected. That is, if two additional values had been included with lower than median water use, the median water usage would drop to 0.60 gal/lb; however, if two values had been included with higher than median water use, the median would shift to 1.3 gal/lb. Based on interpolation between the asymptotes approached by the extremes the median value for water use is 0.62 gal/lb. Using a median water use of 0.62 gal/lb and an effluent concentration of 20 mg/l the effluent limitation is 0.1 lb/1000 lbs.

COD

A long term average ratio of COD/BOD for one greige mill effluent is 7.8. On this a guideline of 0.78 lb/1000 lbs. is calculated.

Suspended Solids

Suspended solids are reduced to an average of 30 mg/l. Effluent limitation guidelines for suspended solids is 0.15 lb/1000 lbs.

NOTICE: These [illegible] in this report and are subject to change based upon comments received and further review by EPA.

Category 4: Woven Fabric Finishing

Water Usage

The water use distribution for this subcategory has been compiled by the American Textile Manufacturers Institute and the Carpet and Rug Institute. From the graphical distribution of Figure IX-3 it is observed that 90 percent of this subcategory uses less than 30 gal/lb, 50 percent use 13 gal/lb, and 15 percent use less than 4 gal/lb.

BOD Guidelines

Table IX-2 summarizes the BOD effluent results from 8 mills - broadwoven, cotton and cotton blend finishing considered as exemplary for category 4. As stated earlier, this category represents the biggest wet processing mills and the biggest water users in the textile industry, and accounts for almost half of the pollution of this industry. These were the first to be regulated by the states relative to instituting waste abatement procedures, and as a result there are many more good plants to consider as exemplary.

The mills all have above 92 percent BOD efficiency. Because of their unique product mixes (varying ratios of cotton to synthetics and varying weights of goods), and differing processing steps involved, the raw waste loads varied from 35 kg (lb)/1000 kg (lb) to 145 kg (lb)/1000 kg (lb) and the water usage is highly varied. (For example, the highest water usage mill, S, processes all corduroys, velvets, and velveteens. Even so, because of the high efficiency of waste treatment, all the mills averaged less than 30 ppm concentration of BOD.

With six major pollution-contributing process steps and the significant difference in BOD load between cotton and synthetics, literally hundreds of combinations of plant sequences are possible and indeed do exist. (See Sections IV and V.) It is felt that the plants cited in Table IX-2 cover the extremes in terms of processing conditions, and because of the high treatability of this waste, no further subcategorization is warranted.

The average of the best gives an effluent limitation of 2.2 lb/1000 lbs. Inspection of the plant with the highest influent concentration reveals that this plant can meet the requirement. Inspection of the plant with the highest water usage (35 gal/lb) indicates that this plant can also meet the requirement.

COD Guidelines

Table IX-3 summarizes the correlations between COD and BOD for various plants in category 4 using their monthly average results for BOD and COD.

NOTE: [illegible] in this report and are subject to change based upon comments received and further review by EPA.

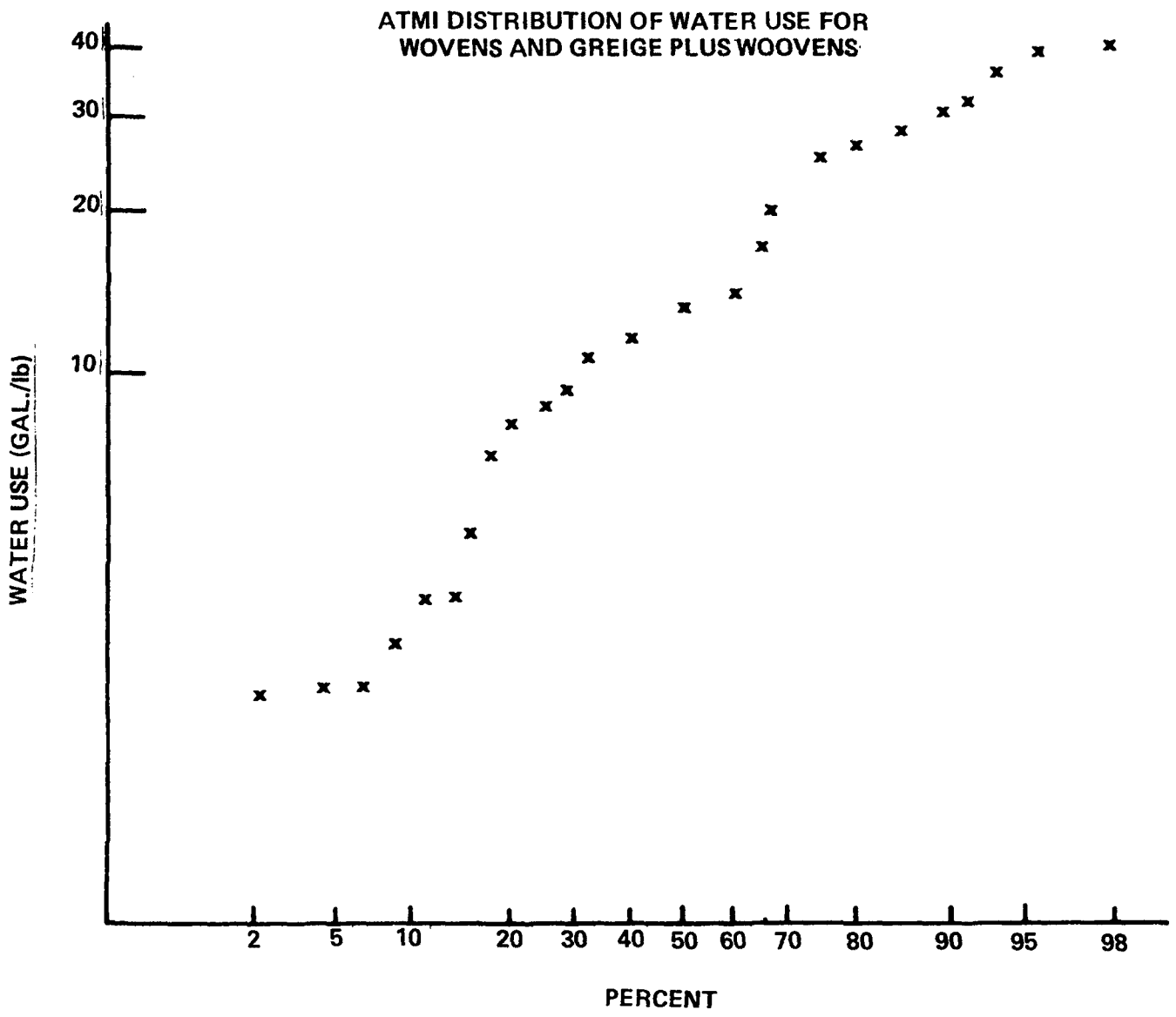


FIGURE IX-3

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TABLE IX-2

BOD PERFORMANCE OF EXEMPLARY MILLS
Category 4: Broadwoven, Cotton and Cotton Synthetic Blends

Mill	Raw BOD[a] mg/l	Raw BOD[a] kg(lb)/1000 kg(lb) prod.	Treated BOD mg/l	Treated BOD kg(lb)/1000 kg(lb) prod	BOD Removal Efficiency %	Production kg(lb)/d	Water Use l/kg(gal/lb)
J	776	88	30	3.4	96.1		113.4 (13.6)
K	566	35	13	0.8	97.7		61.7 (7.4)
M	807	78	23.1	2.2	97.1	211,000 (465,000)	96.7 (11.6)
O	444	37	14	1.2	96.9	60,800 (134,000)	69.2 (8.3)
P	622	146	19.3	4.5	96.9	197,000 (434,000)	230.1 (26.7)
Q	445	50	6.4	0.71	98.5	73,000 (161,000)	110.9 (13.3)
R	356	37	27	2.8	92.3	90,800 (200,000)	104.2 (12.5)
S	167	49	4.2	1.2	97.5	25,700 (56,600)	294.3 (35.3)

(a) average.

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The last column in this table is the pooled results from five plants. Of the four plants analyzed individually, only two have good correlations of COD to BOD. The Plant 0 correlation is the best and for its mix of chemicals used in operations, the intercept would suggest that only about 10 ppm (best estimate, 7.8) of its BOD is nondegradable. Taking the overall average ratio of 13.7:1 suggested by the composite data would give a COD guideline of 2.2x13.7=30.1, say 30 kg (lb)/1000 kg (lb).

The analysis of the composite data of five plants suggest an industry average of 150 ppm COD as nonbiodegradable. The regression equation for the composite data is:

$$COD = 149.5 + 4.02\ (BOD)$$

An average plant water use of 13.5 gal/lb and an average BOD_5 effluent concentration of 20 mg/l gives the following COD limitations:

$$COD = 149.5 + 4.02\ (20)$$

$$COD = 230\ ppm$$

which corresponds to 27 lbs/1000 lbs. This corresponds favorably with the previous calculation, therefore, the effluent guideline for COD is 30 lb/1000 lbs.

Suspended Solids

The best among the exemplary plants with respect to suspended solids are summarized in Table IX-3. It can readily be seen from Table IX-4 that design overflow rate should not exceed 300 gpd/ft^2 for this waste. In addition, it may be necessary in some cases to add polyelectrolytes to maintain the desired effluent concentration. An effluent concentration of 30 mg/l gives an effluent guideline of 3.3 lb/1000 lbs.

...Office ... information in this report and are subject to change based upon comments received and further review by EPA.

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TABLE IX-3
CATEGORY 4: SUMMARY OF EFFLUENT COD BOD CORRELATIONS

	Plants T	M	V	O	Grand Avg. Excl.K,Incl.U
Months Data	12	6	5	12	31
BOD, ppm	162.17	25.5	18.0	13.5	15.48
COD, ppm	874.75	214	254.2	202	211.84
Ratio COD/BOD	5.4	8.4	14.1	14.9	13.7
Correlation COD,BOD	fair	very poor	good	very poor	good
Correlation coefficient	.42	.08	.89	.97	.42
Prob. Correlation above 0	92.6%	56%	99.9%	99.99%	99%
Slope COD/BOD	1.479	N/A	10.9	14.39	4.02
Intercept (1), ppm	634.9	N/A	57.2	7.8	149.5

(1) Inferred COD at O BOD.

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TABLE IX-4

CATEGORY 4 - SUSPENDED SOLIDS

Plant	Average	Std. Dev. of Mo.Avg.	Range of Monthly Averages, ppm	Clarifier Overflow Cu m/m²/day	(gal/ft²/day)
M	98	50	39-193	28.72	(705)
O	121	N/A	N/A	24.50	(600)
Q	61.5	8.0	49-72	12.34	(303)
R	31 (3 mo. only)	-	30-33 (3 mo. only)	12.79	(314)

NOTE: [illegible] are based upon information in this report and are subject to change based upon comments received and further review by EPA.

Category 5: Knit Fabric Finishing

Water Usage

From the water use information supplied to EPA by ATMI-CRI, Figure IX-4 was constructed. The range of water use does not appear to be great, that is, 75 percent of this relatively small sample of the industry use between 10 gal/lb and 30 gal/lb with a median use of 20 gal/lb.

BOD Guidelines

Five plants were originally considered for setting Level I guidelines; their performance is summarized in Table IX-5.

NOTICE: These are tentative recommendations based upon information in this report [illegible]

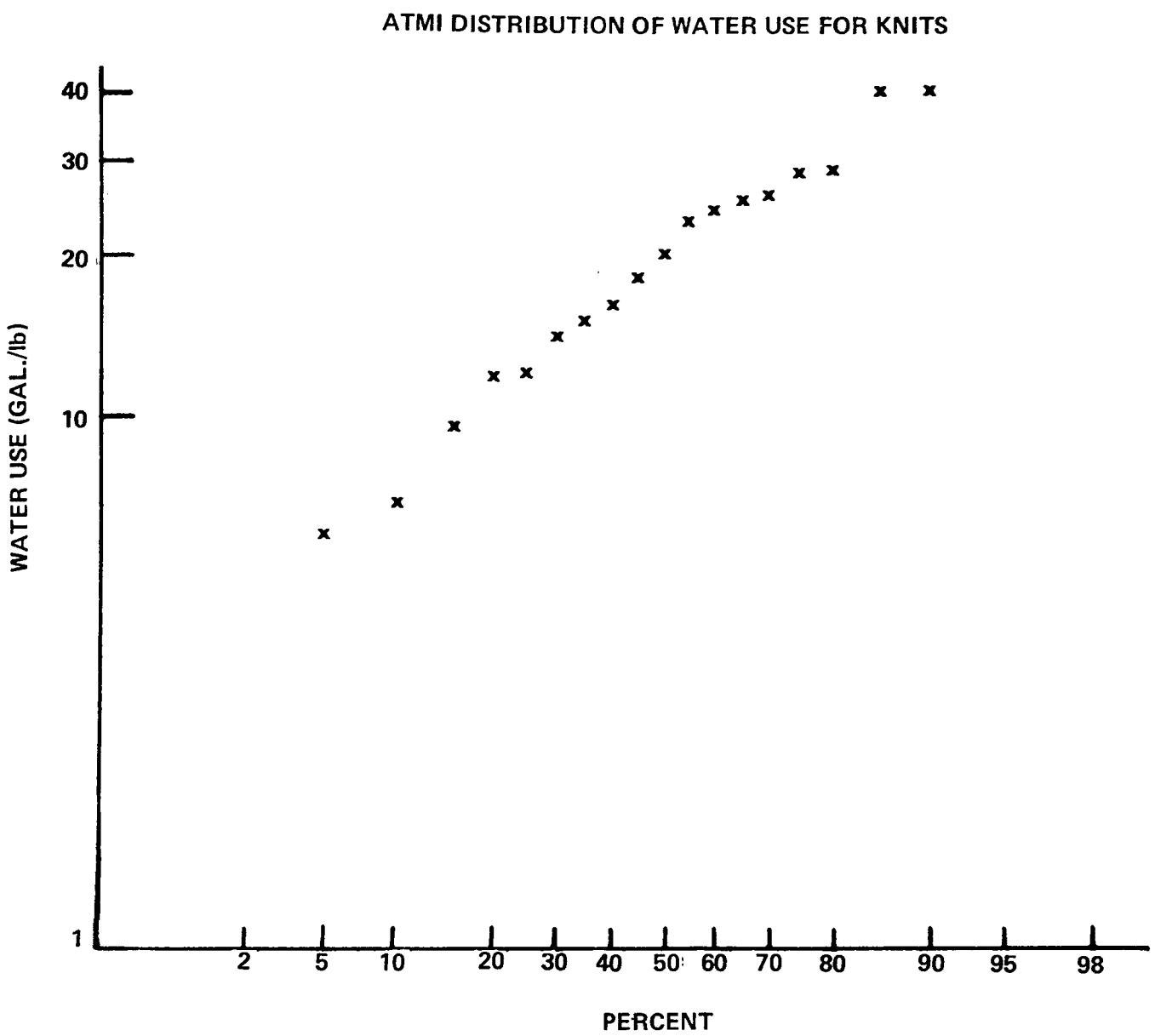

FIGURE IX-4

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TABLE IX-5

BOD PERFORMANCE OF EXEMPLARY MILLS
Category 5: Knits

Mill	Raw BOD mg/l	Raw BOD kg(lb)/1000 kg(lb) prod	Treated BOD mg/l	Treated BOD kg(lb)/1000 kg(lb) prod	BOD Removal Efficiency %	Production kg(lb)/d	Water Use l/kg(gal/lb)
W	481	51.7	37.5	3.61	91.7	14,100 (31,100)	107.5 (12.9)
X	80	17.9	2.0	.45	97.4	28,600 (63,000)	224.3 (26.9)
Y	568	75.6	16.3	2.17	97.2	62,060 (136,700)	132.6 (15.9)
Z	175	18.0	9.7	1.01	94.4	17,200 (37,884)	102.5 (12.3)
AA	249	40.8	30.0	5.01	88.0	17,600 (38,800)	193.4 (23.2)

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Plant AA was originally considered to be included among the exemplary plants because it carried on a significant amount of fabric printing and also had begun to use increasing amounts of flameproofing agent for childrens' knitwear and there were some thoughts that this may affect the treatability of the waste (88 percent vs. 92-97 percent for the other plants under consideration). However, further inquiry revealed this plant operates its aerators alternately at 50 percent and at 100 percent of capacity to keep dissolved oxygen from getting too high and also does not add nutrient to the waste load on a consistent controlled basis. It also has relatively high overflow rates on the clarifier. Among the remaining four plants significant differences can be seen among the raw waste loads, 18 to 75 kg (lb)/1000 kg (lb) of product, but this is normal for the diversity of operations carried on among knit mills. More specifically, the differences were not due to the product mix of raw materials being processed, but rather to the unit operations for the specific fibers being processed.

The average of the best results in a BOD_5 limitation of 2.45 lb/1000 lbs. The plant with the highest water use easily meets this requirement. The plant with the highest influent concentration also meets the requirement.

Plant W, having the lowest efficiency of removal among these plants (91.7 percent), in conjunction with having the second highest raw load, 52 kg (lb)/1000 kg (lb), had the poorest effluent of the four, 37 ppm BOD or 3.6 kg (lb)/1000 kg (lb). This plant, as described in Chapter V has excellent design and operating characteristics, including equalization, nutrient addition, extended aeration, with high concentration of biomass and one of the highest aeration power inputs in the industry and primary and secondary clarifiers. The one failing of this plant is the high suspended solids carryover from the secondary and tertiary clarifier possibly because of the extensive use of dispersed dyes in dyeing the nylon portion of this production (25 percent nylon, 65 percent nylon/acetate) and a relatively high proportion of goods dyed to dark shades. This carryover is despite the fact that the clarifiers are designed at 9.74 Cu $m/d/m^2$ (239 $gal/d/ft^2$) overflow from the secondary clarifier and 13.0 Cu $m/d/m^2$ (320 $gal/d/ft^2$) from the tertiary. The plant recognizes this problem, and this spring installed a rapid-mix basin, flocculation basin, and metering equipment for alum and polyelectrolyte addition prior to secondary clarifier. With this added treatment it is achieving "50 to 75-80 ppm" suspended solids and feels that when the system is optimized, it will achieve 25 to 50 ppm. (Its laboratory settling tests indicate this system should average 25 ppm solids in the overflow.)

NOTICE: These are tentative recommendations based upon information in this report and are subject to change and [illegible] to revised and further review by EPA.

A simple regression analysis was made of suspended solids on BOD for Plant W's effluent. Using that relationship (which indicated 0.2 kg (lb) BOD associated with each kg (pound) of suspended solids carryover), the monthly average BOD was adjusted downward to account for an average suspended solids of 25 mg/l. This had the effect of dropping the average BOD from 3.61 to 2.45 kg (lb)/1000 kg (lb) product, bringing it in line with the other plants.

COD Guidelines

COD data in this industry category are very meager, only two of the exemplary plants have such. Plant W has fairly extensive data with an excellent correlation between monthly average COD and BOD's in the effluent;

COD kg (lb)/1000 kg (lb) product = 2.60 + 11.21 (BOD);

This waste treatment plant removed 74 percent of the COD, the other Plant Y, with less data indicating 69 percent COD removal. From the Plant W data, the effluent limit is calculated to be 30.1 kg (lb)/1000 kg (lb).

Suspended Solids Guidelines

By checking the available data, high suspended solids in other plant-treated effluents within the knit industry were confirmed, probably because of the use of dispersed dyes (Table IX-6).

TABLE IX-6

SUSPENDED SOLIDS DATA, CATEGORY 5

	Average SS mg/l	2nd Clarifier Upflow Cu m/d/m²	(gal/d/ft²)
Plant W	101	9.74	(239)
Plant X	29	12.96	(318)
Plant Y	36	20.70	(508)
Plant Z	48	8.35	(205)
Plant AA	84	24.40	(600)

Based on the above discussion of the technology that Plant W can employ to achieve 25 ppm suspended solids, a limit of 25 ppm seems appropriate. This calculates to a guideline of 4.1 kg (lb)/1000 kg (lb) product.

NOTICE: These are tentative recommendations based upon information in this report and are subject to change based upon [illegible] and further review by EPA.

Category 6: Carpet Mills Including Backing

Water Usage

The distribution of water use within the carpet industry is presented in the Figure IX-5. Roughly 70 percent of the industry uses between 3 gal/lb and 12 gal/lb with a median water use of 6.5 gal/lb.

BOD Guidelines

Two mills are summarized in Table IX-7.

The average of the best results in an effluent limitation of 1.4 kg (lb)/1000 kg (lbs).

COD Guidelines

A small amount of data suggests that faculatative or anaerobic ponds in conjunction with aerobic ponds achieve greater COD reduction than do aerobic ponds alone. Using a COD/BOD ratio of 10:1 an effluent limitation of 14 kg (lb)/1000 kg (lb) is calculated.

Suspended Solids

Data on the suspended solids performance of the two plants of Table IX-7 are very meager and are summarized below:

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	Average	Clarifier Upflow Rate Cu $m/m^2/day$	(gal/ft^2/day)
Plant CC	17	8.026	(197)
Plant DD	40	12.43	(305)

Through proper design of a clarifier, it will average 30 mg/l suspended solids, therefore, an effluent limitation of 1.6 lb/1000 lbs.

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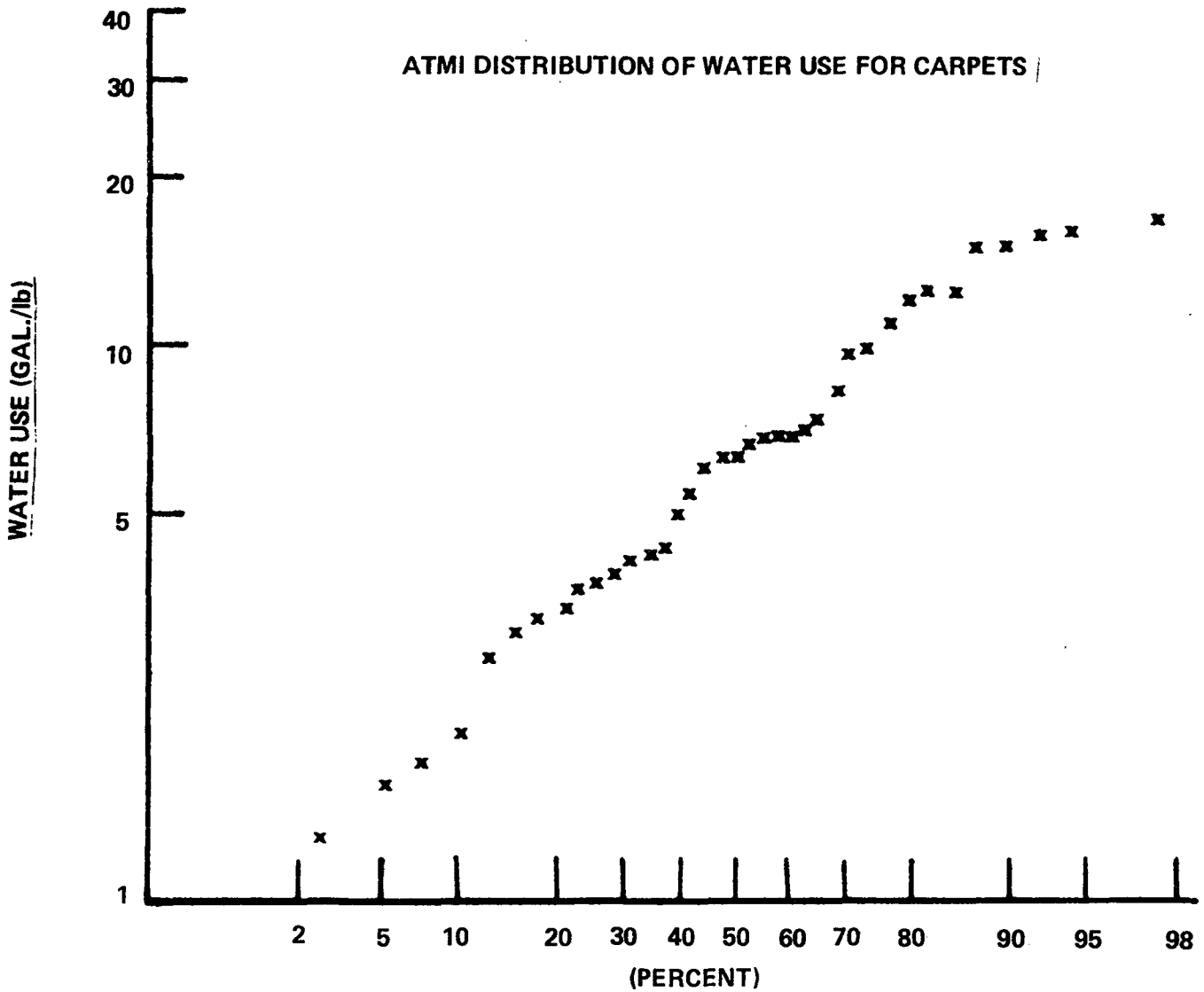

FIGURE IX-5

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report and subject to further revision and further review by EPA.

Category 7: Stock and Yarn Dyeing

Water Usage

A fairly wide distribution of water use is observed in the stock and yarn dyeing subcategory. From the information supplied by ATMI-CRI, roughly 85 percent use less than 30 gal/lb. A median water use of about 20 gal/lb is observed. From Figure IX-6, it is also observed that the water use falls off rapidly indicating that 30 percent use less than 10 gal/lb.

BOD Guidelines

Two mills were considered exemplary relative to setting Level I guidelines, as shown by their effluent characteristics in Table IX-8. Two parameters, raw waste load and water usage, immediately suggest that there may be basic differences between Plant EE and Plant GG. Plant EE processes 100 percent PE and does piece dyeing to later achieve space dyeing effects. It processes pure synthetics, and does not bleach or mercerize. Plant GG processes PE cotton blends.

The average of the best results in an effluent limitation of 2.75 kg (lb)/1000 kg (lbs). Exemplary Plant GG approaches the guideline even though it uses more water than 94% of the stock and yarn category.

COD Guidelines

Only one of the exemplary plants had any COD data. Three month's data averaged 13:1 ratio of COD/BOD. From this the COD will average 35 kg (lb)/1000 kg (lb), based on 13 times the BOD guidelines.

Suspended Solids

The average suspended solids concentration may be as high as 1.5 times the effluent BOD_5 concentration. This results in an effluent limitation of 4.1 lbs/1000 lbs.

NOTICE: These are tentative recommendations based upon information in this report and are subject to change based upon comments received and further review by EPA.

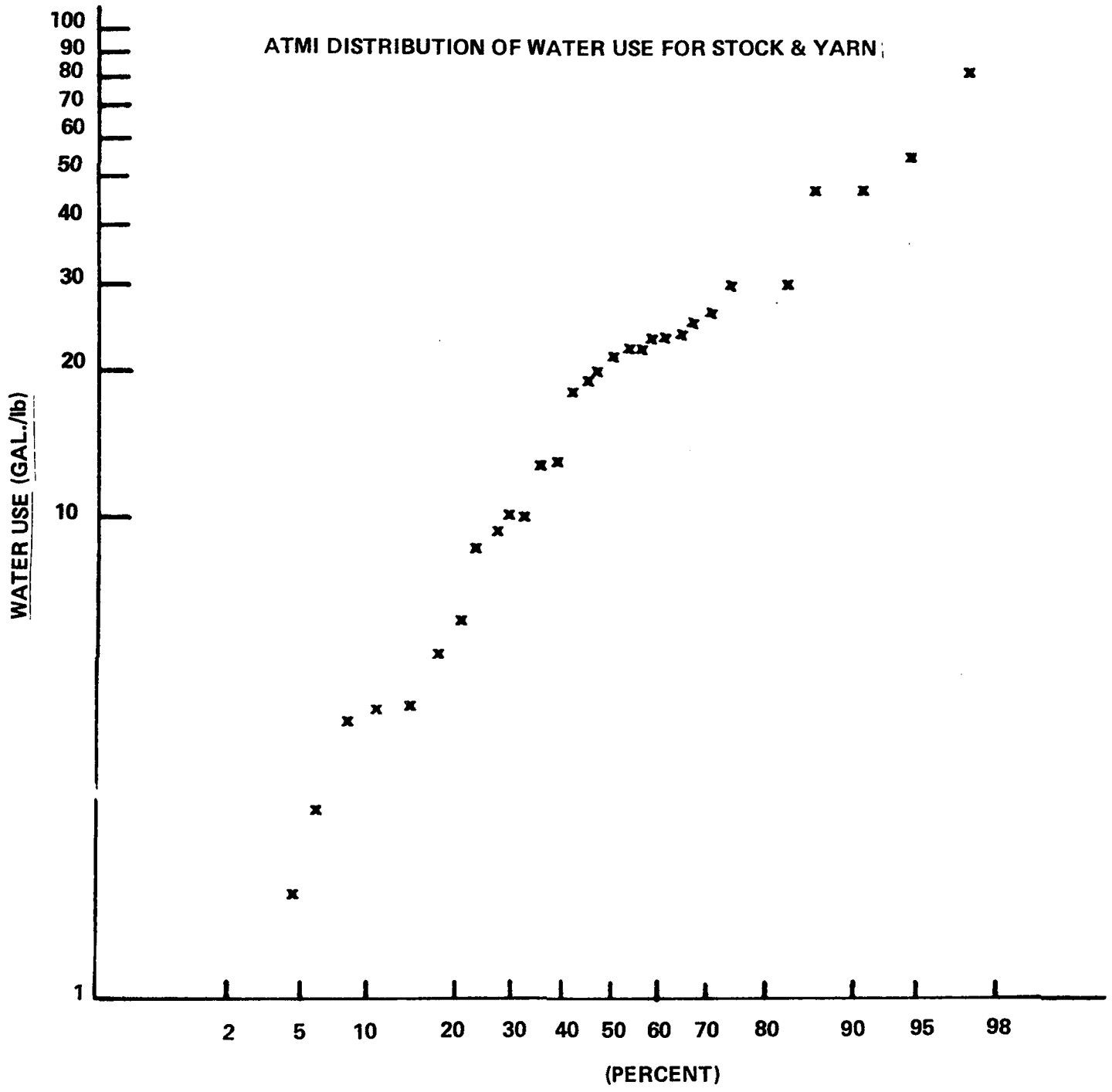

FIGURE IX-6

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NOTICE: These are tentative recommendations based upon information in this report and are subject to change based upon comments received and further review by EPA.

TABLE IX-7

BOD PERFORMANCE OF EXEMPLARY MILLS
Category 6: Carpet Mills

Mill	Raw BOD mg/l	Raw BOD kg(lb)/1000 kg (lb)	Treated BOD mg/l	Treated BOD kg(lb)/1000 (lb)prod.	BOD Removal Efficiency %	Production kg(lb)/d	Water Use l/kg (gal/lb)
CC	186	16.01	12.9	1.09	93.1		86.7 (10.4)
DD	280	9.6	14.0	0.5	95.2	31,330 (69,000)	54.2 (6.5)

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SUMMARY OF EFFLUENT GUIDELINES FOR LEVEL I

Table IX-9 summarizes the guidelines, giving the not-to-exceed limits based on 30 working day average, and maximum daily average.

NOTICE: These are tentative recommendations based upon information in this report and are subject to change based upon comments received and further review by EPA.

TABLE IX-8

PERFORMANCE OF EXEMPLARY MILLS
Category 7: Stock & Yarn Dyeing & Finishing

Mill	Raw BOD mg/l	Raw BOD kg(lb)/1000 kg (lb)	Treated BOD mg/l	Treated BOD kg(lb)/1000 kg (lb)	BOD Removal Efficiency %	Production kg(lb)/d	Water Use l/kg (gal/lb)
EE	333	25.6	22.8	1.75	93.2	19,430 (42,800)	76.7 (9.2)
GG	115	52.9	8.0	3.73	92.9	8,720 (19,160)	461.0 (55.3)

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TABLE IX-9

SUMMARY OF LEVEL I POLLUTANT GUIDELINES - (a)

Category	Maximum 20 Working Day Averages, kg/1000 kg (lb/1000 lb) BOD	COD	Suspended Solids	PH(b)
1. Wool Scouring	2.85	28	2.0	6-8.5
2. Wool Finishing	5.1	51	7.6	6-8.5
3. Greige Goods	0.15	1.17	0.22	6-8.5
4. Woven Fabric Finishing	3.3	45	6.1	6-8.5
5. Knit Fabric Finishing	3.6	45	6.1	6-8.5
6. Carpets	2.1	21	2.4	6-8.5
7. Stock and Yarn Dyeing	4.0	52	6.1	6-8.5

(a) In addition to the guidelines shown, the following apply to all categories.
Coliform organisms 200/ml MPN,
Total chromium-not to exceed 0.25 mg/l
Phenols-not to exceed 0.25 mg/l
Color-not to exceed 200 ADMI units

(b) Values are the maximum permitted range.

Note: Daily maximum may not exceed twice the maximum 20 working day average.

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REFERENCES

IX.1 Waste water treatment Technology--Second Edition, January 73-State of Illinois, Institute of Environmental Quality.

IX.2 28th Annual Purdue Industrial Waste Conference, Lafayette, Indiana, May, 1973, page 13.

IX.3 Industrial Wastes Studies Program, Textile Products, Arthur D. Little Draft Report to EPA, May 1971.

SECTION X

BEST AVAILABLE TREATMENT ECONOMICALLY ACHIEVABLE

Introduction

Congress has stated that* "not later than July 1, 1983, effluent limitations for categories in classes of point sources, other than publicly owned treatment works, which . . . shall require application of the best available technology economically achievable for such category or class, which will result in reasonable further progress toward the national goal of eliminating the discharge of all pollutants". The Environmental Protection Agency has interpreted this section of the law as follows: "Level II technology is not based upon an average of the best performance within an industry category, but is to be determined by identifying the very best control and treatment technology employed by a specific source within the industry category, or subcategory, or where it is readily transferable from one industry to another, such technology may be identified as Level II technology."

In qualifying statements, the EPA has stated, "it is imperative that the effluent limitation and standards to be promulgated by the Administrator be supported by adequate verifiable data and that there be a sound rationale for the judgments made." Further in the same document it is stated, "However, Level II may be characterized by some technical risk with respect to performance and with respect to certainty of cost. Therefore, Level II may necessitate some industrially-sponsored development work prior to its application."

We have been swayed by the words of Congress: "which will result in reasonable further progress toward the national goal of eliminating the discharge of all pollutants."

Proposed Guidelines - Zero Discharge

In most cases a 50% reduction in water usage from the average of the plants in each category is projected.

From the rationale described previously, it is apparent that Level II guidelines can be achieved only by the use of technologies beyond biological treatment.

Achieving zero discharge is a primary aim of the law. In doing this, careful consideration was given to all the advanced treatment alternatives described in Section VIII-5--: phase change, membrane separation and sorption--together with the cost information described in Section VIII. Data showing the application of these technologies to textile waste effluents is scarce, and a wide variety of chemicals may be used by the industry. Therefore, the most promising techniques are (a) secondary biological treatment, followed by (b) clarification to reduce suspended solids, and (c) three stage evaporation or reverse osmosis (see figure X-1).

In making recommendations for Level II guidelines, it should be recalled that guidelines may be characterized by some technical risk.

Level II guidelines of zero discharge are chiefly directed at removal of dissolved salts so that the water is fit for recycle. For removal of these dissolved salts we have considered electrodialysis, ion exchange, reverse osmosis, distillation, freezing techniques and ultrafiltration. (The last two were eliminated from further consideration because of their limited applicability and lack of technical data.)

Electrodialysis and ion exchange are more mature technologies and similar in that they remove only dissolved, ionized salts. With this limitation it is less likely that the treated effluent can be successfully recycled to the process, because of the presence of color or other residual organics or non-ionized salts, such as phosphates. Reverse osmosis and multiple effect evaporation should have an advantage over the former two processes since they remove organic materials in addition to dissolved salts.

In Section VIII we have made detailed cost estimates of these two processes as final treatment steps to obtain zero discharge. The examples chosen were from category 4, Woven Fabric Finishing, and category 5, Knit Fabric Finishing, which represent the major proportion

* Draft: These are tentative recommendations based upon information in this report and are subject to change based upon comments received and further review by EPA.

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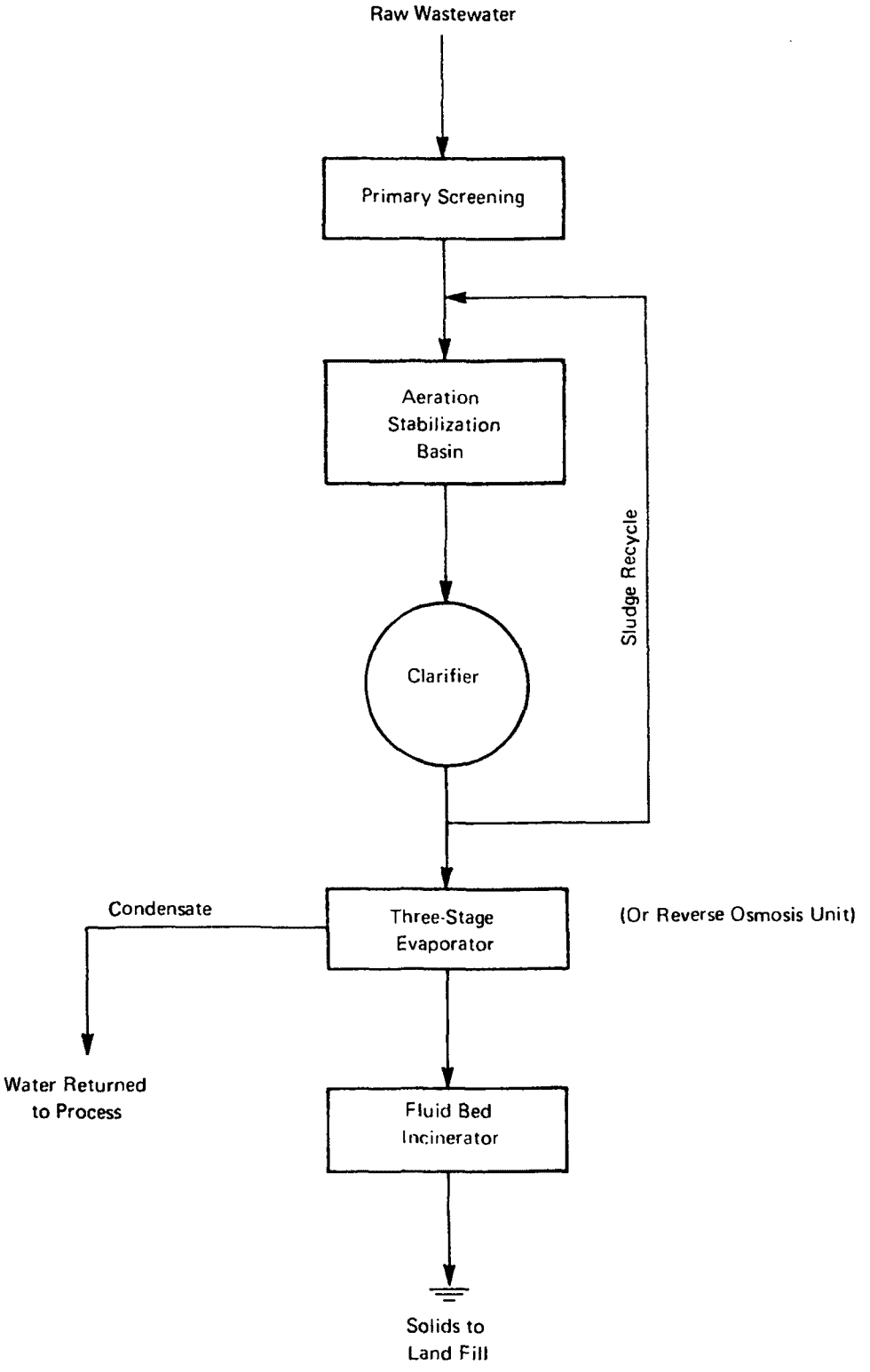

FIGURE X-1 SCHEMATIC FLOW DIAGRAM OF PROCESS STEPS ZERO DISCHARGE TREATMENT

of the effluent from the textile industry. The data show that the two techniques are comparable in cost. Although reverse osmosis may have a somewhat higher technical potential it needs more technical development. The costs developed indicate $0.92 to 1.06/1000 liters ($3.50 to 4.00/1000 gallons) for large plants (including credit for water recycled to the process).

SECTION XI

NEW SOURCE PERFORMANCE STANDARDS & PRETREATMENT STANDARDS

New Source Performance Standards

As stated earlier, it is not clear how the textile industyr can reduce its raw waste loads except by: (a) substitution of treatment chemicals and (b) better process control to minimize reworks, poor dye bath exhaustion, and wastage of process chemicals in general, as discussed in Section VII.

A new plant should practice counter current flow and multiple use of process and wash waters. These will reduce hydraulic loads and for a new waste treatment plant will permit reduced size or longer residence times but will offer few opportunities to recover chemicals (and thereby reduce waste loads).

However, with Level I guidelines, treated effluent BOD concentrations will already be below 30 mg/l (ppm) using standard biological treatment plants. Functionally, there is little reason to lower this BOD load still further.

It is recognized that in settling standards for Level II, a ten year period is built in to collect better data on reliability and cost of the newer abatement technologies, whereas Level III guidelines are to be applicable essentially immediately. Even so, it is recommended that the Level II guidelines be applied as Level III guidelines as well.

Pretreatment Standards

Waste waters from the textile industry have been shown to be biologically degradable under appropriate conditions. Consequently, treatment of these waste waters in municipal sewage systems could be expected to proceed in an analogous manner if appropriate pretreatment and operating considerations are used. Although the BOD portion of these waste waters has been found to be generally as treatable as municipal sewages, the normal operating conditions for the municipal waste water treatment plants may require modification. Furthermore, the COD of the effluent from the combined municipal and industrial waste water treatment plant can be expected to be higher than that normally

NOTICE: These are [illegible] and [illegible] information in this report are subject [illegible] and further review by EPA.

associated with municipal sewage because of the more biological refractory substances found in the industry waste water. Obviously, the proportion of the total flows and loads contributed by the industry source as well as the treatability must be evaluated for each location. If those conditions are recognized and appropriately compensated for, the pretreatment requirements for the waste water from the textile industry should be as follows.

1. Suspended solids that will settle out in sewer lines or accumulate on surfaces should be removed by a screening operation before entering the system. (Short fibers are the principle contributor here.)

2. pH should be adjusted before the waste waters are discharged to municipal sewers.

3. Heavy metals should be removed to levels established for the industry category except appropriate allowances may be made for those metals known to be removed in efficiently operating biological systems. Approximately two-thirds of the chromium, the metal of most concern for textile waste, is removed in the waste treatment plant so pretreatment standards should be set according to the percent of the total waste that is represented by the textile load with a maximum of, say, 2 mg/l (ppm).

4. Toxic and hazardous substances should be precluded. Presumably, their usage within the industry's plant will have been restricted by the EPA's toxic and hazardous materials, rules and regulations.

5. Waste waters should be collected at the plant site, cooled if required, and metered into the municipal sewage system at a rate and schedule compatible with the diurnal characteristic of the system.

6. Removal of colloidal solids at the industrial plant to a level commensurate with those established for the industry category. (One principal item here is latex removal by adjusting pH and coagulating it in carpet mills.)

7. Floating oils should be removed prior to putting the waste waters into municipal sewer systems.

The pretreatment guidelines suggested above for textiles are compatible with the preliminary report "Pretreatment Guidelines for the Discharge of Industrial Wastes to Municipal Treatment Works" by Roy F. Weston, Inc. (EPA Contract No. 68-01-0346); however, the later report should be

consulted for the comprehensive background and rationale to be followed in establishing pretreatment standards for industrial plants.

NOTICE: These are tentative recommendations based upon information in this report and are subject to change based upon results obtained and further review by EPA.

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SECTION XIII

ACKNOWLEDGMENT

Field data and much other information contained in this report has been supplied by A. D. Little, Inc., under EPA Contract No. 68-01-1515.

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SECTION XIV

REFERENCES

A review of the recent literature for references on Textile wastes and waste treatment has produced over 200 references. Brief abstracts of 50 of these references are included as well as the full list of references.

This review covered the following:

SOURCE	COVERAGE THRU
Abstracting and Indexing Services	
Applied Science and Technology Index	March 1973
Chemical Abstracts	April 9, 1973
Engineering Index	November 1972
Pollution Abstracts	March 1973
Textile Information--Sources and References	June 1972*
Water Pollution Abstracts	July 1972*
Journals	
American Dyestuff Reporter	March 1973 (except Aug. 1971)*
America's Textile Reporter Bulletin	January 1973 (except Feb. and April 1972)**
Bulletin Environmental Contamination; Toxicology	June 1972**
Environment	November 1972***
Environmental Science & Technology	March 1973 (except Jan. and Feb. 1973)**
Industrial Waste	March/April 1973***
Industrial Water Engineering	April/May 1973***

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Textile Chemists and Colorists (J. Am. Assoc. TCC)	April 1973
J. Environmental Sciences	March/April 1973 (except May/June 1972)**
Modern Textiles	March 1973
Pollution Engineering	July/August 1971, Sept./Oct. 1971; January/February, March/April, July, August, September and November 1972***
Textile Industries	January 1973 (except June 1971, June and August 1972)**
Textile Institute and Ind. Proc.	October 1972*
Textile Month****	March 1973
Textile Research J.	March 1973
Textile World	April 1973
Water and Wastes Eng.	July 1972, plus January 1973, (except November 1971, January March, August-December 1972)**
Water and Sewage Works	February 1973 (except April and September 1972)**
Water Pollution Control Federation J.	January 1973 (including Textile Waste Bibliographies, June 1971 and 1972)
Water Research	April 1973

*Latest in ADL Library
**Missing from ADL Library
***Only available issues in ADL Library
****Most textile journals covered only industry-related topics, so coverage was limited.

Other journals (CIBA Review, Environmental Pollution and Control, Water

and Wastes Digest, Environment Report, etc.), were checked briefly only to confirm that they did not cover the subject of textile waste treatment.

Bibliographies

The bibliography contained in: "The Cost of Clean Water, Volume III Industrial Waste Profile No. 4 - Textile Mill Products," Federal Water Pollution Control Administration, September 1967.

The bibliography contained in: "State of the Art of Textile Waste Treatment," Water Pollution Control Research Series 12090 ECS 02/71.

The bibliography contained in: The Report for "The American Manufacturer's Institute," by Institute of Textile Technology and Hydroscience, Inc. January 15, 1973.

Aside from documenting design parameters and operating data for existing conventional waste treatment plants, the literature review did not produce a wealth of information of direct use to this case. Most of the experience with more advanced waste treatment methods such as reverse osmosis, carbon adsorption, ozonation, radiolysis, and ion exchange, was confined to either laboratory or pilot plant operations. Due to the variation in the characteristics of the waste to which these methods were applied, meaningful generalizations as to their cost and effectiveness cannot be readily made.

The review did reinforce some already known facts about textile waste treatment in general.

1. Present biological treatment methods, while capable of reducing BOD concentrations to low levels show relatively poor performance with respect to COD and color.

2. While much success has been achieved with carbon adsorption on many wastes, one cannot make a blanket statement that it will reduce COD or color to low levels in all cases. Very often it is only partially effective and/or economically feasible.

3. Presently employed textile waste treatment methods are largely confined to conventional biological treatment such as activated sludge or aerated lagoons.

(2) "The BOD of Textile Chemicals, Updated List - 1966"
American Dyestuff Reporter, (55) No. 18, 39-42, 1966.

(self-explanatory)

(15) "What the Mills are Doing to Control Water Pollution"
Textile Chemist and Colorist, (1) No. 6, 25-36, 1969.

This article gives a brief rundown of waste control activities at:

1. American Enka, N.C. facility, where rayon, nylon, and polyester are produced

2. Burlington Industries (general)

3. Cannon Mills (discussed new design in detail)

4. Cone Mills (general)

5. Dan River Mills (Danville plant)

6. M. Lowenstein & Sons (Lyman Printing and Finishing Co.)

(18) Molvar, A., C. Rodman, and E. Shunney
"Treating Textile Wastes with Activated Carbon"

Discusses activated carbon treatment in general, pilot plant work, and actual operating data for a full size waste treatment system. The mill's identity is not given (dyeing and finishing).

(21) Souther, R.H.
"Waste Treatment Studies at Cluett, Peabody & Company Finishing Plant"
American Dyestuff Reporter, (58) No. 15, 13-16, 1969.

Detailed operating data on the Arrow Co., Division at Waterford, New York. The treatment system consists of an "extended-contact, activated sludge step, bio-aeration process." Also includes caustic recovery.

(22) "Wastewater Treatment Recycles 80 Percent of Industrial Flow"
American Textile Reporter, (83) No. 51, 14-15, 1969.

Very brief description and general flow diagram of the waste treatment system using activated carbon at Hollytex Carpet Mills (near Philadelphia). No real operating data is given.

(25) Jones, E.L., T.A. Alspaugh, and H.B. Stokes

"Aerobic Treatment of Textile Mill Waste"
JWPCF (34) No. 5, 495-512, 1962.

Cone Mills, joint treatment of mill and municipal sewage by contact stabilization process. (Pilot plant operating data.)

(47) Poon, C.P.C.
"Biodegradability and Treatability of Combined Nylon and Municipal Wastes"
JWPCF (42) No. 1, 100-105, 1970.

Treatability study of wastes taken from the Belding Chemical Co. in Thomaston, Connecticut. Strictly a laboratory study.

(49) Kwie, W.W.
"Ozone Treats Wastestreams from Polymer Plant"
Water and Sewage Works, 116, 74-78, 1969.

Laboratory study on ozone treatment of wastes from polymer plant (including SANS). The study did not produce very satisfying results.

(52) Wheatland, A.B.
"Activated Sludge Treatment of Some Organic Wastes"
Proc. 22nd Ind. Waste Conf. Purdue Univ. 983-1008, 1967.

Treatability study on a simulated synthetic fiber production and dyeing waste using a bench scale activated sludge unit.

(53) Carrigue, C.S., and L.U. Jauregui
"Sodium Hydroxide Recovery in the Textile Industry"
Proc. 22nd Ind. Waste Conf. Purdue Univ., 1966.

Castelar Textile Mill, Argentina (cotton goods)
Description of NaOH recovery from the mercerizing process. NaOH is filtered and then concentrated by evaporating. Design criteria, operating data and capital and operating costs are given.

(56) Taylor, E.F., G.C. Gross, and R.F. Rocheleau
"Biochemical Oxidation of Wastes from the New Plant for Manufacturing Orlon at Waynesboro, Va."

Proc. 15th Ind. Waste Conf. Purdue Univ., 1961.

Detailed description of Dupont's Waynesboro works. Waste facilities consist of a catalytic oxidation unit which completely oxidizes the organics associated with the recovery of dimethylformamide and an activated sludge unit for treatment of dilute organic materials such as acrylonitrile, dimethylformamide and formic acid.

(57) Sadow, R.D.
"The Treatment of Zefran Fiber Wastes" (acrylic fiber)

Dow Chemical Company's Williamsburg, Va., plant. Description of waste treatment process which includes primary settling, chemical coagulation, a Dowpac oxidation tower, and secondary settling. Operating data and design criteria are given.

(61) Jones, L.L.
"Textile Waste Treatment at Canton Cotton Mills"
JWPCF (37) No. 12, 1693-1695, 1965.

Gives a rather brief description of their activated sludge unit with design criteria, operating data (sketchy) and cost information.

(62) Smith, A.L.
"Waste Disposal by Textile Plants"
JWPCF (37) No. 11, 1607-13, 1965.

Very general article, gives some synthetic textile waste characteristics and very brief descriptions of waste characteristics and treatment methods at:

1. Chatham Manufacturing Co., Elkin, N.C. (multi-fiber woolen mill)
2. J.P. Stevens Co., Wallace Plant

(63) Dean, B.T.
"Nylon Waste Treatment"
JWPCF (33) No. 8, 864-70, 1961.

Operating experience of the Chemstrand Corp. Pensacola plant which utilizes an activated sluge unit followed by a post-treatment lagoon.

(76) Suchecki, S.M.
"A Dyer's "Operation Cleanup"
Textile Industries (130) No. 6, 113, 1966.

Description of Northern Dyeing Co., Washington, N.J. treatment facilities. Very little operating data given.

(86) Souther, G.P.
"Textile Water Pollution Woes Can be Resolved by Solvents"
American Textile Reporter (54) No. 9, 11, 13, 1970.

Describes solvent sizing and dyeing processes. This is an informative but not very detailed article.

(95) Porter, J.J.
"Concepts for Carbon Adsorption in Waste Treatment"
Textile Chemists and Colorists (4) No. 2, 29-35, 1972.

The history of carbon's entry into the waste treatment field is presented. Interpretations of teh fundamental kinetics and thermodynamics of carbon adsoption are also given with several specific examples cited.

(99) Rodman, C.A.
"Removal of Color from Textile Dye Wastes"
Textile Chemists and Colorists (3) No. 11, 239-47, 1971.

Solutions of four types of dyestuffs were treated by several methods that have been used practically or experimentally for color removal. Among these were coagulation by lime and by alum; extended aeration, activated carbon adsorption, reverse osmosis, and treatment with high pressure oxygen and cobalt-60 radiation.

(100) Rhame, G.A.
"Aeration Treatment of Textile Finishing Wastes in South Carolina"
American Dyestuff Reporter (60) No. 11, 46, 1971.

Operating data of several unidentified plants is presented along with general design criteria.

(103) Porter, J.J.
"Treatment of Textile Waste with Activated Carbon"
American Dyestuff Reporter (61) No. 8, 24-7, 1972.

Considerations in evaluating the potential application of carbon adsorption to a waste stream are discussed along with procedures for conducting laboratory studies.

(106) Stone, R.

"Carpet Mill Industrial Waste System"
JWPCF (44) No. 3, 470-478, 1972.

A description of the waste treatment system of the Walter Carpet Mill, City of Industry, California is presented.

(108) Little, A.H.
"Use and Conservation of Water in Textile Processing"
Journal of the Society of Dyers and Colorists (87) No. 5, 137-45, 1971.

Investigation of water usages in unit processes under normal production conditions. The effects of different dyeing and bleaching processes have been studied. Possible methods of conservation of water are discussed, including Contra-flow washing. In addition, the effects of changes in processing, the size, type and speed of machines and the effects of cloth weight and batch size are discussed.

(110) Masseli, J.W., N.W. Massell, and M.C. Burford
"Factors Affecting Textile Waste Treatability"
Textile Industries for October 1971, p. 84-117

General design parameters of activated sludge waste treatment are discussed along with startup and operational considerations. Waste contributions (in terms of % total BOD) are given for the individual process chemicals used in a typical cotton mill, cotton/synthetic mill, and woolen mill.

(111) Shunney, E.L., Perratti, A.E., and Rodman, C.A.
"Decolorization of Carpet Yarn Dye Wastewater"
American Dyestuff Reporter (60) No. 6, 32-40, 1971.

Laboratory and full-scale operation of bio-regenerated activated carbon treatment of carpet yarn fiber dyeing are discussed. The facility described is the C. H. Masland & Sons plant in Wakefield, Rhode Island.

(113) Rodman, C.A., and E. L. Shunney
"A New Concept for the Biological Treatment of Textile Finishing Wastes"
Chem. Eng. Progr. Symp. Ser. 67, 107, 451-457, 1971.

(Same subject as ref. 111)

(115) Rodman, C.A. and E. L. Shunney
"Novel Approach Removes Color from Textile Dyeing Wastes"

Water and Waste Eng. (8) No. 9, #18-23, 1971.

(Same subject as ref. 111)

(118) "Bio-regenerated Activated Carbon Treatment of Textile Dye Wastewater" Water Pollution Control Research Series 1209 OD WW 01/71.

(Same subject as ref. 111)

(122) Powell, S.D.
"Biodegradation of Authraquinone Disperse Dyes"
Thesis, Georgia Inst. Tech., 9, 238, 1971.

Three authraquinone disperse dyes, Disperse Violet 1 (C.I. 61100), Disperse Blue 3 (C.I. 61505), and Disperse Blue 7 (C.I. 62500), were partially metabolized by bacteria normally present in domestic activated sludge. Disperse Red 15 (C.I. 60710), was left unchanged by the sludge. The nature of the metabolites produced showed that the dyes had not actually been degraded, but merely converted to derivatives of the original dyes.

(123) Hood, W.S.
"Color Evaluation in Effluents from Textile Dyeing and Finishing Processes"

Initial concentration and rates of degradation of dyes and chemicals in textile effluents were studied. Field studies were made to observe conditions and to collect samples of water from streams in the Coosa River Basin. The samples were analyzed for content of specific dye auxiliaries and color. Color degradation was achieved under simulated stream conditions, both in textile effluents and in river samples.

(124) Soria, J.R.R.
"Biodegradability of Some Dye Carriers"
Thesis, Georgia Inst. Tech., 9, 238, 1971.

Carriers covered in this study were resistant to degradation in conventional activated sludge waste disposal plants. Where bacteria were acclimated to the chemicals and treatment times were extended, degradation did occur.

(125) Arnold, L.G.
"Forecasting Quantity of Dyestuffs and Auxiliary Chemicals Discharged into Georgia Streams by the Textile Industry"

Thesis. Georgia Inst. Tech., 9, 238, 1971.

The quantity and concentration of the major textile wet-processing chemicals in effluents are reported.

(126) Pratt, H.D., Jr.
"A Study of the Degradation of Some Azo Disperse Dyes in Waste Disposal Systems"
Thesis, Georgia Inst. Tech., 9, 238, 1971.

Two azo disperse dyes, Disperse Orange 5 (C.I. 11100) and Disperse Red 5 (C.I. 11215), were degraded by the bacteria in conventional waste treatment facilities into aromatic amines. Biological degradation produced identical metabolites as those formed by chemical reduction.

(127) Anderson, J.H.
"Biodegradation of Vinyl Sulfone Reactive Dyes"
Thesis, Georgia Inst. Tech., 9 238, 1971.

Biodegradation of three vinyl sulfone reactive dyes, Reactive Blue 19, Reactive Violet 5, and Reactive Black 5, were investigated under laboratory conditions simulating those employed in conventional activated sludge plants. The study failed to show any evidence of degradation. Reactive Blue 19, and Reactive Violet 5 showed evidence of degradation under anaerobic conditions.

(141) "The Centrifugal Recovery of Wool Grease"
Wool Science Review #37, p. 23-36, 1969.

This very detailed article discussed the composition of wool scour liquor, general principles of recovery, detailed operating characteristics of centrifuges, and the economics of wool grease recovery.

(143) Harker, R.P., and B.M. Rock
"Water Conservation and Effluent Disposal in the Wool Textile Industry"
J. Soc. Dyers and Colourists (87), No. 12, 481-3, 1971.

Discusses the wool textile industry in the U.K. Gives water consumption for various unit processes in terms of gal/lb product. This article also gives typical wool processing effluents and a description of the Traflo-W process which entails chemical coagulation followed by vacuum filtration. BOD is reduced by 80%.

(149) Rea, J.E.

"Treatment of Carpet Wastes for Disposal"
Proc. Industrial Waste and Pollution Conference and Advanced Water Conference, 22nd and 3rd. Oklahoma State University, Stillwater, Oklahoma, March 24-30, 1971.

This paper identifies design criteria and operating data for the waste treatment facilities at Sequoyah Mills in Anadarko, Okla. The waste treatment facilities consist of an aerated lagoon and stabilization pond. Pilot work is included which shows the relationship of BOD removal to aeration time.

(150) Paulson, Per
"Water Purification - An Alternative to Solvent Dyeing"
International Dyer & Textile Printer - June 4, 1971.

A brief description of a new waste treatment process employing sedimentation followed by ion exchange. Pilot plant work on dyeing liquor showed COD removals greater than 90%.

(161) Kulkarni, H.R., S.U. Khan, and Deshpande
"Characterization of Textile Wastes and Recovery of Caustic Soda from Kier Wastes"
Environmental Health (13) No. 2, 120-127, 1971.

A case study of "A Typical Cotton Textile Industry" is presented in the paper with reference to economical method of treatment of the waste waters and recovery of caustic soda during the process of treatment. Ninety-eight percent caustic recovery has been accomplished using dialysis.

(162) "Biodegradation of "Elvanol" - A Report from Du Pont"

The report concludes that domestic and textile mill activated sludge microorganisms can acclimate to "Elvanol" T-25 under conditions attainable in conventional waste treatment systems and that removals of over 90% can be achieved if the organisms are properly acclimated.

(164) Ryder, L.W.
"The Design and Construction of the Treatment Plant for Wool Scouring and Dyeing Wastes at Manufacturing Plant, Glasgow, Va."
J. Boston Soc. Civil Engrs., 37, 183-203, April 1950.

This article gives a very detailed description and design basis for the waste treatment system consisting of equalization, acid-

flocculation, and neutralization. The plant achieves a BOD removal of 60%, SS removal of 96% and a grease removal of 97%.

(168) Rodman, C.A., and E.L. Shunney
"Clean Clear Effluent"
Tex. Manufacturer (99) No. 49, 53-56, 1972.

A description of the Fram Corporation bio-regenerated carbon adsorption process is given along with laboratory and pilot plant operating data. The pilot plant treated waste water from the carpet yarn fibre dyeing plant of C.H. Masland & Sons, Wakefield, Rhode Island. A COD reduction of 81% and a color reduction of 99.4% is reported.

(175) Wilroy, R.D.
"Industrial Wastes from Scouring Rug Wools and the Removal of Dieldrin"
Proc. 18th Ind. Waste Conf., Purdue Univ., April 30, May 1-2, 1963.

The article describes design considerations and operating experience of a waste treatment system consisting of fine screens, sedimentation basin, and an anaerobic lagoon. A BOD reduction of between 80 and 90% and a Dieldrin reduction of 99% is claimed for the system.

(181) Stewart, R.G.
"Pollution and the Wool Industry"
Wool Research Organization of New Zealand, Report No. 10, 1971.

This article is a rather general outline of the sources of wool processing wastes and the present waste treatment technology available.

(190) Rebhun, M., A. Weinberg, and N. Narkis
"Treatment of Wastewater from Cotton Dyeing and Finishing Works for Reuse"
Eng. Bull. Purdue Univ., Eng. Ext. 137 (pt. 2), 1970.

This article describes the results of pilot plant work on the waste from a cotton dyeing and finishing mill in Israel. Alum flocculation followed by filtration was shown to produce a 95% color reduction and a 67% COD reduction. Activated carbon was shown to be a poor sorbent, and greater success was achieved using a weak base ion exchange resins.

(202) Alspaugh, T.A.
"Treating Dye Wastewaters"
45th Annual Conference of the Water Pollution Control Federation
Atlanta, Georgia, Oct. 8-13, 1972.

Alspaugh gives a very thorough evaluation of presently employed and promising future waste treatment unit operations. Experienced removal efficiencies and general treatment costs are also given. A summary of current waste treatment research is given.

(213) Corning, V.
"Pollution Control in Jantzen Dyehouse"
Knitting Times (39) No. 35, 44-45, 1970.

Brief description of Portland, Oregon plant, little detail.

(214) "Textile Water Pollution Cleanup Picks Up Speed"
Textile World, 54-66, November 1967.

Fairly general arcicle but does give some operating data and waste treatment descriptions for several plants:

1. J.P. Stevens & Co., Wallace, N.C. plant

2. UPD's Bluefield, Va., plant

3. Burlington's Cooleemee, N.C.

4. Lyman Printing and Finishing Co., Lyman, N.C.

5. J. P. Stevens & Co., Utica-Mohawk plant

(215) Sahlie, R.S., and C.E. Steinmetz
"Pilot Wastewater Study Gives Encouraging Indications"
Modern Textiles, (50) No. 11, 20-28, 1969.

Description of pilot plant work at Fiber Industries, Shelby, N.C. plant. Article is not very detailed.

(216) "Trade Effluent Control in the Carpet Industry"
Textile Institute and Industry, (3) No. 9, 237-40, 1965.

General discussion, gives values for typical effluents.

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3. Porter, J.J., A.R. Abernathy, J.M. Ford, and D.W. Lyons, "The State of The Art of Textile Waste Treatment." Clemson University (FWPCA Project 12090 ECS), August 1970.

4. "The Cost of Clean Water--Volume III, Industrial Waste Profile No. 4 Textile Mill Products," FWPCA Publication No. I.W.P.-4, Sept. 1967.

5. "Water Pollution Control in the Textile Industry," Textile Chemist and Colorist, 1, No. 7, 23-44, March 1969.

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8. "Standard Methods for the Examination of Water and Wastewater," 12th Edition, American Public Health Association, New York 1965.

9. Eckenfelder, W.W. Jr., "Industrial Water Pollution Control," McGraw-Hill Book Company. New York, 1967.

10. Shindala, A., and M.J. Callinane, "Pilot Plant Studies of Mixtures of Domestic and Dyehouse Wastes," American Dyestuff Reporter, (59) No. 8, 15-19, August 1970.

11. Merrill, W.H. Jr., "How to Determine a Plant's Waste Load," Water and Sewage Works, (116) IW-18-20, (1969).

12. Leatherland, L.C., "Treatment of Textile Wastes," Water and Sewage Works, (116) R-210-214, November 1969.

13. Eckenfelder, W.W. Jr., "Water Quality Engineering for Practicing Engineers," Barnes & Noble, 1970.

14. "Stretch knitter cuts pollution, triples dyehouse production," Textile World, (120) No. 2, 112-116, 1970.

15. "What The Mills Are Doing to Control Water Pollution," Textile Chemist Colorist, (1) No. 6, 25-36, March 1969.

16. Biggs, A.I., "Biological Treatment of Textile Effluents," Chemistry and Industry, 1536-8, September 16, 1967.

17. Northup, H.J., "There are Some Answers to Textile Pollution," Journal of the American Association of Textile Chemists and Colorists, (2) No. 15, 17-23, July 29, 1970.

18. Movar, A.E., C.A. Rodman and E.L. Shunney, "Treating Textile Wastes With Activated Carbon," Textile Chemist Colorist, (2) No. 15, 35-39, August, 1970.

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20. "Activated Carbon Reclaims Textile Industry's Waste Waters," Environmental Science & Technology, (3) No. 4, 314-5, April 1969.

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American Dyestuff Reporter, (54) No. 22, 61-62, October 1965.

27. Morton, T.H., "Water for the Dyer," Journal of the Society of Dyers and Colorists, (83) No. 5, 177-184, May 1967.

28. Barnes, W.V., and S. Dobson, "Surface-active Agents in Textile Processes and their Effect on Effluents," Journal of the Society of Dyers and Colorists, (83) No. 8, 313-20, August 1967.

29. Kwie, W.W., "Ozone Treats Wastestreams From Polymer Plant," Water & Sewage Works, (116) 74-78, February 1969.

30. Michelsen, D.L., "Research on Treatment of Dye Wastes," Textile Chemist and Colorist, (1) No. 7, 179-80, March 1969.

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33. Farrow, J.C., L.J. Hirth and J.F. Judkins Jr., "Estimating Construction Costs of Waste Water Treatment Systems," Textile Chemist and Colorist, (2) No. 3, 35-40, February 1970.

34. Little, A.H., "Treatment of Textile Waste Liquors," Journal of the Society of Dyers and Colorists, (83) No. 7, 268-73, July 1967.

35. "Close-Downs Hit Six More Textile Plants' Pollution Control A Factor," American Textile Reporter, (54) No. 9, 19, 50, April 1970.

36. "Textiles' Water Pollution Woes Can be Resolved by Solvents," American Textile Reporter, (54) No. 9, 11, 13, April 1970.

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SECTION XIV

GLOSSARY

acetate - A manufactured fiber made from cellulose acetate.

acid dye - A type of dye commonly used to color wool and nylon but may be used on other fibers.

Acrilan - Trademark of Monsanto for acrylic fiber.

acrylic - A manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of at least 85% by weight of acrylonitrile units. Made in both filament and staple form. (See Acrilan, Orlon, Creslan.)

Arnel - Trademark (Celanese Corp.) for cellulose triacetate fiber.

Avicron - Trademark (FMC Corp.) for rayon filament yarn.

Avril - Trademark (FMC Corp.) for staple and filament rayon.

beck - A chamber in which goods may be scoured and dyed. May be operated at atmospheric pressure or at elevated temperature and pressure.

biphenyl (or diphenyl) - A carrier used in dyeing polyester.

biochemical oxygen demand (BOD) - A method of measuring rate of oxygen usage due to biological oxidation. A BOD5 of 1000 mg/liter means that a sample (1 liter) used 1000 mg of oxygen in 5 days.

bleaching - Removal of colored components from a textile. Common bleaches are hydrogen peroxide, sodium hypochlorite, and sodium chlorite.

blend - the combination of two or more types of fibers and/or colors in one yarn.

bottom chrome - Term used in application of certain dyes to wool. Involves use of chromium compounds.

butyl benzoate - A carrier used in dyeing polyester.

carded - Yarn in which fibers are separated and aligned in a thin web, then condensed into a continuous, untwisted strand called a "sliver."

carrier - An organic material used in dyeing polyester. (See biphenyl, orthophenyl phenol, trichlorobenzene, butyl benzoate.)

cationic dye - The colored component of this type of dye bears a positive charge.

caustic soda - A strong alkali used, for example, in mercerizing.

cellulose - Major component of cotton and rayon. Also used as the base for acetate fiber.

chemical oxygen deman (COD) - The amount of oxygen required to oxidize materials in a sample by means of a dichromate solution.

combed cotton - Cotton yarn that is cleaned after carding by wire brushes (combs) and roller cards to remove all short fibers and impurities.

crease-resistant - Fabrics that have been treated to make them resistant to wrinkling. One of the most common methods is to incorporate a resin.

Creslan - Trademark owned by American Cyanamid Co. for acrylic fibers.

cross-dyed - Multicolored effects produced in one dye bath from fabrics containing fibers with different affinities to the same dye.

Dacron - Trademark owned by Du Pont for polyester filaments and staple fibers.

denier - Unit of weight indicating size of a fiber filament based on weight in grams of a standard strand of 9000 meters.

desize - Removal of size. Several methods may be used. (See enzyme.)

developed dye - An azo dye whose color is developed by reaction on cotton.

dichromate - A chemical used widely in applying some dyes. Also used in boiler water. A toxic material.

fieldrin - Chemical applied to wool to eliminate damage due to moths. Toxic.

diphenyl - (See biphenyl).

direct dyes - Class of dyestuffs that colors cellulosic fibers in full shades.

disperse dye - A type of dye used to color several synthetic fibers. Applied as a fine dispersion using a carrier. On cloth, padded dye may be baked on or "thermofixed."

dissolved solids - Total solids - suspended solids in a sample of waste water.

dope-dyed - Trade slang for "solution dyed" or "spun dyed" meaning that color is put into the chemical liquid from which synthetic fibers are drawn. Filaments emerge colored.

double knit - Knitted fabric made on a special knitting machine that combines a double set of needles to produce a fabric.

Durable Press - Goods that require no ironing during the normal use-life of a garment. The term applies to apparel and other textile products such as sheets, draperies, etc. A a rule, DP is achieved in two ways: 1. Pre-curing fabrics with a special resin finish then pressing made-up garment. 2. Post-curing fabric with a resin finish then cooking made-up garments in an oven. As a rule, polyester-cotton blends are used, but there are 100% cottons, and other blends also.

enzyme - An agent used to remove starch size.

felt - A mat of fiber of wool often mixed with cotton or rayon.

flock - Short fibrous particles of fibers or short hairs applied by various processes to the surface of a fabric.

fly - Waste fibers or particles which fly out into the air during carding, drawing, spinning, or other fiber processing.

Fortrel - Trademark owned by Fiber Industries, Inc., for polyester fiber.

greige - Fabrics in unbleached, undyed state before finishing. In U.S., "gray goods" or "grey goods."

Herculon - Trademark owned by Hercules, Inc., for polypropylene fibers.

jig-dyed - Dyed in open width on a machine called a "jig." Cloth moves from one roll to another through the dye liquor until the desired shade is obtained.

jute - Coarse, brown fiber from the stalk of a bast plant grown in India. Used mainly for burlap, cordage, and as a backing for rugs and carpets.

kier - A piece of equipment in which cotton is boiled with dilute caustic soda to remove impurities. Also used as a verb to describe the process.

knitting - Process of making fabric by interlocking series of loops of one or more yarns. Types are: jersey (circular knits), tricots (warp knits), double knits.

Kodel - Trademark owned by Eastman Chemical Products Inc. for polyester yarn and fiber.

Lycra - Trademark (Du Pont) for polyurethane multifilament elastic yarn. The fused multifilaments in a bundle form a monofilament yarn that stretches and snaps back.

mercerizing - Finish used on cotton yarns and fabrics to increase luster, improve stretch and dyeability. Treatment consists of impregnating fabrics with cold concentrated sodium hydroxide solution.

Mitin - Trademark owned by Geigy Co., Inc. for a moth-repellent finish for woolens.

modacrylic - Generic name established by the Federal Trade Commission for a "manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of less than 85% but at least 35% by weight of acrylonitrile units."

mordant - A metallic salt used for fixing dyes on fibers.

naphthol dye - A azo dye whose color is formed by coupling with a naphthol. Used chiefly on cotton.

non-woven - A material made of fibers in a web or mat generally held together by a bonding agent.

nylon - Generic name for "a manufactured fiber in which the fiber-forming substance is any long-chain synthetic polyamide having recurring

amide groups as an integral part of the polymer chain."

Orlon - Trademark (Du Pont) for acrylic fiber.

ortho phenyl phenol - A carrier used in dyeing polyester.

package dye - A method for dyeing many cones of yarn at once by pumping a dye solution through the yarn.

permanent finish - Fabric treatments of various kinds to improve glaze, hand, or performance of fabrics. These finishes are durable to laundering.

pH scale - A method used to describe acidity or alkalinity. pH 7 is neutral; above 7 - alkaline; below 7 - acid. The scale extends from 0 to 14 and a change of 1 unit represents a tenfold change in acidity or alkalinity.

pigment prints - Made with insoluble pigment mixed with a binder and thickener to form the printing paste.

pile fabric - Fabric with cut or uncut loops which stand up densely on the surface.

polyamide - (See nylon.)

polyester - A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 85% by weight of an ester of dihydric alcohol and terephthalic acid. (See Dacron, Fortrel, Kodel.)

polypropylene - Basic fiber-forming substance for an olefin fiber.

precured fabric - Technique for imparting durable press by impregnating fabrics with special resins then curing same. Does not require oven after-treatment of apparel. (See durable press.)

Post-cured - Technique for imparting durable press that requires baking apparel in ovens to cure fabrics that have been impregnated with special resins. Most common technique used with polyester and cotton blends. (See durable press.)

printing - Process of producing designs of one or more colors on a fabric. There are several methods, such as roller, block, screen, etc., and several color techniques, such as direct, discharge, and resist.

print paste - A mixture containing a dye or pigment used in printing. Generally contain gums (thickener) and a solvent. (See also pigment prints.)

raschel - Warp-knit, similar to tricot, but coarser. Made in a wide variety of patterns.

rayon - A generic name for man-made fibers, monofilaments, and continuous filaments, made from regenerated cellulose. Fibers produced by both viscose and cuprammonium process are classified as rayon.

reactive dyes - Dyes that react chemically with the fiber.

resin - A chemical finish used to impart a property desired in a fabric, such as water repellency or hand, etc. (See durable press.)

resist dye - Method of treating yarn or cloth so that in dyeing the treated parts do not absorb the dyestuff.

roller prints - Machine made, using engraved copper rollers, one for each color in the pattern.

scouring - Removal of foreign components from textiles. Normal scouring materials are alkalies (e.g., soda ash) or trisodium phosphate, frequently used in the presence of a surfactant. Textile materials are sometimes scoured by use of a solvent.

screen prints - A screen of fine silk, nylon, polyester, or metal mesh is employed. Certain areas of the screen are treated to take dye, others to resist dye. A paste color is forced through the screen onto the fabric by a "squeegee" to form the pattern.

sequestrant - A chemical used to bind foreign metal ions. Frequently used in dyeing. A common sequestrant is EDTA.

size - A material applied to warp yarns to minimize abrasion during weaving. Common sizes are starch, polyvinyl alcohol (PVOH), and carbonxymethyl cellulose. Sizes are applied continuously in a slasher.

softener - A chemical used to apply a soft, pleasant hand. Fat derivatives and polyethylene are common softeners.

solution-dyed - Synthetic fibers sometimes are dyed by adding color

to the chemical polymer before fibers are formed. Also called dope dyed.

standard raw waste load (SRWL) - A description of the properties of waste water before treatment.

starch - Organic polymer material used as a size; highly biodegradeable.

sulfur dye - A class of dyes which dissolve in aqueous sodium sulfide forming products with a marked affinity for cotton; the dyes are regenerated by air oxidation.

suspended solids - Amount of solids separated by filtration of a sample of waste water.

textured - Bulked yarns that have greater volume and surface interest than conventional yarn of same fiber.

top chrome - Term used in application of certain dyes to wool. Involves use of chromium compounds.

top-dyed - Wool which is dyed in the form of a loose rope of parallel fibers prior to spinning fibers into yarn.

total organic content (TOC) - The total organic materials present in a sample of waste water.

total oxygen demand (TOD) - The amount of oxygen necessary to completely oxidize materials present in a sample of waste water.

total solids - Amount of residue obtained on evaporation of a sample of waste water.

triacetate - Differs from regular cellulose acetate, which is a di-acetate. The description implies the extent of acetylation and degree of solubility in acetone.

tricot - Warp-knitted fabric. Tricots are flat knitted with fine ribs on the face (lengthwise) and ribs on the back (widthwise).

tufted fabric - Fabric decorated with tufts of multiple ply yarns. Usually hooked by needle into fabric structure. Used widely for carpets.

vat dye - A type of dye applied from a liquor containing alkali and a powerful reducing agent, generally hydrosulfite. The dye is subsequently

oxidized to the colored form. Widely used on cellulosic fibers.

warp - Set of lenthwise yarns in a loom through which the crosswise filling yarns (weft) are interlaced. Sometimes called "ends."

weaving - The process of manufacturing fabric by interlacing a series of warp yarns with filling yarns at right angles.

yarn - An assemblage of fibers or filaments, either manufactured or natural, twisted or laid together so as to form a continuous strand which can be used in weaving, knitting, or otherwise made into a textile material.

yarn-dyed - Fabrics in which the yarn is dyed before weaving or knitting.
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