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DEVELOPMENT DOCUMENT FOR PROPOSED EFFLUENT LIMITATIONS GUIDELINES AND NEW SOURCE PERFORMANCE STANDARDS FOR THE

TEXTILE MILLS

POINT SOURCE CATEGORY

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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DEVELOPMENT DOCUMENT

for

PROPOSED EFFLUENT LIMITATIONS GUIDELINES

and

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for the

TEXTILE MILLS

POINT SOURCE CATEGORY

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ABSTRACT

This document presents the findings of a study of the textile manufacturing industry for the purpose of developing waste water effluent limitation guidelines and Federal standards of performance for new sources in order to implement Section 304(b) and 306 of the Federal Water Pollution Control Act Amendments of 1972 (the "Act"). This study covers approximately 7,000 plants in S.I.C. 22.

Effluent limitations guidelines are set forth for the degree of effluent reduction attainable through the application of the "Best Practicable Control Technology Currently Available", and the "Best Available Technology Economically Achievable", which must be achieved by existing point sources by July 1, 1977, and July 1, 1983, respectively. The "Standards of Performance for New Sources" set forth the degree of effluent reduction which is achievable through the application of the best available demonstrated control technology, processes, or other alternatives.

The proposed regulations for July 1, 1977, require in-plant waste management and operating methods, together with the best secondary biological treatment technology currently available for discharge into navigable water bodies. This technology is represented by preliminary screening, primary treatment (wool scouring only), coagulation (carpet mills only), and secondary biological treatment.

The recommended technology for July 1, 1983, and for new source performance standards, is in-plant waste management and preliminary screening, coagulation (carpet mills only), primary sedimentation (wool scouring only), biological secondary treatment and advanced treatment such as multi-media filtration or activated carbon adsorption.

Supportive data and rationale for development of the proposed effluent limitation guidelines and standards of performance are contained in this report.

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SECTION I

CONCLUSIONS

The purpose of this report is to establish waste water effluent limitation guidelines for the textile manufacturing industry. A conclusion of this study is that this industry comprises seven subcategories:

1. Wool Scouring
2. Wool Finishing
3. Greige Mills
4. Woven Fabric Finishing
5. Knit Fabric Finishing
6. Carpet Mills
7. Stock and Yarn Dyeing and Finishing

The major criteria for the establishment of the subcategories are the biochemical oxygen demand (BOD5), chemical oxygen demand (COD), and total suspended solids (TSS) in the plant waste water. Subcategorization is required on the basis of the raw material used and the production process employed. Evaluation of such factors as age of facilities, location and climate and similarities in available treatment and control measures substantiate this industry subcategorization. However, the facility's size required an exception within the subcategorization. Different limitations were established for plants within six subcategories due to unequal economic impacts created by diseconomies of scale.

The wastes from all subcategories are amenable to biological treatment processes and at least eighteen textile manufacturing plants are able to achieve high levels of effluent reduction (BOD5 and total suspended solids) through secondary biological treatment systems. These systems treat waste waters from dyeing and finishing broadwoven cotton and cotton synthetic blends, knits and stock and yarn. It is estimated that the costs for all plants within the industry to achieve the best practicable effluent reduction would result in final product price increases ranging from 0.1 cents per kilogram product (0.2 cents per pound product) to a high of 0.8 cents per kilogram (1.8 cents per pound). The average price increase is less than 0.4 cents per kilogram (0.9 cents per pound).

The cost of achieving the best available effluent limitations is estimated to result in further final product price increases ranging from 0.05 to 0.4 cents per kilogram (0.1 to 0.8 cents per pound) product processed for all greige mills and for all small plants in the other six subcategories. Cost increases are expected to range from 0.4 to 2.0

cents per kilogram (0.8 to 4.5 cents per pound) for larger plants in the industry subcategories (except greige mills).

The estimated final product costs required to achieve best practicable and best available effluent reductions range between 0.3 and 1.1 cents per kilogram (0.6 and 2.5 cents per pound) for small plants and 0.5 to 2.5 cents per kilogram (1.0 and 5.4 cents per pound) for larger plants.

SECTION II

RECOMMENDATIONS

The waste water effluent reduction limitations attainable through the application of the best practicable control technology currently available are based on the performances of exemplary secondary biological systems treating textile manufacturing waste water. Best practicable control technology currently available includes the following treatment components: preliminary screening, primary sedimentation (wool scouring only), coagulation (carpet mills only), and secondary biological treatment.

The waste water effluent reduction limitations attainable through the application of the best available control technology economically achievable are based on the best practicable control technology plus advanced treatment including multi-media filtration for greige mills and small textile mills in the remaining six subcategories and activated carbon adsorption for larger mills in the six subcategories. Both filtration and carbon absorption may be needed where large quantities of dispersed dyes or materials with poor adsorptive capacity are discharged.

Recommended best practicable effluent limitations to be achieved by July 1, 1977, are set forth in Table 1 and recommended best available limitations to be achieved by July 1, 1983, are set forth in Table 2. These limitations are the average of daily values for any period of thirty consecutive days. Maximum limitations for any one day for BOD_5, TSS, COD and oils and grease should not exceed these thirty day limitations by more than one hundred percent.

The waste water effluent reduction limitations for new sources are the same as those attainable through the application of the best available control technology economically achievable. These limitations are possible because of the present availability of the treatment and control technology to attain this level of effluent reduction.

TABLE 1

MAXIMUM THIRTY DAY AVERAGE
RECOMMENDED EFFLUENT LIMITATION
GUIDELINES FOR JULY 1, 1977

Plant Subcategory	Effluent Limitations (1) BOD5 kg/1000kg (lb/1000lb)	TSS kg/1000kg (lb/1000lb)	COD kg/1000kg (lb/1000lb)
1. WOOL SCOURING (2)			
Plant capacity less than 6,500 kg/day (14,300 lb/day)	3.7	3.7	NA
Plant capacity greater than 6,500 kg/day (14,300 lb/day)	3.7	3.7	24
2. WOOL FINISHING			
Plant capacity less than 900 kg/day (1,980 lb/day)	7.5	7.5	NA
Plant capacity greater than 900 kg/day (1,980 lb/day)	7.5	7.5	56
3. GREIGE MILLS			
All plant sizes	0.45	0.45	
4. WOVEN FABRIC FINISHING			
Plant capacity less than 1,000 kg/day (2,200 lb/day)	2.2	6.9	NA
Plant capacity greater than 1,000 kg/day (2,200 lb/day)	2.2	6.9	33
5. KNIT FABRIC FINISHING			
Plant capacity less than 3,450 kg/day (7,590 lb/day)	1.8	8.0	NA
Plant capacity greater than 3,450 kg/day (7,590 lb/day)	1.8	8.0	24
6. CARPET MILLS			
Plant capacity less than 3,450 kg/day (7,590 lb/day)	4.3	4.3	NA
Plant capacity greater than 3,450 kg/day (7,590 lb/day)	4.3	4.3	30
7. STOCK AND YARN DYEING AND FINISHING			
Plant capacity less than 3,100 kg/day (6,820 lb/day)	3.5	9.2	NA
Plant capacity greater than 3,100 kg/day (6,820 lb/day)	3.5	9.2	47

NA MEANS NOT APPLICABLE

(1) Plant capacities and discharge limitations are stated for Subcategories 1 and 2 per weight of raw wool received at the wool scouring or wool finishing operation and are stated for Subcategories 3, 4, 5, 6 and 7 per weight of final material produced by the facility.

For all subcategories pH should range between 6.0 to 9.0 at any time.

For all subcategories Most Probable Number (MPN) of Fecal Coliforms should not exceed 400 counts per 100 ml.

(2) For all Wool Scouring plants (Subcategory 1) Oils and Grease should not exceed 1.9 kg (lb)/1000 kg (lb) grease wool.

TABLE 2

MAXIMUM THIRTY DAY AVERAGE
RECOMMENDED EFFLUENT LIMITATION
GUIDELINES FOR JULY 1, 1983

Plant Subcategory	Effluent Limitations (1) BOD5 kg/1000kg (lb/1000lb)	TSS kg/1000kg (lb/1000lb)	COD kg/1000kg (lb/1000lb)
1. WOOL SCOURING (2)			
Plant capacity less than 6,500 kg/day (14,300 lb/day)	2.5	2.5	NA
Plant capacity greater than 6,500 kg/day (14,300 lb/day)	2.5	2.5	64
2. WOOL FINISHING			
Plant capacity less than 900 kg/day (1,980 lb/day)	5.0	5.0	NA
Plant capacity greater than 900 kg/day (1,980 lb/day)	5.0	5.0	14.9
3. GREIGE MILLS			
All plant sizes	0.3	0.3	NA
4. WOVEN FABRIC FINISHING			
Plant capacity less than 1,000 kg/day (2,200 lb/day)	1.5	4.6	NA
Plant capacity greater than 1,000 kg/day (2,200 lb/day)	1.5	4.6	8.8
5. KNIT FABRIC FINISHING			
Plant capacity less than 3,450 kg/day (7,590 lb/day)	1.2	5.3	NA
Plant capacity greater than 3,450 kg/day (7,590 lb/day)	1.2	5.3	6.4
6. CARPET MILLS			
Plant capacity less than 3,450 kg/day (7,590 lb/day)	2.9	2.9	NA
Plant capacity greater than 3,450 kg/day (7,590 lb/day)	2.9		8.0
7. STOCK AND YARN DYEING AND FINISH-ING			
Plant capacity less than 3,100 kg/day (6,820 lb/day)	2.3	6.1	NA
Plant capacity greater than 3,100 kg/day (6,820 lb/day)	2.3	6.1	12.5

NA MEANS NOT APPLICABLE

(1) Plant capacities and discharge limitations are stated for Subcategories 1 and 2 per weight of raw wool received at the wool scouring or wool finishing operation and are stated for Subcategories 3, 4, 5, 6 and 7 per weight of final material produced by the facility.

For all subcategories pH should range between 6.0 to 9.0 at any time.

For all subcategories Most Probable Number (MPN) of Fecal Coliforms should not exceed 400 counts per 100 ml.

(2) For all Wool Scouring plants (Subcategory 1) Oils and Grease should not exceed 1.9 kg (lb)/1000 kg (lb) grease wool.

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 pursuant 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 subcategory were identified through analyses of: (1) the sources and volumes of water and waste waters and (2) the constituents of all waste waters including toxic or hazardous constituents and other constituents which result in taste, odor or color. 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 subcategory were 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 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 in Table 3 are scattered 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. As shown below, almost 80 percent of the industry is located in the southern and mid-atlantic states.

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

Table 3

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	-	-	-	16

Table 3 (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[illegible]

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 computed on a clean basis 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 or 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.

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 grouped 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 4 gives details of the process water used and discharged divided as far as possible according to the EPA 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 5, 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 4

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

Table 5

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

Profile of Manufacturing Processes

As mentioned above the industry's basic raw materials are wool, cotton and synthetic fibers. The fiber and fabric finishing operations are described below for each of these three materials. Finally, these operations are related to the selected subcategorization through brief process descriptions of each subcategory. The rationale for subcategorization along with detailed descriptions of the seven segments is given in Section IV.

Wool Fiber and Fabric Finishing Operations

Wool fiber consumption is smaller than either cotton or synthetic fiber consumption and the trend seems to be toward less demand in the future on a percentage basis. The operations required to produce a piece of finished woolen fabric are described below; either knitting or weaving can be done at a given mill. Scouring is the first wet process that wool fibers receive. This process removes all the natural and acquired impurities from the wcolen fibers. There are two methods of wool scouring - detergent scouring and solvent scouring. In the United States, the detergent scouring process is used almost exclusively. There are two types of detergent scouring - the soap-alkali process and the neutral detergent scouring process. In the soap-alkali process, a soap or synthetic detergent and a milk alkali such as sodium carbonate or soda ash is added to a bath at a pH of 9.5 to 10.5 and heated to temperatures of 130°F. This process ocnsumes a volume of 8,000 to 12,000 gallons of water per 1000 pounds of wool fiber. In the neutral detergent process, non-ionic detergents fo the ethylene oxide condensate class are added to water at a pH of 6.5 to 7.5 and a temperature of 135° to 160°F.

The process is carried out in a series of four open bowls called "scouring train." The first two bowls contain the detergent or soap alkali and perform the scour. The last two bowls serve to rinse the fibers clean. For every pound of scoured woolen fiber one and one-half pounds of waste impurities are produced; therefore, wool scouring produces one of the strongest industrial wastes in terms of BOD. This process contributes 55 to 75 percent of the total BOD load in wool finishing.

The next processes are the burrpicking and carbonizing step which is done to remove any vegetable matter remaining in the wool after scouring. If the wool is to be stock dyed, it is done prior to dyeing; if the wool is to be piece dyed, the fabric is carbonized prior to dyeing.

Due to the popularity of multi-colored fabrics, stock dyeing is used more often today than is piece good dyeing. The two classes of dyes used on wool fiber are acid dyes and metallized dyes. In the dyeing of wool fibers it is impossible to fix definite formulas. The dye, grade of wool, and the type of dyeing machine will alter the formulation. In the acid dyeing baths the temperature of the solution will vary from 140° to 212°F. In the metallized dyeing the average final temperature is 185°F. The pH varies depending on the amount of residual alkali left in the wool fibers after the scouring process. The volume of waste water generated by dyeing, either stock or piece goods is large and highly colored. The BOD load is contributed by the process chemicals used, and the contribution of wool dyeing to the mill's total BOD load is 1 to 5 percent.

Although the mixing and oiling step does not contribute directly to the water waste volume, the oil finds its way into the waste stream through the washing after fulling operation. The percentage contribution of total BOD load of this process varies with the type of oil used. The traditional oiling agent is olive oil, which produces a high BOD that could contribute 10 percent of the total BOD load; however, there is a trend toward the use of non-ionic emulsifiers in oiling, that greatly reduces the BOD contribution in this area.

Fulling is another operation that does not directly contribute to the waste stream, until the process chemicals are washed out of the fabric in the wash after fulling operation. There are two common methods of fulling, alkali fulling and acid fulling. In the former case, soap or synthetic detergent, soda ash, and sequestering agents are used in the fulling solution. In acid fulling, the fabric is impregnated with an aqueous solution of sulfuric acid, hydrogen peroxide, and minor amounts of metallic catalysts (chromium, copper and cobalt). In either case, the water is heated to a temperature of 90° to 100°F. Acid fulling is always followed by alkali fulling.

Following the fulling operation, the goods are washed to remove the fulling chemicals mentioned above and the carding oil described in the mixing and oiling disussion. It is estimated that from 10 to 25 percent of the fulled cloth's weight is composed of process chemicals that will be washed out in this process and wasted. Due to this large amount of waste, wool washing after fulling is the second largest source of BOD, contributing from 20 to 35 percent of the total. The usual procedure in this process is to subject the fulled cloth to two soapings, two warm rinses, and one cold rinse. In the first soaping, nothing is added to the water, the soaping action takes place when agitation of the fabric causes the soap or synthetic detergent ot produce subs, thus washing the fabric. In the second soaping, a 2 percent solution of soap or synthetic detergent is used. The warm water rinsings are done at 100° to 110°F., while the cold rinse is done below 100°F. This process consumes from 40,000 to 100,000 gallons of water for each 1000 pounds of wool fabric. Analyses show that wool, once throughly washed, will produce little or no BOD of itself on being rewashed.

After the dusting process, which follows carbonizing the fabric or stock of fibers, the acids used in carbonizing must be removed. In order to accomplish this, the wool is rinsed to remove the bulk of the acid. Following the rinse, the wool is neutralized by a low concentration solution of sodium carbonate. After this neutralization bath the fabric is rinsed again. Since sulfuric acid and soda ash have little or no BOD, this process contributes less than 1 percent of the total BOD.

In the processing of woolen fibers, five sources of pollutional load exist - scouring, dyeing, washing after fulling, neutralizing the carbonizing, and bleaching with optical brighteners. Figures 1 and 2 outline the operations that take place in woolen fabric manufacturing.

Cotton Fiber and Fabric Finishing Operations

The consumption of cotton fibers by textile mills in the United States exceeds that of any other single fiber; however, the total synthetic fiber poundage consumed by the textile industry is greater than that of cotton. The operations required to produce a piece of finished cotton fabric are described below; either weaving or knitting can be done at a given mill.

Slashing is the first process in which liquid treatment is involved. In this process, the warp yarns are coated with "sizing" in order to give them tensile strength to withstand the pressures exerted on them during the weaving operation. Such substances as starch, starch substitutes, polyvinyl alcohol, carboxy methyl cellulose, gelating glue and gums have been used as size agents. The source of pollution in this process results from the cleaning of slasher boxes, rolls, and make up kettles. The volume is therefore usually low; however, the BOD can be quite high, especially if starch is used.

The operation of desizing removes the substance applied to the yarns in the slashing operation, by hydrolyzing the size into a soluble form. There are two methods of desizing - acid desizing and enzyme desizing. In acid desizing, the fabric is soaked in a solution of sulphuric acid, at room temperature, for 4 to 12 hours, and then washed out. In enzyme desizing, couplex organic compounds produced from natural products or malk extracts are used to solubilize the size. The bath is maintained at a temperature of 130° - 180°F. and a pH of 6-7.7, for a period of 4-8 hours. Due to the unstable nature of these organic compounds, the whole bath must be discarded after each batch. After the size has been solubilized, the fabric is rinsed clean. Desizing contributes the largest BOD of all cotton finishing processes - about 45 percent.

Scouring follows desizing. In this process, the cotton was and other non-cellulosic components of the cotton are removed by hot alkaline detergents or soap solutions. In most modern plants, scouring is done in conjunction with desizing rather than as separate operation. Caustic soda and soda ash along with soaps and synthetic detergents and inorganic reagents are used to remove the non-cellulois impurities. The bath is characterized by a pH of 10 to 13 and temperatures of 250°F. Although the strength of alkali in the beginning of the operation is between 1 percent and 5 percent, the waste liquor will have a 0.3 percent alkaline concentration, the rest being taken out of solution by the cotton fibers. As in the desizing operation, the scouring process is a batch operation requiring the fabric to remain in the kier for a period of from 2 - 12 hours. Scouring is the second largest BOD contributing process in the finishing of cotton textiles - about 31 percent. Following the "boil-out," the goods are rinsed with hot and cold water to remove residual alkali.

Bleaching, the next process, removes the natural yellowish coloring of the cotton fiber and renders it white. The three bleaches most commonly used for cotton are sodium hypochlorite, hydrogen peroxide, and sodium chlorite. In hypochlorite bleaching, the fabric is rinsed, saturated with a weak solution of sulfuric or hydrochloric acid, rinsed again, and then passed through the hypochlorite for a period of up to 24 hours. Then process is done at room temperature with a pH range of 9 to 11. When bleaching with sodium chlorite, acetic acid is used in place of sulfuric or hydrochloric acid, the temperature of the bath is hot (180° - 185°F), and the pH is 3.5-5.5. Hydrogen peroxide is used for continuous bleaching. This process calls for a washer, with a 140° - 175°F temperature, saturation with caustic soda at 175° - 180°F, passage through the peroxide at 195°F, and a final rinse. The pH range used in hydrogen peroxide bleaching is 9 to 10. The final rinse may contain an antichlor, sodium bisulfite or sulfuric acid, to remove residual chlorine from the fabric. The bleaching process contributes the lowest BOD for cotton finishing.

The mercerization process was originally developed to give increased luster to cotton fabrics. Today it is still used for that purpose, but more importantly to impart increased dye affinity and tensile strength to the fabric. It is estimated that only 30 percent of all cotton fabrics are now mercerized, and with the increasing use of cotton-polyester blends, less will probably be done in the future. The process uses a 15 to 30 percent solution of sodium hydroxide at room temperature for 1/2 to 3 minutes. The fabric is then rinsed in an acid wash to neutralize the fabric and washed in water and then dried. The effluent from this process is alkaline and high in dissolved solids, but low in BOD.

After mercerizing, the goods are sent to the dye house or color shop. In the dye house they are dyed either in small volumes of batch process machines, or on continuous dyeing ranges in large volumes. There are five important classes of dyes used on cotton fabrics: vat, developed, sulphur, direct, and aniline black.

The dyeing process is carried out in an aqueous bath with pH variations In the color shop, the goods are printed with colored designs or patterns. The usual method is by roller machines. The color is imparted to the fabric from the rolls which contain the printing paste. This paste contains dye, thickener, hygroscopic substances, dyeing assistants, water, and other chemicals. The pollutional load from the color shop comes mainly from the wash-down rinses used to clean the equipment in the shop and the cloth rinsings. The pollutional load is rather low in both volume and BOD. When a mill does both printing and dyeing, the BOD contribution of the combined processes is 17 percent, and the total BOD load comes from the process chemicals used.

Synthetic Fiber and Fabric Finishing Operations

In this category of textile fibers there are two broad classifications: cellulosic and non-cellulosic fibers. The two major cellulosic fibers are rayon and cellulose acetate. The major non-cellulosic fibers are nylon, polyester, acrylics and modacrylics. There are other fibers in both classes, but at present they are not consumed in as large a volume as the six fibers mentioned above. The largest volume of synthetic fibers consumed by textile mills comes from the non-cellulosic fibers; and the trend is toward an even greater demand in the future, particularly for polyester fibers. Synthetic fibers can be converted into fabrics in one of two ways. Continuous filament yarns can be used to manufacture 100 percent synthetic fabrics, or staple yarns can be used to produce fabrics that are blends of man-made fibers or man-made and natural fibers. Blended fabrics are processed according to the natural fiber component of the yarn. As in cotton and wool processing, the yarns are either woven or knitted as a given mill.

The first process in which synthetic fibers are subject to an aqueous treatment is stock dyeing, unless the fabric is to be piece dyed. When stock dyeing is used, the liquid waste discharge will vary from about 8 to 15 times the weight of the fibers dyed.

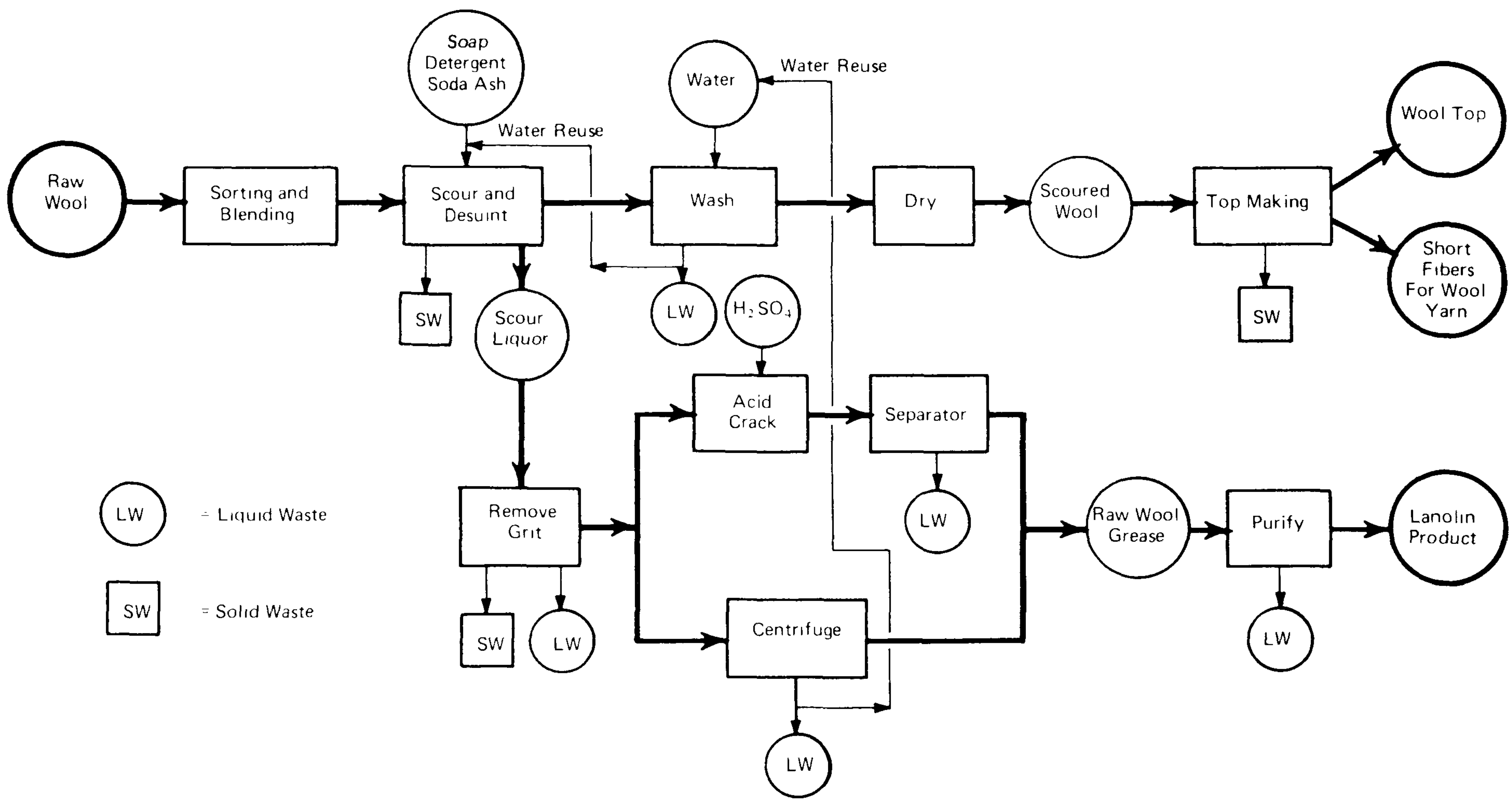
Due to the low moisture regain of the synthetics, static electricity is a problem during processing. To minimize this problem, anti-static oils are applied to the yarns, which also serve as lubricants and sizing compounds. These compounds commonly used are: polyvinyl alcohol, styrene-base resins, polyalkylen glycols, gelatin, polyarylic acid, and polyvinyl acetate. These compounds become a source of water pollution when they are removed from the fabrics during scouring. Since the manufacture of synthetic fibers can be well controlled, chemical impurities are relatively absent in these fibers; therefore, only light scouring and little or no bleaching are required prior to dyeing; and if synthetics are bleached, the process is not normally a source of organic or suspended solids pollution; however, the process will generate dissolved solids if chlorine bleaches are used.

Process Description by Subcategory

Subcategory 1 - Wool Scouring: A generalized flow diagram of the wool scouring process is shown in Figure 1. Scouring consists of sorting the fleece and feeding it to a hopper. 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 wool top, the wool is combed and gilled. The products are short fibers (used for wool yarn) and long fibers (used for worsted yarn).

Subcategory 2 - Wool Finishing: The wool finishing process is depicted in Figure 2. 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 by carbonizing and then cleaned of spinning oils and any weaving sizes by a light scour. 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.



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 1 Subcategory 1: Wool Scouring

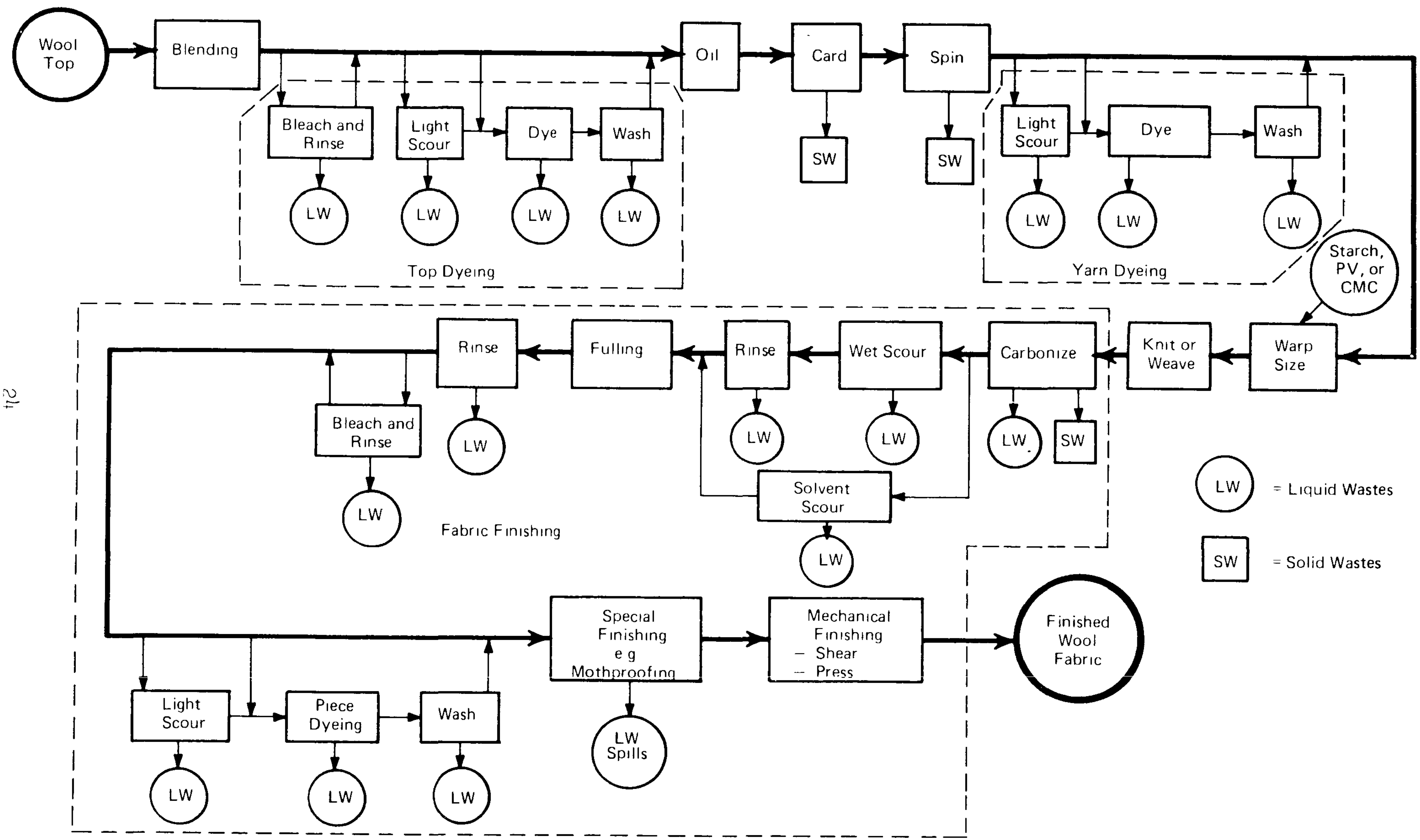


Figure 2 Subcategory 2: Wool Finishing

Subcategory 3 - Greige Mills: 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. Many operate as completely independent facilities. Figure 3 shows operations generally performed at this type of greige mill.

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. Cooling and humidifying water used in a greige mill represents a substantial portion of the total water usage. Industrial wastes from knit greige good is nil. If any wastes are generated they are from the knitting oils, however, these would only enter the waste stream through spills, wash up or possible washing of the final product.

For carpet 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 removed by coagulation.

Subcategory 4 - Woven Fabric Finishing: 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.

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. A flow sheet for woven fabric finishing is given in Figure 4.

Subcategory 5 _ Knit Fabric Finishing: The wet processing operations performed in knit fabric finishing are shown schematically in Figure 5. 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 5. The wet process operations employed in a plant depend on the nature of the goods involved and the end product requirements.

Subcategory 6 - Carpet Mills: 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. The relative quantities of yarn, beck, and continuous dyeing, and printing and latexing may vary widely.

The yarn is tufted onto a polypropylene or jute woven backing in a dry operation (Figure 6). 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 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 continous 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.

Subcategory 7 - Stock and Yarn Dyeing and Finishing: In this category is crude yarn obtained from a spinning facility. The yarn may be natural, synthetic, or blended. Wet processes used by yarn mills include scouring, bleaching, mercerizing and dyeing (Figure 7).

Several techniques are available for processing raw yarn into the finished product. The mcst 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 is knit and the fabric is piece dyed, washed, rinsed and dried. The fabric is then unravelled and the yarn is wound on cones.

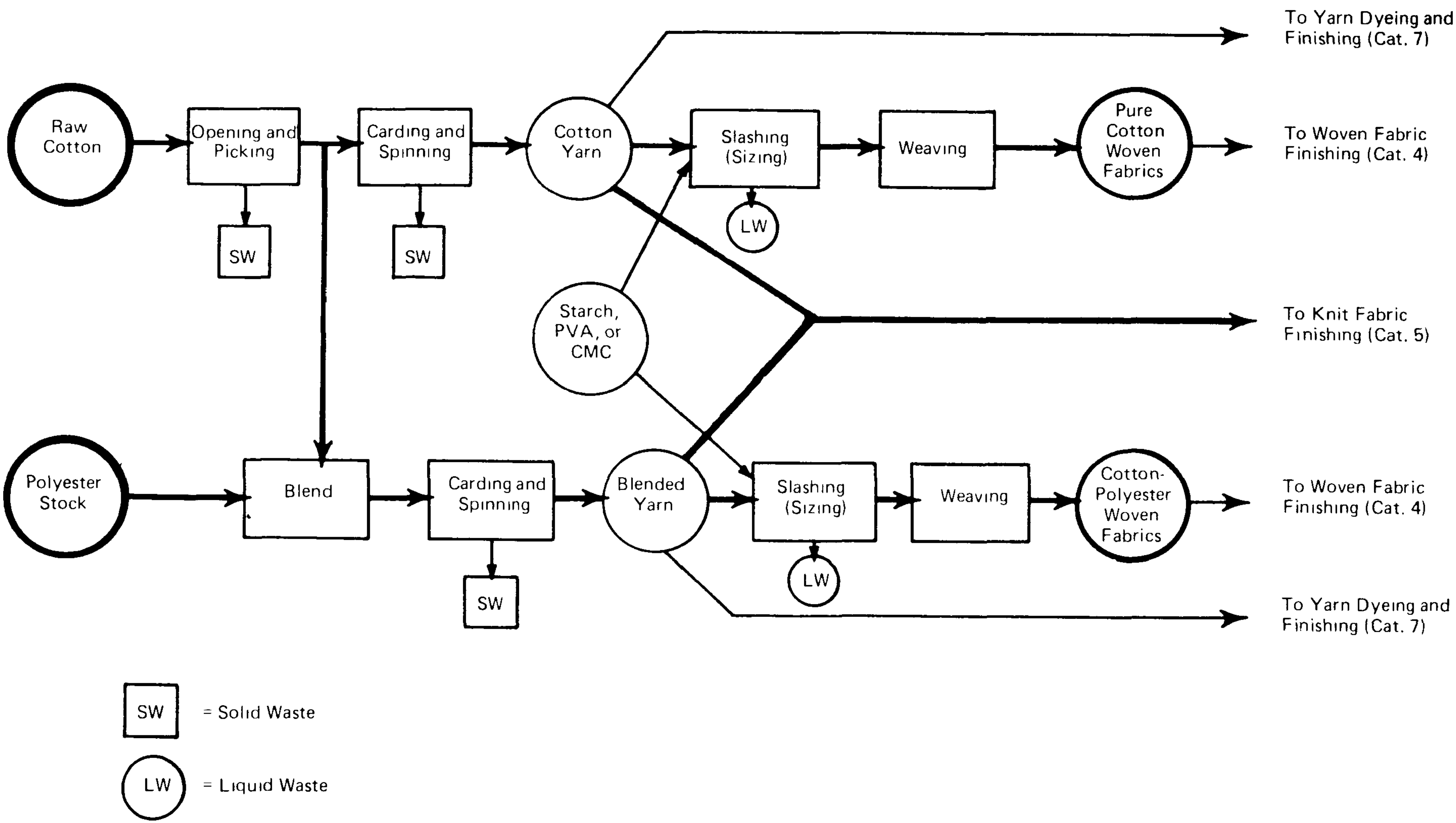


Figure 3 Subcategory 3: Greige Mills

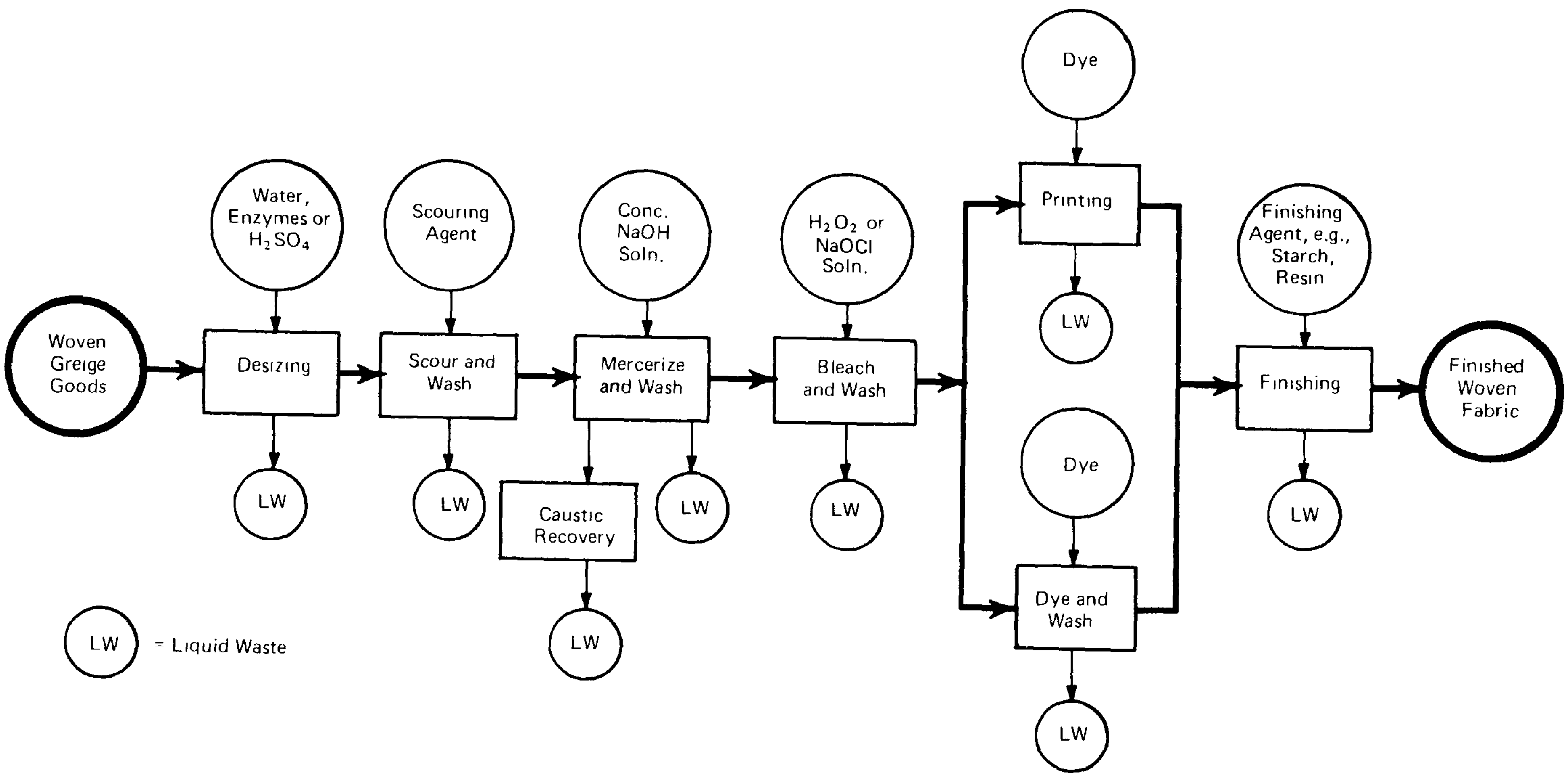


Figure 4 Subcategory 4: Woven Fabric Finish

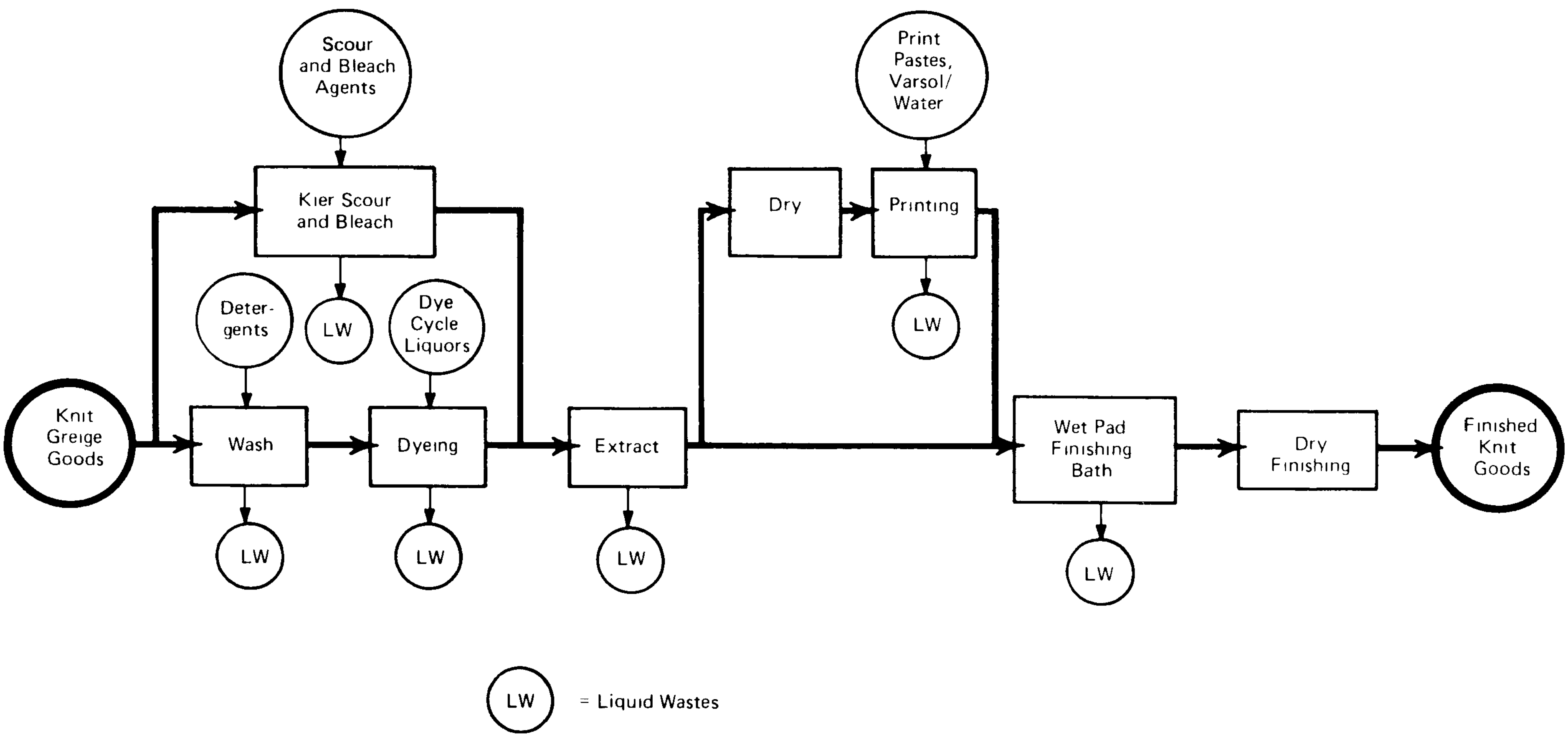


Figure 5 Subcategory 5: Knit Fabric Finishing

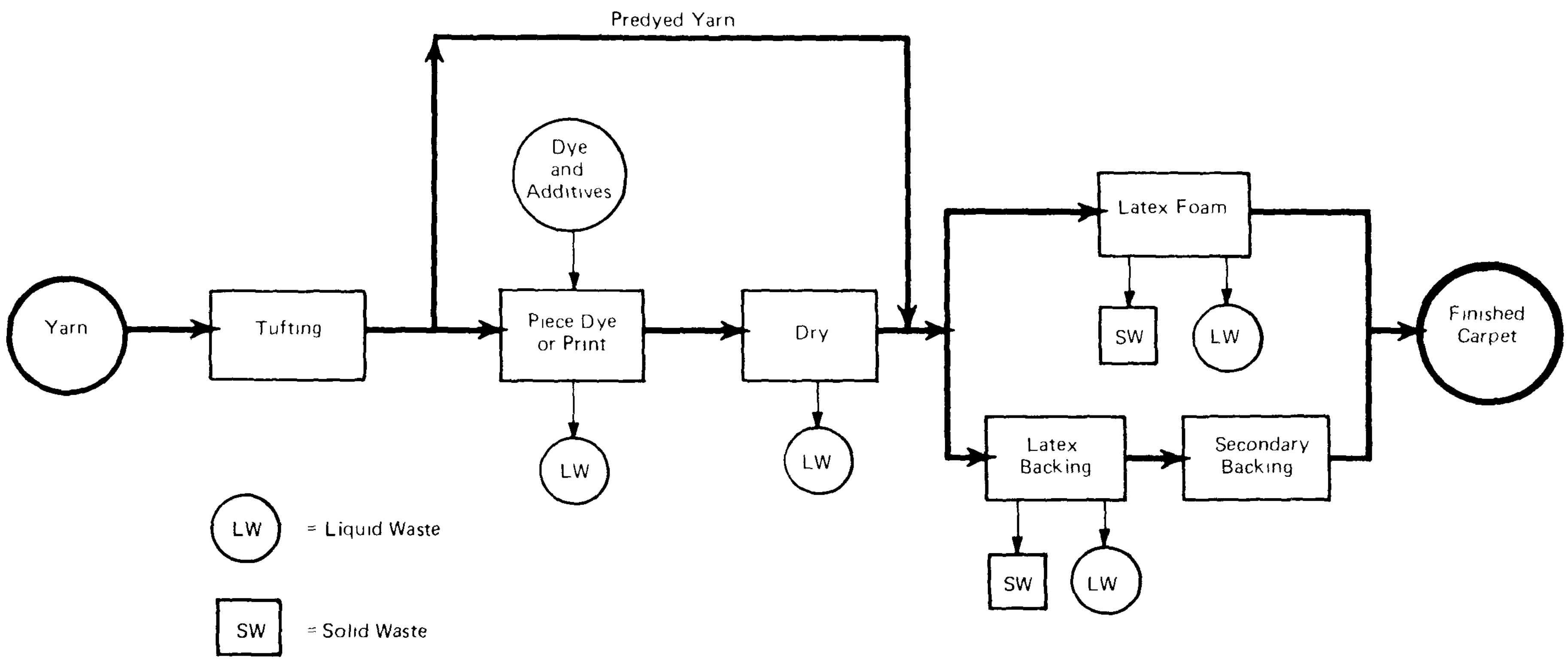


Figure 6 Subcategory 6: Carpet Mills

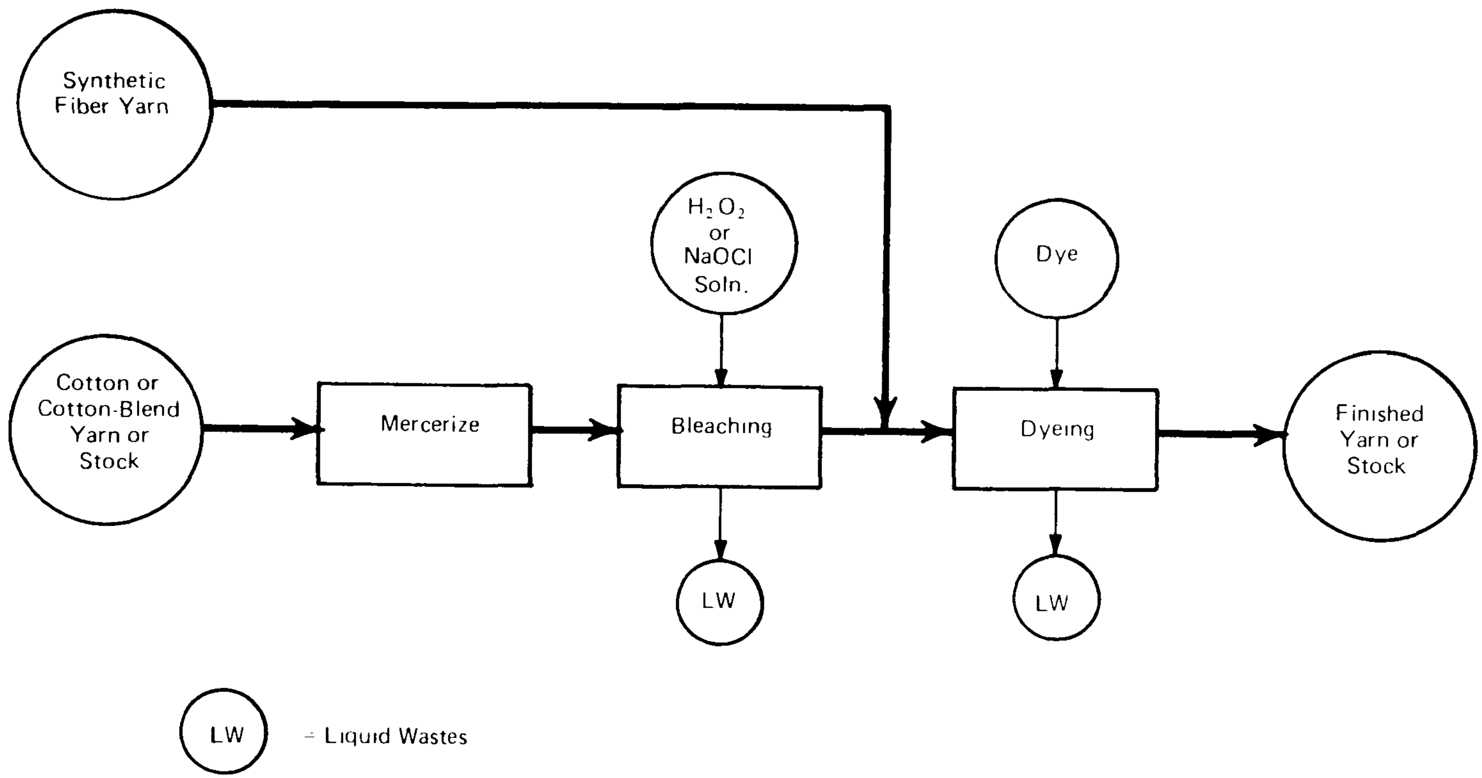


Figure 7 Subcategory 7: Stock and Yarn Dyeing and Finishing

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, Subcategory 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. A previous categorization scheme prepared for EPA which employed unit processes to synthesize the raw waste loads. This method was also judged too difficult to implement.

d. The preliminary system developed by EPA in the "interim guidance" for the textile industry.

e. The system developed by the Institute of Textile Technology and Hydrosciences in the study for the 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.

A comparison of the EPA interim guidance and the ATMI/CRI categorizations with those used in this study is given in Table 6.

Table 6

Industry Categorization

EPA	EPA: Preliminary	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
		13. Specialized Finishing

Categorization

The following factors were considered in establishing subcategories in the textile industry.

a) raw material
b) age and size of facilities
c) products and production processes
d) location and climate
e) waste treatability

The principal basis for subcategorization is the configuration of the predominant material being processed. Knit and woven fabrics are different and each is different from carpet, yarn or other fibers. Special processes such as wool scouring and latex application provide additional subcategorization. Waste water volume and characteristics vary widely for the different materials and processes and support the proposed categorization. Although waste water volume and characteristics vary significantly, the treatability of textile wastes by similar biological treatment methods has been demonstrated. Thus, subcategorization by waste treatability is not required. Location and climate have a material effect upon pollution control methodology for any given operation or segment of the industry. However, the impact of either location or climate is not sufficient for defining or substantiating subcategories. (Variability in treatment operation has been taken into account in Section IX). Available data indicates that neither the age nor the size of facilities significantly affects waste character or water usage. Any technological effect of size or age is predominately reflected in the type or size of production facility, and was taken into consideration through this factor.

The subcategorization selected for the purpose of developing waste water effluent limitations guidelines and standards are as follows:

1. Wool scouring
2. Wool finishing
3. Greige mills
4. Woven fabric finishing
5. Knit fabric finishing
6. Carpet mills
7. Stock and yarn dyeing and finishing

Subcategories 1 and 2 deal with wool processing; subcategories 3, 4, 5 and 7 covers the various types of processing for cotton and synthetic fibers; and subcategory 6 covers the carpet industry. These subcategories are described in detail below.

Subcategory 1 - Wool Scouring

Wool scouring and topmaking is conveniently separated as a subcategory and 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. In addition, the preparation and cleaning of wool requires 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 highly concentrated waste.

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 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 materials 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 variability in raw waste loads.

Subcategory 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 Woven Fabric Finishing and Knit Fabric Finishing, but have a higher raw waste load.

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

This industry consists of many small mills -- most of them in the North (New England, New York and New Jersey) and most are fully integrated mills -- and about 25 larger mills, mostly in the South (Virginia, the Carolinas and Georgia).

A sample of 29 textile mills participated in a waste treatment survey prepared by the Wool Manufacturers Council of the Northern Textile Association. Of the 29 mills, 25 were wool finishers and 4 were cotton and synthetic mills. Of the 29 mills 7 have completed tie-ins into municipal treatment facilities: 15 plan to tie into municipal facilities that are in various stages of construction or planning; 4 have completed private treatment facilities and 3 have plans to construct private treatment facilities.

Most small mills do some 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 blends: the rest process primarily other fabrics.

The processes of carding and spinning wool into yarn, and subsequent weaving or knitting into fabric are included in Subcategory 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 (1) the wide variety of chemicals used to process wool fabrics and (2) high raw waste loading.

In addition to processing all wool fabrics, today's wool finishing mills process wool blend fabrics and fabrics made of 100% synthetic fibers. The percentage of wool used by a woolen mill is based on market demand and availability of wool. The variety of fabrics varies from mill to mill, season to season and year to year. Shifts back and forth between fibers cannot be predicted.

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.

High water usage in the subcategory appears to be a result of washing after the fulling operation (peculiar to 100 percent wool fabrics).

Size as used on cotton and synthetic wovens is not used by wool mills. Wax lubricants and emulsified oil are sometimes used in processing wool yarns. These waxes and oils are difficult to remove and require thorough washing to be removed properly. 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 Subcategory 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.

Subcategory 3 - Greige Mills and Carpet Backing

Although there are many greige goods mills, they carry out mainly dry operations (with the exception of slashing) 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, and because of the similar dry nature of carpet backing operations these mills are included in this subcategory.

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 a low percentage of the total plant flow.

Greige mills generally manufacture yarn and unfinished fabric. In general greige mills include the production of woven greige goods knit greige goods and greige yarn production. However, knit greige goods production is almost always combined with a finishing operation and therefore may be included in the knit finishing subcategory. Carpets are sometimes backed in a separate plant. The industrial portion of the waste water consists of equipment washing which may be performed once a day or once a week. The resulting waste flow is small.

It has been estimated 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. No carpet backing mills were found which did not discharge to a municipal system.

Subcategory 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 included in this subcategory because the greige goods section of these mills contributes only a small amount to the overall effluent load.

The size removed after weaving is a major contribution to the BOD load from the plant. Two sizing compounds are commonly employed: starch and polyvinyl alcohol (PVA). PVA tends to be less readily biodegradable than starch and therefore presents a lower BOD_5 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.

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

This category encompasses mills which finish woven goods (or integrated greige goods and finishing mills). It has been estimated that about 600 mills fall into subcategory 4. About 20 percent treat their own waste, 75 percent enters municipal systems, and 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.

Subcategory 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, raw waste load levels are lower.

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.

While the industry has shown substantial growth in value of shipments, it has been estimated that through consolidation and other factors the current number of plants in this industry is about 2500. Of this number, it has been estimated 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 therefore, 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 subcategory 7 guidelines.

Of the 1400 plants believed to have wet process operations, it has been estimated that 85 percent discharge to municipal treatment systems. The great bulk of these are hosiery plants (700-800) located primarily in North Carolina, Tennessee, and Pennsylvania.

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 subcateogry 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.

Subcategory 6 - Carpet Mills

Carpet mills form a distinct part of the industry although their effluents are similar in many ways to those of Subcategory 5, Knit Fabric Finishing. Carpets use mostly synthetic fibers (nylon, acrylics and polyesters) but some wool is still processed. As in Subcategory 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. However, carpet mills often do latexing in the same plant with the finishing. Latex is settled in separate basins prior to release of the segregated stream to the treatment plant and the additional load on these mills is negligible.

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.

Subcategory 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.

Subcategory 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.

It has been estimated that 750 plants 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.

Categorization: Economic Considerations

The size of the production facilities is another significant factor which requires an exception within the subcategorization. Severe diseconomies of scale create economic impacts which require separate limitations for small plants. As illustrated in Section VIII, the unit costs attributable to activated carbon adsorption (best available technology) for small industry plants as compared to medium sized plants are reflected in an average price increase for a small plant of 4.2 cents per kilogram product (1.9 cents per pound of product) as compared with an average price increase for a medium sized plant of 2.3 cents per kilogram (1.0 cents per pound). It is estimated that disproportionate cost increases such as those indicated above would force the closing of as many as 500 small facilities. Thus, an exemption in the form of less stringent limitations is required for small textile mills. The basis for this size exception is based on economic trends developed in Section VIII and developed in Table 7.

The subcategories including size exemptions selected for the purpose of developing waste water effluent limitations guidelines and standards are as follows:

1. WOOL SCOURING
   Plant capacity less than 6,500 kg/day (14,300 lb/day)
   Plant capacity greater than 6,500 kg/day (14,300 lb/day)

2. WOOL FINISHING
   Plant capacity less than 900 kg/day (1,980 lb/day)
   Plant capacity greater than 900 kg/day (1,980 lb/day)

3. GREIGE MILLS

4. WOVEN FABRIC FINISHING
   Plant capacity less than 1000 kg/day (2,200 lb/day)
   Plant capacity greater than 1000 kg/day (2,200 lb/day)

5. KNIT FABRIC FINISHING
   Plant capacity less than 3,450 kg/day (7,590 lb/day)
   Plant capacity greater than 3,450 kg/day (7,590 lb/day)

6. CARPET MILLS
   Plant capacity less than 3,450 kg/day (7,590 lb/day)
   Plant capacity greater than 3,450 kg/day (7,590 lb/day)

7. STOCK AND YARN DYEING AND FINISHING
Plant capacity less than 3,100 kg/day (6,820 lb/day)
Plant capacity greater than 3,100 kg/day (6,820 lb/day)

TABLE 7

BASIS FOR SIZE EXCEPTION WITHIN TEXTILE SUBCATEGORIZATION

Number of Employees	Number of Establishments By Subcategory						
	1	2	3(1)	4	5	6(2)	7
1-4	14	54		63	95		38
5-9	5	17		27	59		23
10-19	10	22		56	93		25
20-49	21	64		91	124		40
50-99	6	41		76	63		32
100-249	7	60		70	75		20
250-499	4	35		32	23		10
499-2,499	1	17		51	9		3
Total	68	310		449	541		192
1-19	29	93		146	247		86
Percent	(43%)	(30%)		(33%)	(46%)		(45%)
lb product/day / Employee	750	100		120	400	400	360
No. Employees	19	19		19	19	19	19
(lb/day) (1000)	14.3	1.98		2.2	7.59	7.59	6.82
kg/day (1000)	6.5	0.9		1.0	3.45	3.45	3.10

(1) No size exception for Subcategory 3 because of small waste load.

(2) Size exception calculated from associated data because only limited economic data available on carpet mills.

SECTION V

WASTE CHARACTERISTICS

INTRODUCTION

Many of the mechanical operations used in the manufacture of textile fabrics are common to the industry as a whole and the character of the waste waters are similar. Typically, the textile fibers are combined into yarns and then the yarns into fabrics. After the fabrics are manufactured, they are subject to several wet processes collectively known as finishing and it is in these finishing operations that the major waste effluents are produced.

In Section III wool, cotton and synthetic fiber and fabric finishing operations were briefly described. General descriptions of the manufacturing processes were given in Section IV for the purpose of industry subcategorization. In this section the waste waters from each operation within each subcategory are characterized.

The principle parameters used to characterize waste effluents were the flow, biochemical oxygen demand, chemical oxygen demand, total suspended solids and oil and grease. As discussed in Section VI, these parameters are considered to be the best available measure of the waste load.

Subcategory 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 constitutes a special problem in treatment since it does not appear to be readily biodegradable. Therefore, a grease recovery step is important to reduce pollution.

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 in insecticides. These items appear randomly in the effluent.

Wool scouring is generally performed in a series of scouring bowls. In these scouring bowls, the heavier dirt and grit settles to the coneshaped 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 scouring liquor is processed to break the emulsion and recovery of the wool grease. Two methods are commonly used to do this: centrifuging and acid-cracking.

In centrifuging (as shown in Figure 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 streams consists mainly of dirt and grit, and is sent to the treatment plant.

An alternative means to break the grease emulsion for wool grease recovery is the acid-cracking grease recovery system, also shown in Figure 1. Sulfuric acid is added to the scour liquor to break the grease/water emulsion. Heating the mixture increases the efficiency of separation. 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.

In the centrifugal method, about 60 percent of the grease is recovered: the remaining 40 percent is attached to the dirt and grit. In the acid-cracking method, pilot plant performance indicates a 98 percent recovery of grease from the degritted liquor.

Grease yield, in total , is 8 to 15 percent by weight of the greasy wool, and this constitues 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 in 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 increased recycling of the scour liquor have been voiced by industry, but with appropriate technological innovation, an even greater amount of recycling may be possible.

Objections to increased recycling of the scour liquor have been voiced by industry, but with appropriate technological innovation, an even greater amount of recycling may be possible.

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. Water load is increased by air conditioning and air scrubbing.

Subcategory 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 non-existent.

Since many wool mills investigated are working 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 wool-blend mill wastes.

As a result of the abcve, the principal component that distinguishes the wool mill Subcategory 2 from Subcategory 5, Knit Finishing, is the chromium used to dye the wool.

The Subcategory 2 mills have a higher water usage rate than any other finishing category. The heaviest contributor appears to be the rinsing after fulling. The wet unit processes are described in more detail below.

Heavy Scour

Heavy scouring is the term applied to the washing of the fabric by the use of detergents, wetting agents, emulsifiers, alkali, ammonia, or various other washing agents. The purpose of this heavy scour is to remove oils, grease, dirt, fulling solutions, emulsified oil, lubricants or any other substances that are either introduced in prior processing steps or that is carried to the finished fabric from the raw stock.

This process is one of the most important steps in wool finishing because if all of the foreign materials are not completely washed out, the finished fabric is susceptible to rotting, smelling, bleeding and will not accept dyes uniformly.

Fancy goods, in contrast to piece dyed goods, are only scoured prior to mechanical finishing. Piece dyed goods on the other hand must be scoured completely prior to the dyeing step. The weight, foreign material content and degree of felting of the fabric all have a direct bearing on the degree of scouring required.

Heavy weight, closely woven fabrics with a high percentage of recycled wool require very heavy detergents, long wash times and extensive rinsing to clean the goods. High organic and hydraulic loadings are associated with this type of fabric. Light open goods with a low percentage of wool generally scour more easily with lighter detergents, shorter wash times and less rinsing resulting in lower organic and hydraulic discharges.

Some mills produce both types of goods at the same time and relative proportion of each type will vary greatly causing great fluctuations in organic hydraulic discharge. Also some mills produce only light open goods while others produce heavy, close woven fabrics. The majority of finished product weights range from 12 ounces per yard to 26 ounces per yard; however, because of the differences in raw stock and felting requirements the hydraulic and organic discharges may differ greatly.

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 worsted, 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 hydraulic load in an all-woolen mill investigated.

Crabbing. Crabbing is the name given to the operation used to align the fabric rectilinearly. Since the fabric comes in wet and goes out wet, no effluent of significants 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 dyeing, 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.

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 quantitites 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 ((100°C) 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 from this unit process 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 to 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 cooled with clear water and rinsed until the dump or overflow water is clear.

Finishing. After it is dyed and rinsed, the fabric is removed from the beck and, when used, soil repellents 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.

Mothproofing is accomplished with Mitten-FF for government fabrics or with Dieldren for certain other specialized fabrics. 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.

Subcategory 3 - Greige Mills

Waste 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.

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 or warp yarn. 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 total waste load at a greige mill is typically greater tan 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 Subcategory 4 below).

Subcategory 4 - Woven Fabric Finishing

The wastes associated with finishing woven goods result from removal of foreign material during the cleaning and from the various chemicals used in finishing the fabric.

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.

After the desizing agent has been applied, the goods are placed in a bind or a steamer to provide the residence time required. Residence time 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 30 minutes at 180 F or a few minutes at 210 to 212 F. Finally, the goods are washed with water to remove the decomposed starches from the fabric. Polyvinyl alcohol and carboxymethyl cellulose are both removable with water alone. The goods are washed with water at 180F or higher on washers without the use of steamers, J-boxes, or padders. 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 abcut 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 biodegradeable, 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

Scouring is dcne to remove much of the natural impurities of cotton, using 2 to 3 percent sodium hydroxide; phosphate, 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 fabrics. The goods (in rope form) are plaited into the kier by the kier plaiter, the covers are 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 250 F and pressures of 10 to 20 psig. The goods are scoured for 6 to 12 hours. The kiers are then cocled 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.

Certain heavyweight fabrics normally are not processed in rope 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 maching, also known as the progressive jig. The jig is loaded with a scouring solution and the goods are fed through continuously by coils and the temperature and residence time are maintained for proper scouring of the goods. The goods are wound onto rolls in the maching 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 rcll.

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.

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 form 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

Physically, mercerization swells the cellulose fibers as alkali is asbsorbed 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 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).

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. The BOD level is low due to a 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

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 continuously 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.

Hypocholorite 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 leaste 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 solution and more drastic operating conditions and has resulted in the develcpment of the small open width J-box which permits effective bleaching with residence times of only 10 to 15 minutes.

Continous Pressure Scouring and Bleaching. The newest type of steamer for bleaching ranges is an enclosed type with pressure locks and seals. This enables the steamers to be operated as a pressure vessel and the reaction time for the chemical is reduced from 40 minutes to only one to 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 problem 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.

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 is the most ccmplex of all textile finishing processes. Table 8 shows the dyes used in the textile industry, the fibers they are generally used to color, and the relative amounts of each dye used by the industry.

Table 8

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).

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 9 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 chemical used in dyeing may depend significantly on the dyeing procedure which the fabric manufacturers finds 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 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 continuous 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.

Dyeing processes contribute substantially to textile wastes. Color is an obvious waste. 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. 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 9 shows alternative chemicals that may be used as substitutes for sodium dischromate. Controls are available for the reduction of vat dyes and their reoxidation; use of the controls will minimize wastes.

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.

Table 9

Chemicals Used in Application of Dyes[1]

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

Table 9 (continued)

Chemicals Used in Application of Dyes[1]

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

[1] (In 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 oxidants, 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.

Printing wastes are comparable in many respects to dye wastes. 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

Special finishes such as resin treatment, water proofing, flame proofing, and soil release endows the 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 ureaformaldehyde-glyoxal compound ("DMDHEU"), a fatty softner, 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.

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.

Subcategory 5 - Knit Fabric Finishing

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.

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 subcategory 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 temperatures before being wound on a perforated beam. Batching helps control shrink and yield, and also enchances 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 alsc have fabric printing operations.

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

The main difference 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 frcm comparable unit operations performed on different fibers--cotton, 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 suppliers 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 and 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 operations.

Subcategory 6 - Carpet Mills

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

Subcategory 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 detergents, 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 the 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 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

WASTE WATER PARAMETERS OF MAJOR SIGNIFICANCE

A thorough analysis of the literature, industry data and sampling data obtained from this study, and EPA Permit data demonstrates that the following waste water parameters are of major pollutional significance for the textile industry:

Biochemical Oxygen Demand (5-day, 20° C., BOD_5)
Suspended Solids (SS)
pH
Chemical Oxygen Demand (COD) - (Large plants)
Fecal Coliforms
Grease and Oil (Subcategory 1 - Raw Wool Scouring)

Rationale for Selection of Major Parameters

Biochemical Oxygen Demand

This parameter is an important measure of the oxygen utilized by microorganisms in the aerobic decomposition of the wastes at 20°C over a five day period. More simply, it is an indirect measure of the biodegradability of the organic pollutants in the waste. BOD_5 can be related to the depletion of oxygen in a receiving stream or to the requirements for waste treatment.

If the BOD_5 level of the final effluent of a mill into a receiving body is too high, it will reduce the dissolved oxygen level in that stream to below a level that will sustain most fish life; i.e. below about 4 mg/l. Many states currently restrict the BOD_5 of effluents to below 20 mg/l if the stream is small in comparison with the flow of the effluent. A limitation of 200 to 300 mg/l of BOD_5 is often applied for discharge to municipal sewers, and surcharge rates often apply if the BOD_5 is above the designated limit.

Concentrations of BOD_5 in the raw wastes may vary from 50 mg/l to 3000 mg/l. The values depend on the fibers processed, the chemicals used, and on processing methods. The oxygen demanding portion of the wastes are treatable biologically, with only a few exceptions. The use and degree of removal in a given time are quite variable.

Suspended Solids

This parameter measures the suspended material that can be removed from the waste waters by laboratory filtration, but does not include coarse or floating matter than can be screened or settled out readily. Suspended solids are present in textile waste waters 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. Suspended solids are a visual and easily determined measure of pollution and also a measure of the material that may settle in tranquil or slow moving streams. A high level of suspended solids is an indication of high organic pollution.

pH

The variations in pH cannot be characterized across the industry since some processes require highly acid conditions and others highly alkaline. Neutralization is practical where pH control is necessary to prevent adverse effects in biological waste treatment systems. These systems operate effectively at a pH range between 6.0 and 9.0.

Chemical Oxygen Demand (COD)

COD is another measure of oxygen demand. It measures the amount of organic and some inorganic pollutants under a carefully controlled direct chemical oxidation by a dichromate-sulfuric acid reagent. COD is a much more rapid measure of oxygen demand than BOD_5 and is potentially very useful.

COD provides a rapid determination of the waste strength. Its measurement will indicate a serious plant or treatment malfunction long before the BOD_5 can be run. A given plant or waste treatment system usually has a relatively narrow range of COD:BOD_5 ratios, if the waste characteristics are fairly constant, so experience permits a judgment to be made concerning plant operation from COD values. COD limitations are to be applied only to the large plants.

Fecal Coliforms

Microbiological testing for the presence of fecal coliforms will indicate the potential for the waste water to contain pathogenic bacteria. Sanitary sewage is a component of many textile waste treatment plants, and is often desired for its nutrient value.

Grease and Oil

Wool wax is a substantial pollutant in the wool scouring subcategory; in other textile subcategories, other materials measured as grease and oil are much less troublesome.

Rationale for Selection of Minor Parameters

Total Dissolved Solids (TDS)

The dissolved solids in waste water are mainly inorganic salts. They are particularly important as they are relatively unaffected by biological treatment processes and can accumulate in water recirculation systems. Failure to remove them may lead to an increase in the total solids level of ground waters and surface water sources. The dissolved solids in discharge water, if not controlled, may be harmful to vegetation and may also preclude various irrigation processes. There is not sufficient data available to establish effluent limitations for TDS, but at land treatment systems TDS must be managed to insure satisfactory performance without damage to the physical properties of the soil or to the quality of the ground waters.

Alkalinity

The measure of alkalinity is an indicator of bicarbonate, carbonate and hydroxide present in the waste water. The alkalinity of water appears to have little sanitary significance. Highly alkaline waters are unpalatable, and may adversely affect the operation of water treatment systems. However, pH limitations require the control of alkalinity and thus no alkalinity limitations are needed.

Ammonia Nitrogen and Other Nitrogen Forms

The three most common forms of nitrogen in wastes are organic, ammonia and nitrate. Organic nitrogen will break down into ammonia, nitrogen and nitrate. When ammonia nitrogen is present in effluent waste water, it may be converted to nitrate nitrogen by oxidation. When ammonia and nitrates are added to ponds and lakes, they contribute to euthrophication. Additions of ammonia or urea as a nutrient to nitrogen deficient waste is a common practice in the industry.

Phosphates

Phosphorus like nitrate is linked directly to the eutrophication process of lakes and streams. When applied to soil, phosphorus does not exhibit a runoff potential because it is readily absorbed tenaciously on soil particles. In this case, movement of phosphorus to ground water is essentially precluded and runoff can only occur if actual erosion of the soil takes place. Phosphates may also be added as nutrients to biological treatment systems.

Temperature

The temperature of effluent waste water is important, since release of water at elevated temperatures into surface or ground water formations could result in damage to the micro-ecosystems. The design of treatment facilities is also dependent upon the plant effluent temperature. Raw waste from many textile mills is hot, but the temperature reduction occurs naturally in waste treatment, and the temperature of the final effluent should be very close to ambient. Therefore, effluent water temperature does not present a problem.

Color

Color is found throughout the textile industry. Some colors are water soluble and some are not (dispersed dyes). Biodegradability is highly variable. Many hues are used in dyeing, and may appear in wastes; their combination in waste streams 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.

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. Chromium is the most significant heavy metal in the textile industry, although others are employed selectively.

Other Heavy Metals

Copper salts are still used in some dyeing operations of the textile industry. Since it is harmful 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 considered 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 waste water to exceed harmful 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.

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.

SECTION VII

CONTROL AND 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 waste 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 waste water streams.

At present, the textile industry is concerned principally with end-of-pipe treatment of its waste waters. However, the application of waste water treatment technology has often been instituted without detailed investigation of the alternatives to water and waste water 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 waste water 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 waste waters at the end-of-pipe. A large number of plants, especially small ones, send waste waters into municipal sewage systems where they may be a minor portion of the total flow; however, in some instances the waste water flow to a municipal plant is predominantly waste water from textile plants.

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.

On the other hand there are many unit operations which are dependent on chemical concentrations to provide desired effects. The raw waste loads of pollutants produced by these processes can be substantially reduced through water reduction. A plant can also 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 subcategory 1 the concentration levels of pollutants at the inlet to the waste water treatment plants are not excessively high for industrial waste waters. Consequently, a significant reduction in hydraulic capacity should normally effectively lower the total emitted pollutants from a given waste water 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.

Procedures and methods for preventing spills and leaks should be the paramount 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 by reducing the amount of wash water.

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 a number of machines. 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.

Rope washers generally are more effective than open-width washers, but may be susceptible 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 flows. 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 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 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 economical 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, further water economies can be achieved by machine improvements and by wider use of countercurrent 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 repellents 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.

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 intrcduced 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 Scouring of Woven Fabric. Despite intense effort 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.

Solvent Scouring of Knit Fabric. Solvent scouring of some synthetic knit fabrics is well established and growing. Commercial use is based on superior results, fast drying 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. However, the process used generates both aqueous and solvent wastes. No advantages have been demcnstrated 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. The advantages and limitations 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 sclve current liquid effluent problems arising from dyeing operations.

Solvent Finishing Wcven Goods. It has been shown that many functional finishes can be applied from solvents. 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.

Solvent Finishing of Knit Fabric. 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.

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 are actively working in this direction. 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.

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. Solvent size/desize will eventually find practical application. 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 In Process Changes

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).

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.

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.

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.

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.

Woven and Knit Fabric Finishing and Stock and Yarn Dyeing. 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 dyeing polyester is increasing, and reducing carrier usage significantly. Printing processes frequently use solvents (Varsol) which can be recovered by flotation and distillaticn.

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 an increase in raw waste load. This can be abated to some extent by the use of pressure dye becks, as in subcategories 4 and 5, that permit a reduction in the use of carriers and their attendant heavy BOD load.

Biological Treatment Technology

The treatment of waste effluents by biological methods is an attractive alternative when a high proportion of the biodegradable material is in the soluble form, as is the case in the textile industry. These methods are applicable in this industry irrespective of plant size, age or location.

Many types of microoganisms remove organic materials from liquid wastes. Those most commonly used in treatment systems are heterotrophs, which utilize organic carbon for their energy and growth. Some are aerobic and require molecular oxygen for converting wastes to carbon dioxide and water. Others are anaerobic and grow without molecular oxygen. Anaerobic microorganisms grow more slowly than aerobes and produce less sludge per unit of waste treated than do aerobic microorganisms. Anaerobes also release acids and methane, and their action on sulfur-containing wastes may create odor problems. Some microorganisms are facultative; that is, they can grow in either an aerobic or anaerobic environment.

The biological treatment of industrial wastes often lacks necessary nutrients in the waste to sustain desirable biological growth. Added nutrients, most often nitrogen and sometimes phosphorus, may be required for efficient biological treatment of processing wastes. Processing wastes generally requires the addition of nitrogen before successful biological treatment. Often this can be economically accomplished by the addition of nutrient-rich wastes from another source for combined treatment.

A discussion of the various methods of biological treatment is presented in the following sections.

Activated Sludge: In this case the active biota is maintained as a suspension in the waste liquid. Air, supplied to the system by mechanical means, mixes the reaction medium and supplies the microorganisms with the oxygen required for their metabolism. The microorganisms grow and feed on the nutrients in the inflowing waste waters. There are fundamental relationships between the growth of these microorganisms and the efficiency of the system to remove BOD_5.

A number of activated sludge systems have been designed, all of which have their own individual configurations. Basically, these designs consist of some type of pretreatment, usually primary sedimentation, and aeration, followed by sedimentation which will allow the sludge produced to separate, leaving a clear effluent. Portions of the settled sludge are recirculated and mixed with the influent to the aeration section, usually at a proportion ranging between 10 to 100 percent, depending upon the specific modification ot the basic activated sludge process.

The goal of these plants is to produce an actively oxidizing microbial population which will also produce a dense "biofloc" with excellent settling characteristics. Usually, optimization of floc growth and overall removal is necessary since very active microbial populations do not always form the best flocs.

Activated sludge treatment plants are capable of removing 95 percent or better of the influent BOD_5 from textile manufacturing plants.

The extended aeration modification of the activated sludge process is similar to the conventional activated sludge process, except that the mixture of activated sludge and raw materials is maintained in the aeration chamber for longer periods of time. The common detention time in extended aeration is one to three days, rather than six hours. During this prolonged contact between the sludge and raw waste, there is ample time for organic matter to be adsorbed by the sludge and also for the organisms to metabolize the removal of organic matter which has been built up into the protoplasm of the organism. Hence, in addition to high organic removals from the waste waters, up to 75 percent of the organic matter of the microorganisms is decomposed into stable products and consequently less sludge will have to be handled.

In extended aeration, as in the conventional activated sludge process, it is necessary to have a final sedimentation tank. Some of the solids resulting from extended aeration are rather finely divided and therefore settle slowly, requiring a longer period of settling.

The long detention time in the extended aeration tank makes it possible for nitrification to occur. If it is desirable for this to occur, it is necessary to have sludge detention times in excess of three days. This can be accomplished by regulating the amounts of sludge recycled and wasted each day. Oxygen enriched gas could be used in place of air in the aeration tanks to improve overall performance. This would require that the aeration tank be partitioned and covered, and that the air compressor and dispersion system be replaced by a rotating sparger system, which costs less to buy and operate. When co-current, staged flow and recirculation of gas back through the liquor is employed, between 90 and 95 percent oxygen utilization is claimed.

Activated sludge in its varied forms is an attractive alternative in textile waste treatment. Conventional design criteria is not directly transferrable from municipal applications. However, high levels of efficiency are possible at the design loadings normally employed in treating other types of high strength organic wastes. The general experience has been that biological solids separation problems can be avoided if the dissolved oxygen concentration remains above zero throughout the aeration basin, if management minimizes very strong, concentrated waste releases, and if sufficient amounts of nitrogen are available to maintain a critical nitrogen: BOD_5 ratio. This ratio has been recommended to be 3 to 4 kg(lb) N per 100 kg(lb) of BOD_5 removed. Numerous cases have been reported of successful combined treatment of textile and domestic wastes by activated sludge and its modifications. Activated sludge systems require less room than other high reduction biological systems, but have higher equipment and operating costs. Properly designed and operated systems can treat textile wastes to achieve high BOD reductions.

Biological Filtration (Trickling Filter): The trickling filter process has found application in treatment of many industrial wastes. Very tall filters employing synthetic media, high recirculation, and forced air circulation have been used to treat strong wastes in the 300-4000 mg/l BOD_5 range.

The purpose of the biofilter system is to change soluble organic wastes into insoluble organic matter primarily in the form of bacteria and other higher organisms. As the filter operates, portions of the biological growth slough off and are discharged as humus with the filter effluent. Usually, some physical removal system is required to separate this insoluble organic material which can be treated by other suitable methods, usually anaerobic fermentation in a sludge digestor.

Trickling filters are usually constructed as circular beds of varying depths containing crushed stone, slag, or similar hard insoluble materials. Liquid wastes are distributed over this bed at a constant rate and allowed to "trickle" over the filter stones. Heavy biological growths develop on the surface of the filter "media" throughout the depth of the filter and also within the interstitial spaces.

The biological film contains bacteria, (Zooglea, Sphaerotilus, and Beggiatoa); fungi (Fusarium, Geotrichum, Sepedonium); algae, both green and blue-green (Phormidium, Ulothrix, Mononostrona); and a very rich fauna of protozoa. A grazing fauna is also present on these beds consisting of both larval and adult forms of worms (Oligochaeta), insects (Diptera and Coleoptera among others), and spiders and mites (Arachnida).

A common problem with this type of filter is the presence of flies which can become a severe nuisance. Insect prevention can usually be prevented by chlorinating the influent or by periodically flooding the filter.

Recirculation of waste water flows through biological treatment units are often used to distribute the load of impurities imposed on the unit and smooth out the applied flow rates. Trickling filter BOD_5 removal efficiency is affected by temperature and the recirculation rate. Trickling filters perform better in warmer weather than in colder weather. Recirculation of effluent increases BOD_5 removal efficiency as well as keeping reaction type rotary distributers moving, the filter media moist, organic loadings relatively constant, and increases contact time with the biologic mass growing on the filter media.

Furthermore, recirculation improves distribution, equalizes unloading, obstructs entry and egress of filter flies, freshens incoming and applied waste waters, reduces the chilling of filters, and reduces the variation in time of passage through the secondary settling tank.

Trickling filter BOD_5 removal efficiency is inversely proportional to the BOD_5 surface loading rate; that is, the lower the BOD_5 applied per surface area, the higher the removal efficient. Approximately 10-90 percent BOD reduction can be attained with trickling filters.

Anaerobic Processes: Elevated temperatures (29° to 35°C or 85° to 95°F) and the high concentrations typically found in industrial wastes make these wastes well suited to anaerobic treatment. Anaerobic or faculative microorganisms, which function in the absence of dissolved oxygen, break down the organic wastes to intermediates such as organic acids and alcohols. Methane bacteria then convert the intermediates primarily to carbon dicxide and methane. Also, if sulfur compounds are present hydrogen sulfide may be generated. Anaerobic processes are economical because they provide high overall removal of BOD_5 and suspended solids with no power cost (other than pumping) and with low land requirements. Two types of anaerobic processes are possible: anaerobic lagoons and anaerobic contact systems.

Anaerobic lagoons are used as the first step in secondary treatment or as pretreatment prior to discharge to a municipal system. Reductions of 85 percent in BOD_5 and 85 percent in suspended solids can be achieved with these lagoons. A usual arrangement is two anaerobic lagoons relatively deep (3 to 5 meters, or about 10 to 17 feet), low surface-area systems with typical waste loadings of 240 to 320 kg BOD_5/1000 cubic meters (15 to 20 lb BOD_5/1000 cubic feet) and a detention time of several days.

Plastic covers of nylon-reinforced Hypalon, polyvinyl chloride, and styrofoam can be used on occasion to retard heat loss, to ensure anaerobic conditions, and hopefully to retain obnoxious odors. Properly installed covers provide a convenient method for collection of methane gas.

Influent waste water flow should be near, but not on, the bottom of the lagoon. In some installations, sludge is recycled to ensure adequate anaerobic seed for the influent. The effluent from the lagoon should be located to prevent short-circuiting the flow and carry-over of the scum layer.

Advantages of an anaerobic lagoon system are initial low cost, ease of operation, and the ability to handle shock waste loads, and yet continue to provide a consistent quality effluent. Disadvantages of an anaerobic lagoon are odors although odors are not usually a serious problem at well managed lagoons.

Anaerobic lagoons used as the first stage in secondary treatment are usually followed by aerobic lagoons. Placing a small, mechanically aerated lagoon between the anaerobic and aerobic lagoons is becoming popular. It is currently popular to install extended aeration units following the anaerobic lagoons to obtain nitrification.

The anaerobic contact system requires far more equipment for operation than do anaerobic lagoons, and consequently is not as commonly used. The equipment, consists of equalization tanks, digesters with mixing equipment, air or vacuum gas stripping units, and sedimentation tanks (clarifiers). Overall reduction of 90 to 97 percent in BOD and suspended solids is achievable.

Equalized waste water flow is introduced into a mixed digester where anaerobic decomposition takes place at a temperature of about 33° to 35°C (90° to 95°F). BOD_5 loadings into the digester are between 2.4 and 3.2 kg/cubic meter (0.15 and 0.20 lb/cubic foot), and the detention time is between three and twelve hours. After gas stripping, the digester effluent is clarified and sludge is recycled at a rate of about one-third the raw waste influent rate. Sludge at the rate of about 2 percent of the raw waste volume is removed from the system.

Advantages of the anaerobic contact system are high organic waste load reduction in a relatively short time; production and collection of methane gas that can be used to maintain a high temperature in the digester and also to provide auxilary heat and power; good effluent stability to waste load shocks; and application in areas where anaerobic lagoons cannot be used because of odor or soil conditions. Disadvantages of anaerobic contractors are high initial and maintenance costs and some odors omitted from the clarifiers.

Anaerobic contact systems are usually used as the first stage of secondary treatment and can be followed by the same systems that follow anaerobic lagoons or trickling filter roughing systems.

Other Aerobic Processes: Aerated lagoons have been used successfully for many years in a number of installations for treating industrial wastes. However, with recent tightening of effluent limitations and because of the additional treatment aerated lagoons can provide, the number of installations is increasing.

Aerated lagoons use either fixed mechanical turbine-type aerators, floating propeller-type aerators, or a diffused air system for supplying oxygen to the waste water. The lagoons usually are 2.4 to 4.6 m (8 to 15 feet) deep, and have a detention time of two to ten days. BOD_5 reductions range from 40 to 60 percent with little or no reduction in suspended solids. Because of this, aerated lagoons approach conditions similar to extended aeration without sludge recycle.

Advantages of this system are that it can rapidly add dissolved oxygen (DO) to convert anaerobic waste waters to an aerobic state; provide additional BOD5 reduction; and require a relatively small amount of land. Disadvantages are the power requirements and that the aerated lagoon, in itself, usually does not reduce BOD5 and suspended solids adequately to be used as the final stage in a high performance secondary system. Aerated lagoons are usually a single stage of secondary treatment and should be followed by an aerobic (shallow) lagoon to capture suspended solids and to provide additional treatment.

Aerobic lagoons (or stabilization lagoons or oxidation ponds), are large surface area, shallow lagoons, usually 1 to 2.3 m deep (3 to 8 feet), loaded at a BOD5 rate of 22-56 kilograms per hectare (20 to 50 pounds per acre). Detention times will vary from several days to six or seven months; thus aerobic lagoons require large areas of land.

Aerobic lagoons serve three main functions in waste reduction:

1. Allow solids to settle out.

2. Equalize and control flow.

3. Permit stabilization of organic matter by aerobic and facultative microorganisms and also by algae.

Actually, if the pond is quite deep, 1.8 to 2.4 m (6 to 8 feet), so that the waste water near the bottom is void of dissolved oxygen, anaerobic organisms may be present. Therefore, settled solids can be decomposed into inert and soluble organic matter by aerobic, anaerobic or facultative organisms, depending upon the lagoon conditions. The soluble organic matter is also decomposed by microorganisms causing the most complete oxidation. Wind action assists in carrying the upper layer of liquid (aerated by air-water interface and photosynthesis) down into the deeper portions. The anaerobic decomposition generally occurring in the bottom converts solids to liquid organics which can become nutrients for the aerobic organisms in the upper zone.

Algae growth is common in aerobic lagoons; this currently is a drawback when aerobic lagoons are used for final treatment. Algae may escape into the receiving waters, and algae added to receiving waters are considered a pollutant. Algae in the lagoon, however, play an important role in stabilization. They use CO_2, sulfates, nitrates, phosphates, water and sunlight to synthesize their own organic cellular matter and give off free oxygen. The oxygen may then be used by other microorganisms for their metabolic processes. However, when algae die they release their organic matter in the lagoon, causing a secondary loading. Ammonia disappears without the appearance of an equivalent amount of nitrite and nitrate in aerobic lagoons. From this, and the fact that aerobic lagoons tend to become anaerobic near the bottom, it appears that some denitrification is occurring.

High winds can develop a strong wave action that can damage dikes; Riprap, segmented lagoons, and finger dikes are used to prevent wave damage. Finger dikes, when arranged appropriately, also prevent short circuiting of the waste water through the lagoon. Rodent and weed control, and dike maintenance are all essential for good operation of the lagoons.

Advantages of aerobic lagoons are that they reduce suspended solids, oxidize organic matter, permit flow control and waste water storage. Disadvantages are the large land required, the algae growth problem, and odor problems.

Aerobic lagoons usually are the last stage in secondary treatment and frequently follow anaerobic or aerated lagoons. Large aerobic lagoons allow plants to store waste water discharges during periods of high flow in the receiving body of water or to store for irrigation during the summer. These lagoons are particularly popular in rural areas where land is available and relatively inexpensive.

Rotating Biological Contactor: The rotating biological contactor (RBC) consists of a series of closely spaced flat parallel disks which are rotated while partially immersed in the waste waters being treated. A biological growth covering the surface of the disk adsorbs dissolved organic matter present in the waste water. As the biomass on the disk builds up, excess slime is sloughed off periodically and is removed in sedimentation tanks. The rotation of the disk carries a thin film of waste water into the air where it absorbs the oxygen necessary for the aerobic biological activity of the biomass. The disk rotation also promotes thorough mixing and contact between the biomass and the waste waters. In many ways the RBC system is a compact version of a trickling filter. In the trickling filter the waste waters flow over the media and thus over the microbial flora; in the RBC system, the flora is passed through the waste water.

The system can be staged to enhance overall waste water reduction. Organisms on the disks selectively develop in each stage and are thus particularly adapted to the composition of the waste in that stage. The first couple of stages might be used for removal of dissolved organic matter, while the latter stages might be adapted to other constituents, such as nutrient removal.

The major advantages of the RBC system are its relatively low installed cost, the effect of staging to obtain dissolved organic matter reductions, and its good resistance to hydraulic shock loads. Disadvantages are that the system should be housed to maintain high removal efficiencies and to control odors. Although this system has demonstrated its durability and reliability when used on domestic wastes, it has not yet been fully tested to treat textile processing wastes.

Rotating biological contactors could be used for the entire aerobic secondary system. The number of stages required depend on the desired degree of treatment and the influent strength. Typical applications of the rotating biological contactor, however, may be for polishing the effluent from anaerobic processes and from roughing trickling filters and as pretreatment pricr to discharging wastes to a municipal system. A BOD5 reduction of over 90 percent is achievable with a multi-stage RBC.

Performance of Biological Treatment Systems

Evaluation of data obtained from the textile waste water treatment plants surveyed indicate that the operational mode for exemplary biological systems is extended aeration. No exemplary plant has an average residence time in the aeration basin of less than 17 hours. Eighteen exemplary biological systems with an average BOD removal efficiency of greater than 95 percent are listed in Table 27. The complete treatment scheme for most exemplary waste treatment plants includes screening and extended aeration followed by clarification and polishing lagoons.

Removal of fibers from the waste water 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 satisfactcrily through the use of bars or screens.

Removal of BOD5 and suspended solids from textile waste water is accomplished most satisfactorily through the employment of extended aeration including clarification and sludge return. Textile waste water usually contains ample phosphates which are available as nutrients for the microorganism of the biological system. Nitrogen in the form of ammonia or nitrate may be required in some cases in which this nutrient deficiency has been identified.

Suspended solids are removed from biologically-treated waste water 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 may be 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 sedimentation. In general, the clarifiers used in the textile industry are designed for overflow rates considerably less than those usually found in municipal systems.

Excluding the high BOD5 values for wool scouring-subcategory 1, the average BOD5 concentration of the exemplary treatment is about 20 mg/l, running from a low of 2 to a high of 83 mg/l. Of this group approximately 20 percent exceeded 30 mg/l.

In effect, many of the waste water treatment plants are being operated as a two-stage biological system since polishing lagoons of various residence times may follow the aerated basin.

Chemical oxygen demand (COD) is measured less frequently than BOD5. As in the case of BOD5, the COD of wool scouring waste is greater than that of waste waters from other categories, both on a concentration basis. 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 waste water treatment plants, which indicates the refractory nature of some of the components of the waste waters. Although COD is probably a better measure of the pollutant level of waste waters, other parameters such as total organic carbon (TOC) or total oxygen demand (TOD) might be even more indicative.

Although the ratio of COD to BOD is generally recognized as an indicator of the biologically refractory nature of waste water pollutants, the variability in this ratio is affected by many factors. One 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, has been 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. However, 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.

Textile process operations often require high-temperature water, however, heat reclamation is also widely practiced as a matter of economics so the waste waters sent to the treatment plants usually do not present any significant thermal shock problems. Furthermore, the long residence time generally found in the waste water 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 reduce the biological activity and thus the efficiency of BOD5 removal.

Color in the waste waters 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 possibility for removing color.

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 an activated sludge treatment plant removes a substantial portion.

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. Proper removal of chrome is dependent on proper removal of suspended solids.

Other Constituents: Wastewaters from ancillary operations such as cooling towers, steam generating facilities and water treatment plants may be significant factors in the waste water volumes emitted from the textile industry. In those instances where one must handle cooling tower and boiler blowdowns that contain corrosion inhibiting chemicals, algacides and biocides, the technology for selective removal is usually available. Of course, the best practicable control technology currently available for process waste waters 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 waste water 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 waste water composition occurs.

Since the textile industry is predominantly a batch type process operation rather than continuous, it follows that both flow rates and waste water composition will vary significantly. That the industry recognizes this variability is apparent from the nature of the waste water 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 shock loading 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 possibility of consistent operation; however, many treatment systems have an adequate overcapacity already installed as insurance against the results of equipment failure. It is 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 waste water treatment plants. Nevertheless, no practical in-line instrumentation can replace the judicious attention to operational details of a conscientious crew of operators.

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 in Section IX by the solid line in Figure 19. 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 and properly designed facility can be controlled within ± 25 percent of the average on a monthly operating basis. A system with minimal operational control or an allowance of ± 50 percent of the averages on a monthly basis has been used to calculate the maximum monthly effluent limitation.

ADVANCED WASTE WATER TREATMENT TECHNOLOGY

In all categories of textile plants, it is assumed that good secondary treatment will have a high quality effluent as demonstrated by the exemplary plants. 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 advanced waste treatment process.

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.

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

1. phase change
2. physical separation
3. sorption
4. chemical clarification

Phase Change

Distillation: 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 from ambient temperatures to the temperature of the outgoing brine. Recirculation of the brine improves thermal efficiency considerably and all modern MSF plants are of this design.

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 deaerate the flash chambers and to produce a vacuum.

The vertical tube evaporator (VTE) is a long-tube vertical distillation type of desalting plant, (146.3 mgd) .

In the climbing-film vertical evaporator, the most common design, the brine is maintained at a predetermined level inside the vertical tubes. These tubes are heated externally by the incoming steam in the first effect or by the hot product vapors in subsequent effects. This is in direct contrast to a submerged tube type of unit which has the steam inside and the boiling brine 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 to Textile Waste Treatment. The waste waters from the textile industry may have a moderately high concentration of organic chemicals in comparison with the concentrations in brackish or saline waters.

In some instances, it might be necessary to treat waste water 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 waste waters containing carbonaceous substances. If the waste water streams contain very low concentrations of organics and high concentrations of dissolved inorganic salts, the applicability of evaporation is more readily predicted, being essentially an evaluation of economics.

Freezing Techniques:

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.

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.

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 compressed 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.

Relevance to Textile Waste Treatment. 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.

Although neither type of freezing plant has been used in the textile industry for waste water treatment. it might be attractive 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.

Physical Separation

Filtration:

The removal of suspended solids or colloidal material from water by filtration is accomplished by one of a number of mechanisms which may be generally classified as straining or transport attachment. Straining is the elimination of particulate matter by size discrimination; that is, a particle of greater diameter than a pore opening will be physically restrained from passage.

Transport - Attachment refers to a two step principle and is applied to particulate matter which may be much smaller than the pore size. The particles are transported across the stream lines to the proximity of the filter medium where attachment forces predominate.

Filtration is the most common form of advanced waste water treatment practiced today. This is due to its relatively inexpensive nature and its effectiveness in removing suspended solids and the organics associated with those solids. It provides excellent preparation of waste for application of other advanced waste treatment techniques and is an integral part in many designs of these systems.

Relevance to Textile Waste Treatment. Rapid sand type filters have had considerable use in waste treatment systems for direct filtration of secondary effluent.

Early work on filtration of secondary effluent took place in Europe. Truesdale and Birkbeck reported on tests run between October, 1949, and May 1950, at the Luton Sewage Works. Beds of sand 2 feet deep, ranging in size from 0.9 mm to 1.7 mm, exhibited 72 to 91 percent removal of suspended solids and 52 to 70 percent removal of BOD. Flow rates ranged from 1.33 to 3.3 IMP.gal/min/ft2.

Naylor, Evans and Dunscome later reviewed 15 years of studies of tertiary treatment at Luton. A 3-foot deep bed of 10 to 18 mesh sand consistently provided an effluent of 4 to 6 mg/l suspended solids at flow rates of 3.3 Imp.gal/min/ft2.

In the U. S., most direct filtration work has been with activated sludge effluent. At the Hyperion Plant in Los Angeles, sand of 0.95 mm effective size was used in a shallow bed (11 inches deep) traveling backwash filter. This study lasted for six months during which time 46 percent suspended solids removal and 57 percent BOD removal were obtained. Filtraticn rate was 2 gal/min/ft2. Difficulty was encountered in cleaning the filters and performance gradually deteriorated during the study. Use of a finer sand (0.45 mm effective size) in an attempt to yield a better effluent was a failure due to very rapid clogging of the filter.

Much greater success utilizing the traveling backwash filter for activated sludge effluent treatment was obtained by Lynam in Chicago. The effective size of sand used in this study was 0.58 mm. Suspended solids removal of 70 percent and BOD removal of 80 percent were obtained at flow rates of 2 to 6 gal/min/ft2. Terminal headloss was quite low (11 inches of water.) The range of flows studied exhibited no significant difference in terms of suspended solids removal.

Culp and Culp reviewed the work on plain filtration of secondary effluent with both single medium and multimedia filters. They concluded that, with either type of filter, better results would be obtained as the degree of self flocculation of the sludge increased. Thus, a high-rate activated sludge effluent which contains much colloidal material should filter poorly, while an extended aeration effluent should filter well. Multi-media filters exhibit a marked superiority for filtration of activated sludge effluent because of the high volume of floc storage available in the upper bed and the polishing effect of the small media. They indicated the expected performance of multi-media filters for plain filtration of secondary effluents as shown in Table 10.

Table 10

EXPECTED EFFLUENT SUSPENDED SOLIDS FROM MULTI-MEDIA FILTRATION OF BIOLOGICAL EFFLUENTS

Biological System	Effluent TSS (mg/l)
High Rate Trickling	10 - 20
2 - Stage Trickling Filter	6 - 15
Contact Stabilization	6 - 15
Conventional Activated Sludge	3 - 10
Extended Aeration	1 - 5

The application of filtration to biologically treated effluent is dependent on the nature of the biological system and the biological solids produced by that system rather than the nature or characteristics of the raw waste. That is, application of filtration to secondary effluent from textile wastes will remove the biological solids the same as it would remove the biological solids generated from other wastes.

Reverse Osmosis. 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. Much of the research and development work was made, 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 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. And to do this 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.

In a typical reverse osmosis system. Feedwater is pumped through a pretreatment section which removes suspended solids 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.

Three types of reverse osmosis configurations are currently popular. The first, known as the "spiral wound" configuration, uses flatsheet 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 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.

<u>Relevance to Textile Wastes Treatment.</u> 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). However, the costs increase greatly for smaller plants, because of greater labor costs.

The major technical limitation of the process for treatment of secondary effluent 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 remove the suspended solids from 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.

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. This system, which 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: 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.

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.

Relevance to Textile Waste Treatment. 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 to macromolecules and suspended solids.

Concentration and recovery of disperse dyes by ultrafiltration may be feasible, where a single color is in the waste stream. Concentration of polymeric cotton sizing materials (PVA and CMC) is technically feasible since the UF membranes will retain the polymers and pass the polymer-free water at reasonable fluxes. An experimental system 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: 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.

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.

Relevance to Textile Waste Treatment 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. 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 150 plants which have been built.

Unfortunately, electrodialysis has not been used to treat textile plant wastes although some efforts have been made to investigate its use in dye removal. 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.

Suspended solids in the feed stream are undesirable. High levels of organic materials must be avoided as they may attack the membranes. Thus feed water to the plant should have a low BOD and COD and these will not be substantially changed by the process.

Sorption Systems

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. The concentrated liquid waste stream is normally converted to a solid waste by evaporation. Such processes include adsorption on activated carbon and ion exchange.

Activated Carbon: Activated carbon is a commercially available and particularly versatile absorbent primarily because of its relatively low cost (22 to 110¢/kg or 10 to 50¢/lb) and large surface area (about 112 hectares 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 with less than 10% loss per cycle. However, attempts are being made to develop techniques for the use of powdered carbon, 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 adsorbent, shows some selectivity:

Strongly Adsorbed	Weakly adsorbed
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 sclution, the pH and the temperature.

Typical adsorption capacities of activated carbon at different residual COD levels are illustrated in Figure 8.

Several types of water carbon contactors have been proposed and utilized. Usually one cr 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. A schematic of a treatment process including thermal regeneration is illustrated in Figure 9.

Relevance to Textile Waste Treatment. 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. The Pomcna plant has been run for over four years and deserves detailed description.

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 carbon is periodically backwashed to remove entrapped suspended solids and regenerated when necessary after a steady state adsorption capacity of about 0.4 to 0.5 kilograms of COD per kilogram of carbon has been reached. 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 11.

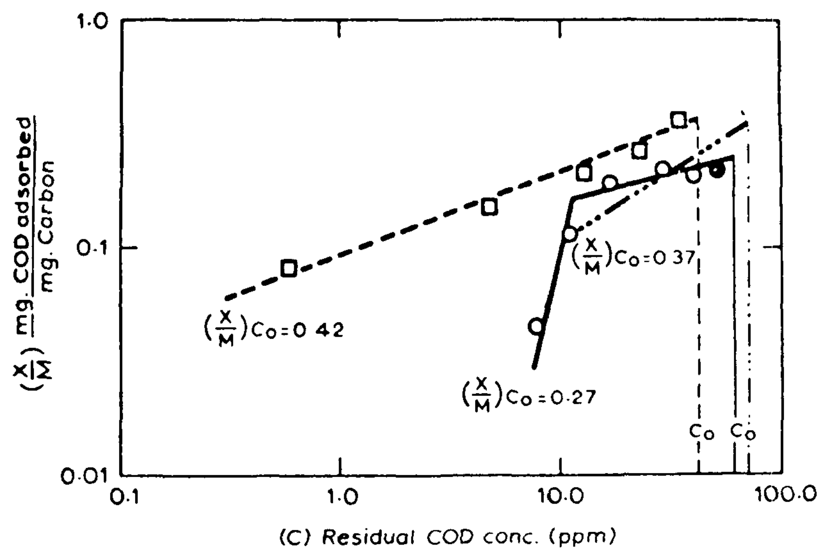


Figure 8

COD Isotherms Using Virgin Carbon and Different Secondary Sewage Effluents (after Masse, 1967)

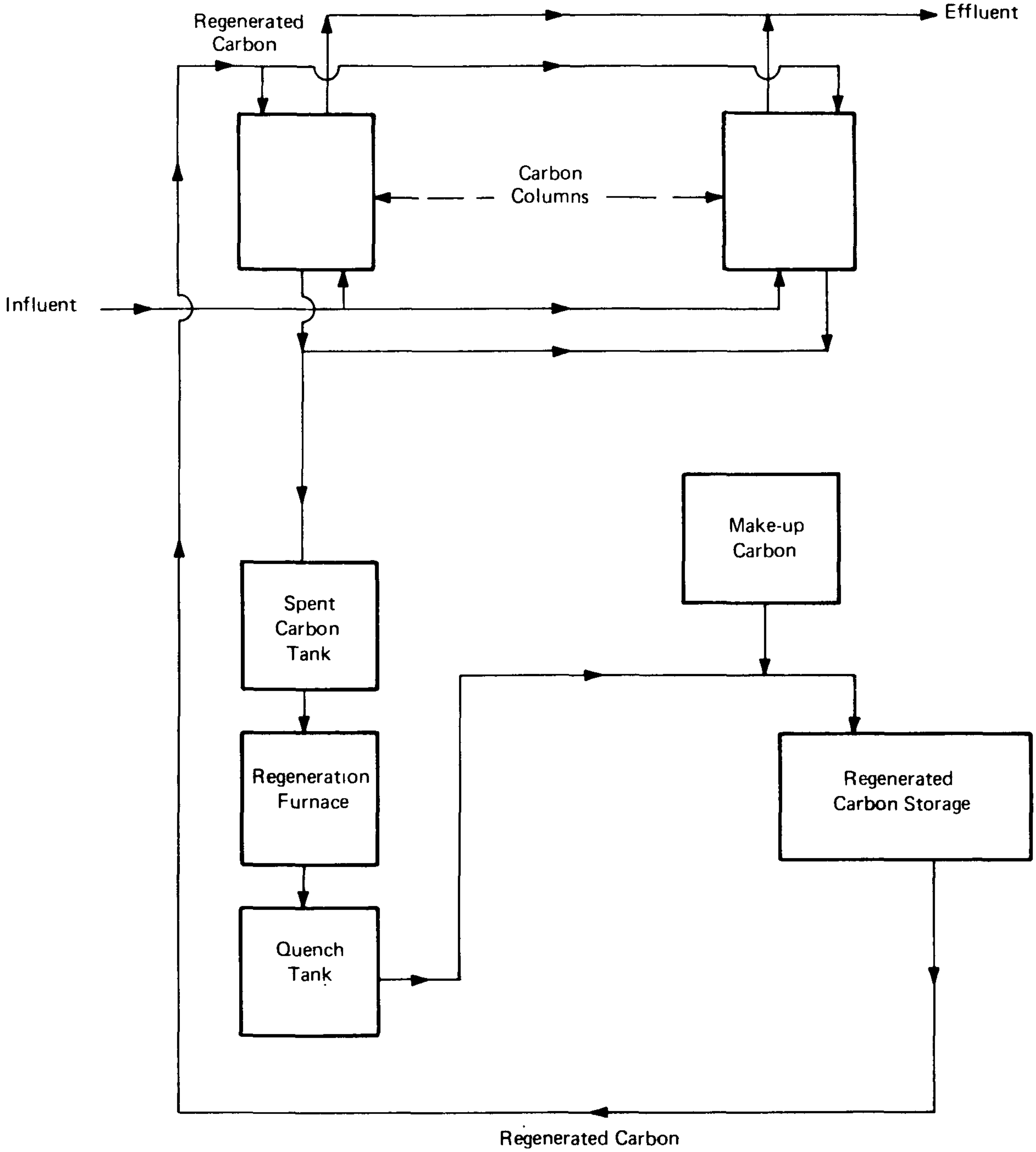


Figure 9

Schematic of an Activated Carbon System Including Thermal Regeneration

Table 11

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

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. 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. Because of operating difficulties the carbon had to be replaced before saturation, at a loading of only 0.133 kilograms TOC/kilogram carbon.

Activated carbon treatment was also used successfully at Lake Tahoe to produce drinkable water from secondary effluent. 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 a carpet mill, in Pennsylvania. Of the raw waste from the dyeing and rinsing plant, 80 percent was treated and reused. Capacity of the system was 1900 cu m/day (500,000 gallons per day) and it utilized 22,700 kilograms (50,000 pounds) of granular activated carbon. The carbon was regenerated by heating it in a furnace.

EPA has supported work in a unique activated carbon system in which regeneration is accomplished by backwashing the absorbed organic material into an aerobic biological treatment unit.

After encouraging results in a laboratory unit operating on synthetic textile waste water, a pilot system was installed at a carpet yarn fiber dyeing plant. The flow of the pilot system has a capacity of 190 cu m/day (50,000 gpd).

A range of studies on the treatment of dye waste waters were made by a textile company in North Carolina. The company encountered only partial success in the use of carbon for effluent polishing following biological treatment. In this study anthracite-based media proved unreliable in removing 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.

There are several further instances of the use of activated carbon adsorption for the treatment of textile wastes, particularly in regard to color removal. A mill in Pennsylvania, operates a closed dye cycle using alum, diatomaceous earth, and carbon to yield a color of less than 50 units. The consensus appears to be that while color can be removed by activated carbon, some elements (particularly the dispersed dyes) are not adsorbed. Chemical coagulation 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 municipal waste water. Some successful experience also has been accumulated in the treatment of textile wastes. The advanced process is suitable for reducing low-level organic contamination, but it affects the levels of dissolved ionic solids very little.

Ion Exchange. 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 anion and 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.

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. The waste regenerate streams are usually quite concentrated and can be disposed of economically by simple evaporation.

The most important class of ion exchangers, 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 depends on the nature of the fixed ionic groups, with the exchanger preferring those ions which strongly associate with the fixed 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.

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, but others quote efficient cleansing of 2500 mg/l streams at costs less than that for electrodialysis or reverse osmosis.

Relevance to Textile Waste Water Treatment. 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. The dissolved solids levels of the secondary sewage effluents would appear to be in the proper range for effective use of ion exchange. Costs for a 50 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. 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. The process relies on a series of three ion exchange beds.

This process has been operated successfully at the pilot plant scale on brackish water; the concentration was reduced to a final effluent of 20 to 30 mg/l, at an operating cost estimated to be equivalent to 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 (1970). A commercial plant achieving similar results was operating in the United States for several years.

More conventional ion exchange resins have been used for the desalination of brackish water. A pilot 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).

Recently, countercurrent ion exchange has begun to make an impact on American ion exchange technology. 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. 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.

One additional advantage of ion exchange is applicable to highly alkaline textile waste streams. For example, if the effluent is sodium hydroxide the cation exchanger alone may be used.

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

The quality of the waste stream necessary to make ion exchange feasible is 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 be necessary to filter suspended solids to a low level before allowing the water to enter the ion exchange columns. Any oxidizing agents in the waste stream 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 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 clarification the waste water still contains a variety of suspended solids. These may be removed by chemical clarification methods, which, in addition, have been found to be effective for color removal.

Textile wastes typically contain a complex mixture of suspended solids, mostly of organic composition. They include color bodies, proteins, soaps, fibers, mineral fines, oil and grease. Carpet mill wastes can contain considerable quantities of latex. 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.

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.

Coagulation is generally accomplished by adding coagulants that contain multivalent cations. These include:

> lime, aluminum sulfate, ferric chloride, copperas, ferrous sulfate, ferric sulfate and sodium aluminate.

The multivalent cations Al^{+++}, Fe^{+++} and Fe^{++} are strongly hydrated and hydrolyzed, forming acidic solutions. 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.

Addition of 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 experimentally. Unfortunately, the optimum values of these parameters may not be the same for different components of the waste water; thus turbidity removal may demand an operating pH different from that needed for color removal.

Coagulant aids may also be used 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 characteristics.

Relevance to Textile 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).

Chemical clarification has frequently been used in the treatment of textile waste. 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 adsorbed by activated carbon. A description of some typical experience in the textile industry will illustrate the usefulness of the process.

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 Virginia. BOD of the combined wastes was reduced by 60 percent and suspended solids by over 90 percent.

In Israel, experimental results showed 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 Cationic polyelectrolytes 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. Calcium chloride coagulation was used in a plant 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 cf 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.

In a review of treatment methods for dye waste waters, 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 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 with 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.

A company in Pennsylvania reports successful color removal of a closed dye cycle water using a combination of alum treatment, diatomaceous earth filtration and carbon adsorption.

SECTION VIII

COST, ENERGY, AND NON-WATER QUALITY ASPECTS

Cost and Reduction Benefits of Alternative Treatment and Control Technologies

A detailed economic analysis showing the cost effectiveness of various treatment and control technologies upon the seven subcategories within the Textile industry is given in this document. Five alternative treatment methods have been considered for Subcategories 1 to 7. For the seven subcategories, the alternatives include:

Alternative A - No waste treatment or control.

Alternative B - Preliminary and biological treatment.

Alternative C - Multi-media Filtration

Alternative D - Activated Carbon Adsorption

Alternative E - Multiple Effect Evaporation and Incineration.

Basis of Economic Analysis - Following is a summary of the basis for cost estimates:

1. Investment - Investment costs have been derived principally from published data on waste water treatment plant construction costs, consultants' cost data, and information from equipment manufacturers and suppliers.

   Published cost data for treatment facilities is derived primarily from experience with waste water treatment installations. Cost information has been reported by some textile manufacturers, but the data are not extensive enough to serve as a basis for the estimates presented herein. Basic data were developed by preparation of graphical relationships between cost and size for each unit operation. Based on treatment plant configuration, design criteria, and size, costs for individual unit operations were added together to determine major facility costs.

   An allowance of 15 percent of the total investment has been included as yardwork which includes general site clearing and grading inter-component piping, lighting, control structures, road paving, and other items outside the structural confines on an individual plant component. An additional allowance of up to 25 percent of the total investment has been included to cover land, continqencies, engineering and overhead.

2. Depreciation and Cost of Capital (Interest) - It was assumed that the annual interest costs (cost of capital) and depreciation would be constant over the life of the treatment facilities. A principal repayment period of 10 years was used. Costs were depreciated on a straight line basis and the depreciation period of 10 years was assumed equal to the principal repayment period and the economic life of the facilities.

   Cost of money was assumed to be an average of the cost of debt capital and the cost of equity capital. Cost of debt capital was assumed to be 8 percent and the cost of equity capital 22 percent. Data for the last 10 to 12 years indicated that the average net return on equity capital for the chemical industry and other manufacturing has been 10 to 12 percent. Assuming corporate income tax is equal to net return (50% of gross return), gross return is estimated to be debt capital and 40 percent equity capital. From this analysis, an average rate for the cost of money equal to 13.6 percent was determined. An average annual value for cost of money was derived by subtracting the straight line depreciation cost from the investment cost, times the capital recovery factor. The costs were about 8 percent of the capital investment.

3. Insurance and Taxes - An annual cost of 1 1/2 percent of the initial investment was used for insurance and taxes on the waste treatment plant.

4. Operation and Maintenance Labor - Operation and maintenance labor manhour requirements were based mainly on published data and independent estimates. The operational requirements include general management and supervisory personnel, equipment operators and laborers, and clerical and custodial personnel. Maintenance labor includes mechanical electrical, laborers, and other appropriate repair personnel.

   Based on labor rates in the Textile industry and municipal waste water treatment plants an August, 1971 average labor rate of $5.00 per hour (including fringe maintenance labor costs).

5. Chemicals - Chemical costs used in the economic analysis are based on published literature typical in the U.S. The costs used are:

   Lime - $22.00 per metric ton ($20.00 per ton)

Soda Ash - $3.96 per 100 kilograms ($1.80 per 100 pounds)

Ferric Chloride - $8.80 per 100 kilograms ($4.00 per 100 pounds)

Polymer - $0.44 per kilogram ($0.20 per pound)

Chlorine - $13.20 per 100 kilograms ($6.00 per 100 pounds)

Sulfuric Acid - $36.40 per metric ton ($33.00 per ton)

Ammonia - $35.90 per metric ton ($32.50 per ton)

6. Energy - In broad context, energy includes electric power and fuel. Electric power consumption for major units such as aeration, pumping, and mixing was estimated from available data. An allowance of ten percent was made for small power users such as clarifiers, chemical feed equipment, ventilation equipment, and so forth. The cost of electric power was assumed to be $0.015/kwhr. Motor efficiency was assumed to be 70 percent.

   For alternative E, steam is required for evaporation. The cost of steam ranged from $1.76 to $2.42/1,000 kg of steam ($0.80 to $1.10/1,000 lb of steam).

Information on actual treatment cost experience in the textile industry was available in varying degrees of completeness from the exemplary plants visted. To verify the quality of the data received and to provide a broader basis for estimation, a costing model was developed based on standard waste water 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 to 3.0 MGD), 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 12. The costs calculated from the model, therefore, are believed to be realistic bases for estimating the (replacement) 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 10 to 18. (For very small plants (about 110 cu m/day or 30,000 gpd), an overall cost figure of $264 for 1 cu m/day or $1.00 for 1 gpd was assumed.) Figures 14 to 18 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 costs as function of hydraulic land 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.

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 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 waste water 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.

TABLE 12

Accuracy Of Standardized Costing Methodology

Example Plant	EPA cost estimate	company reported cost for actual plant	Ratio EPA reported
Plant A (0.394 MGD)			
Subcategory 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 MGD)			
Subcategory 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 MGD)			
Subcategory 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 $6,000)

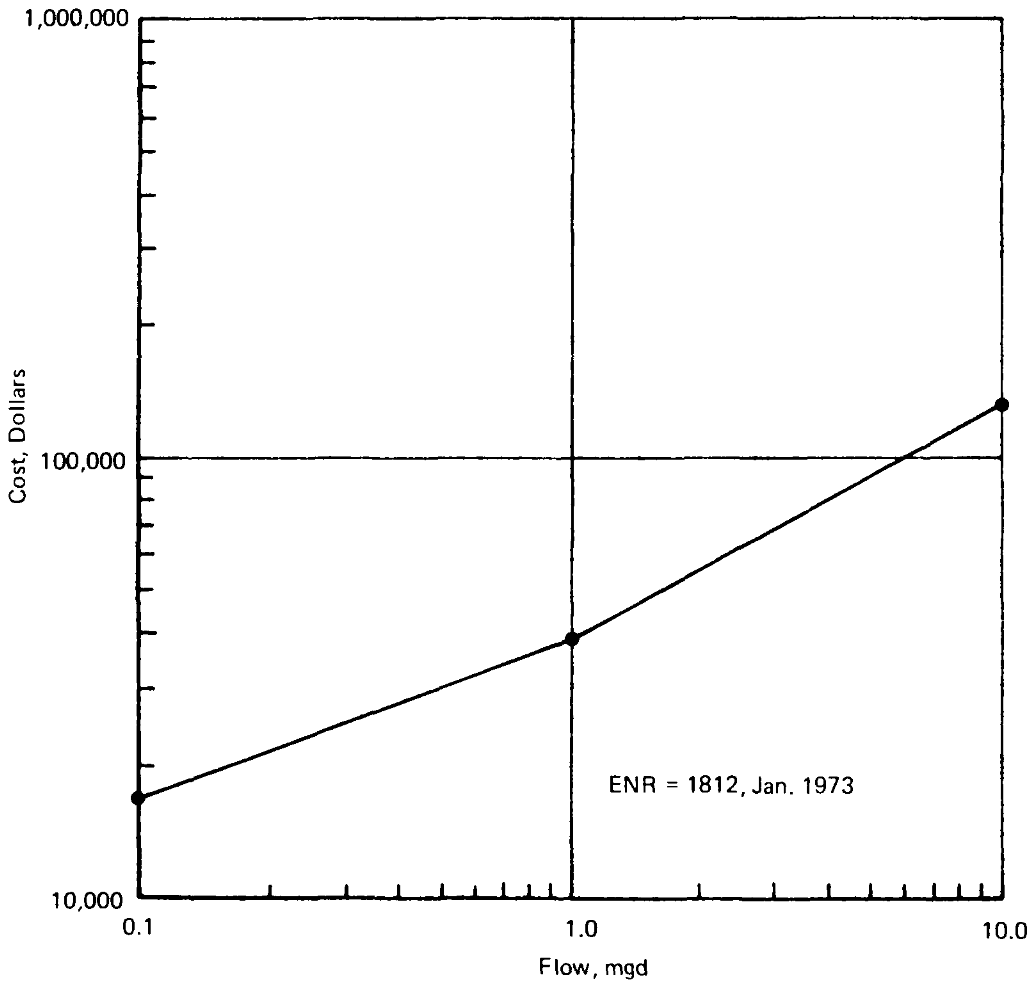


Figure 10
Aerated Stabilization Basin Construction Cost

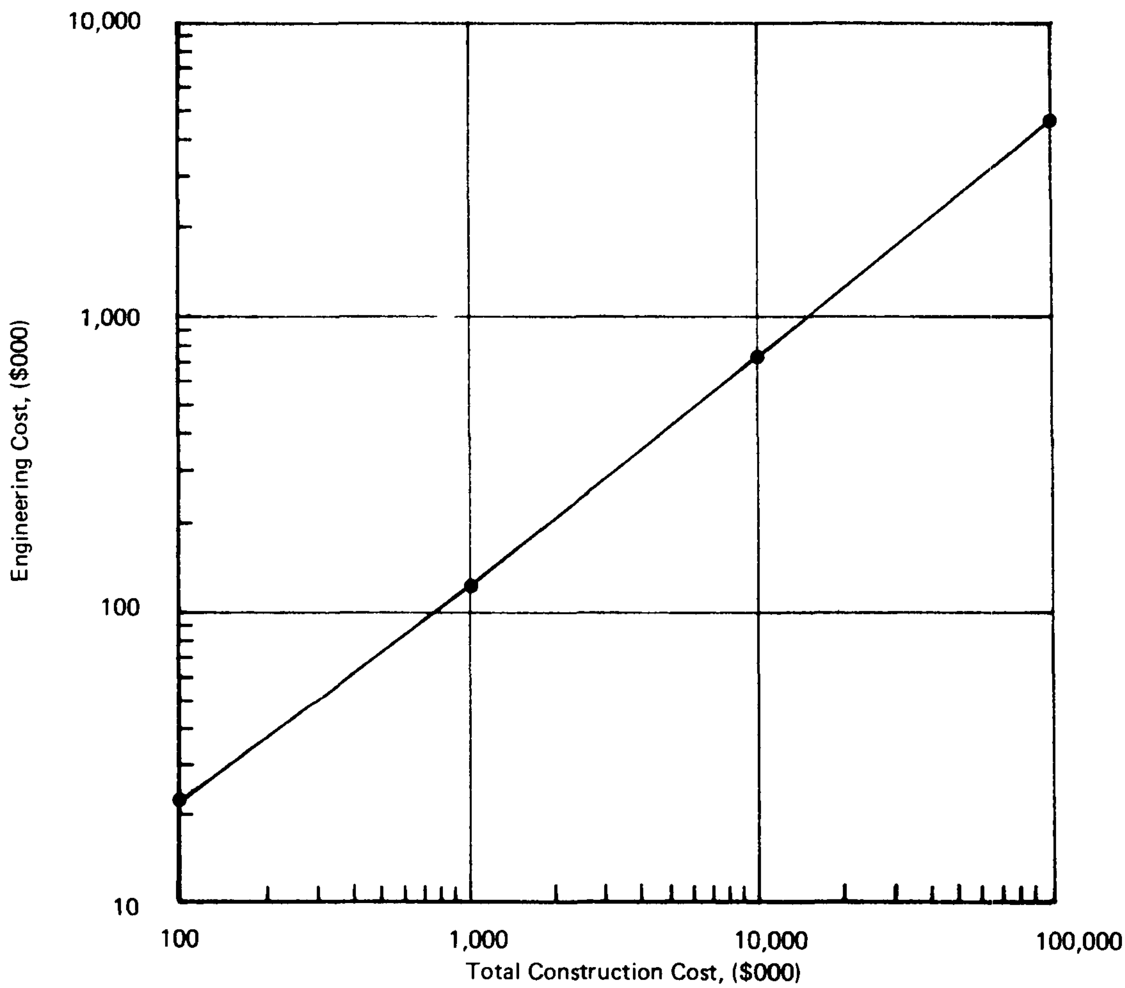


Figure 11
Engineering Costs

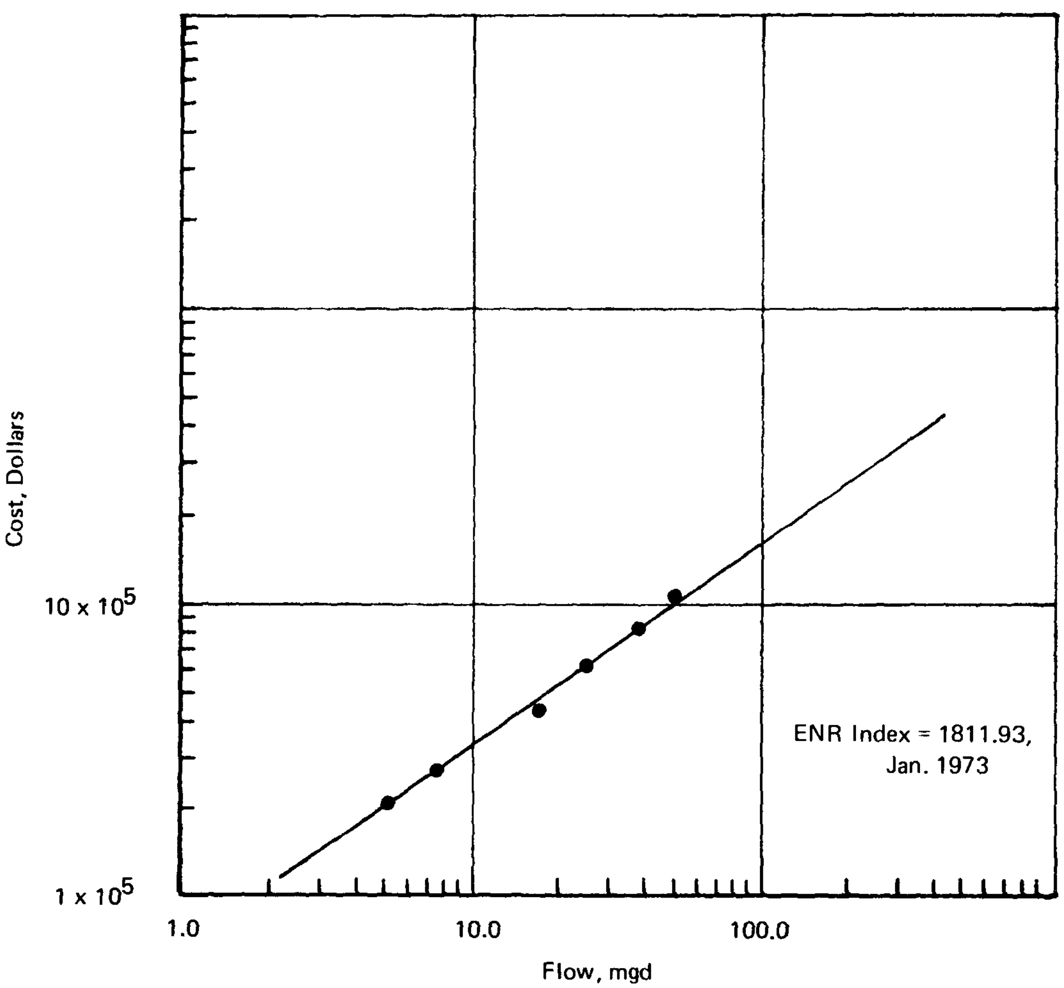


Figure 12
Clarifier Capital Cost

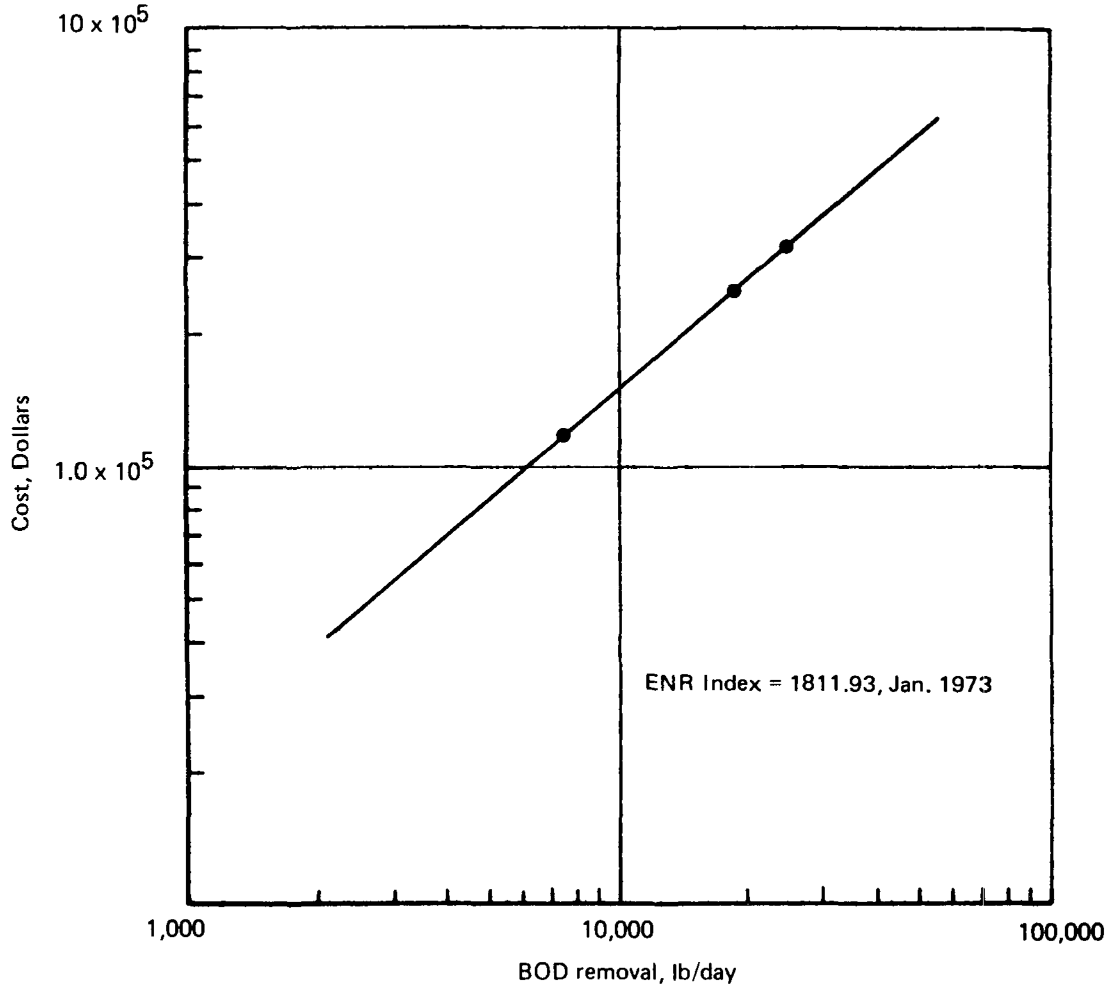


Figure 13
Aerated Stabilization Basin
(Aeration Equipment Only)

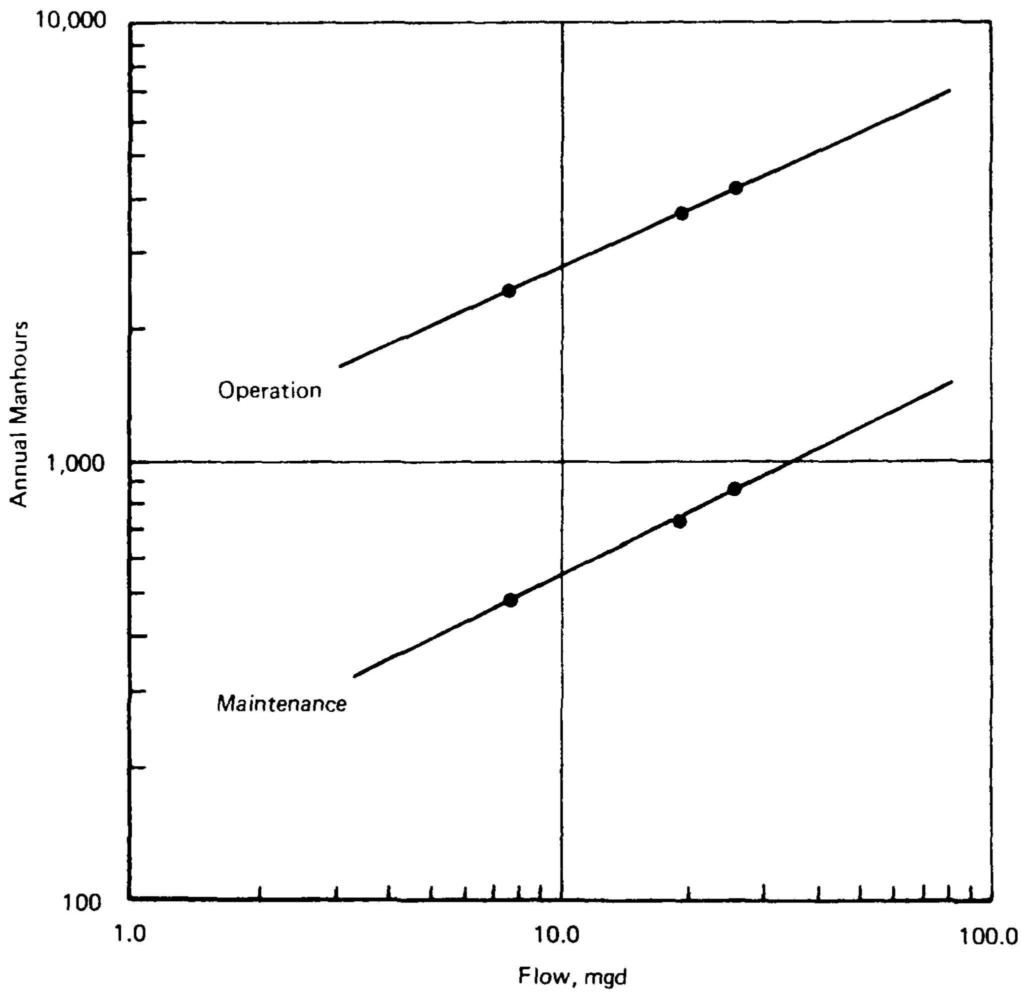


Figure 14
Aerated Stabilization Basin
Annual Operation and Maintenance Labor

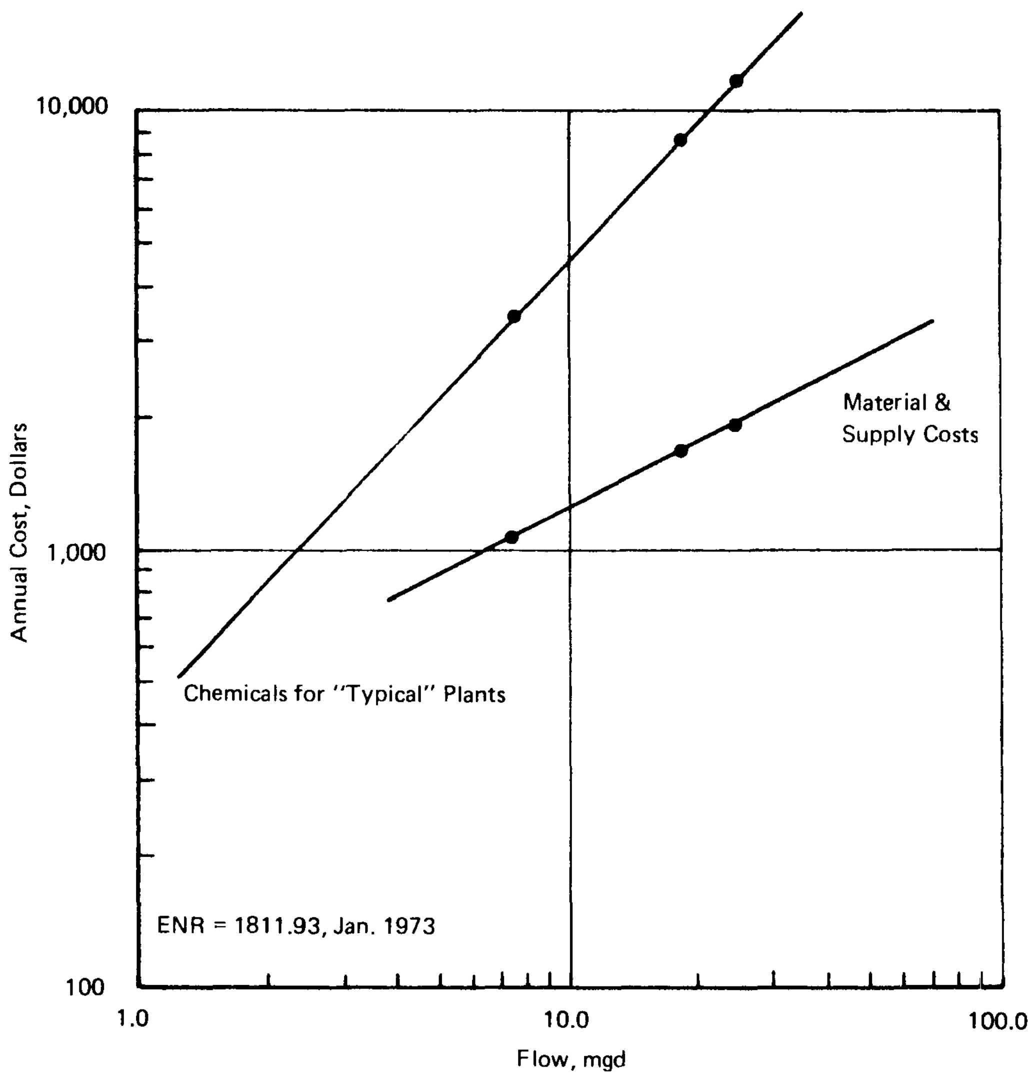


Figure 15

Aerated Stabilization Basin
(Material and Supply Costs, Annual)
(Chemical Costs)

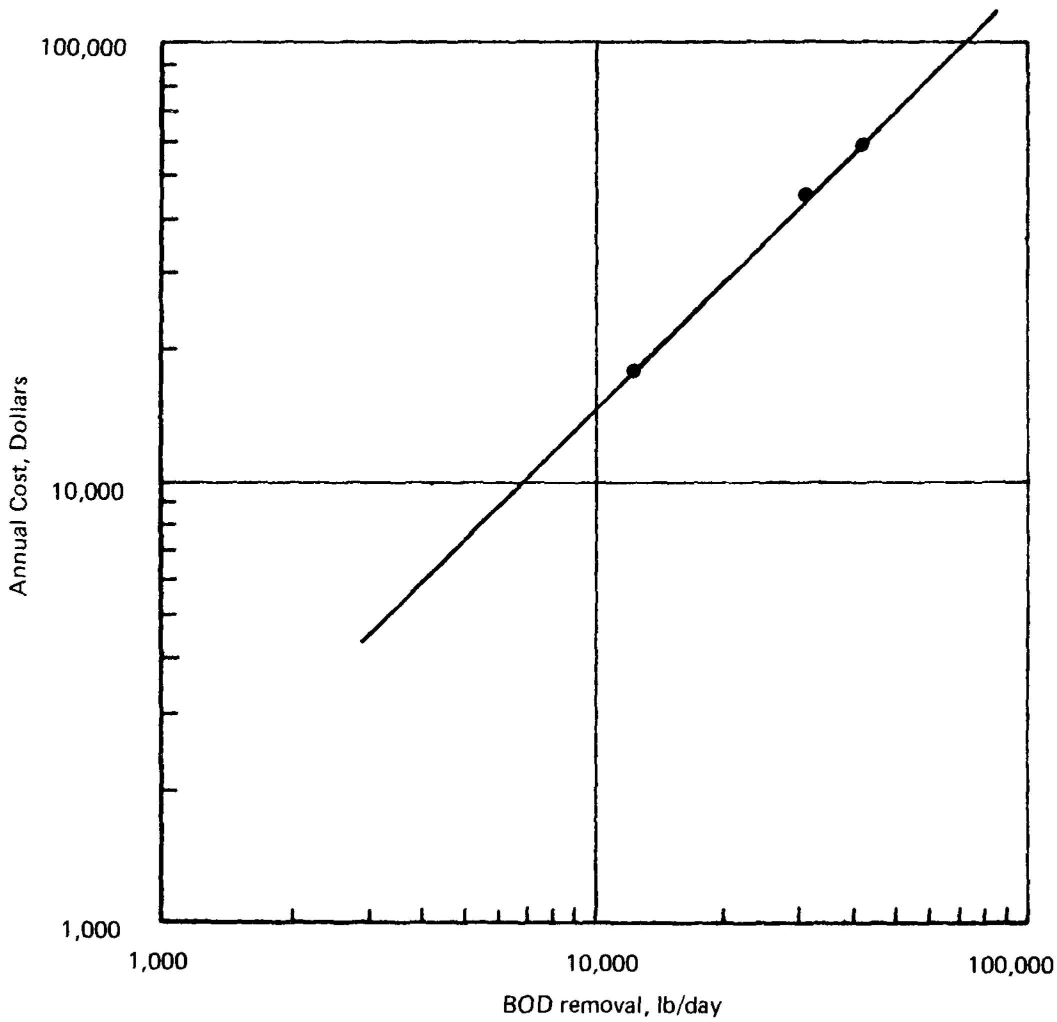


Figure 16

Aeration Equipment
Annual Power Costs
(Aerated Stabilization Basin)

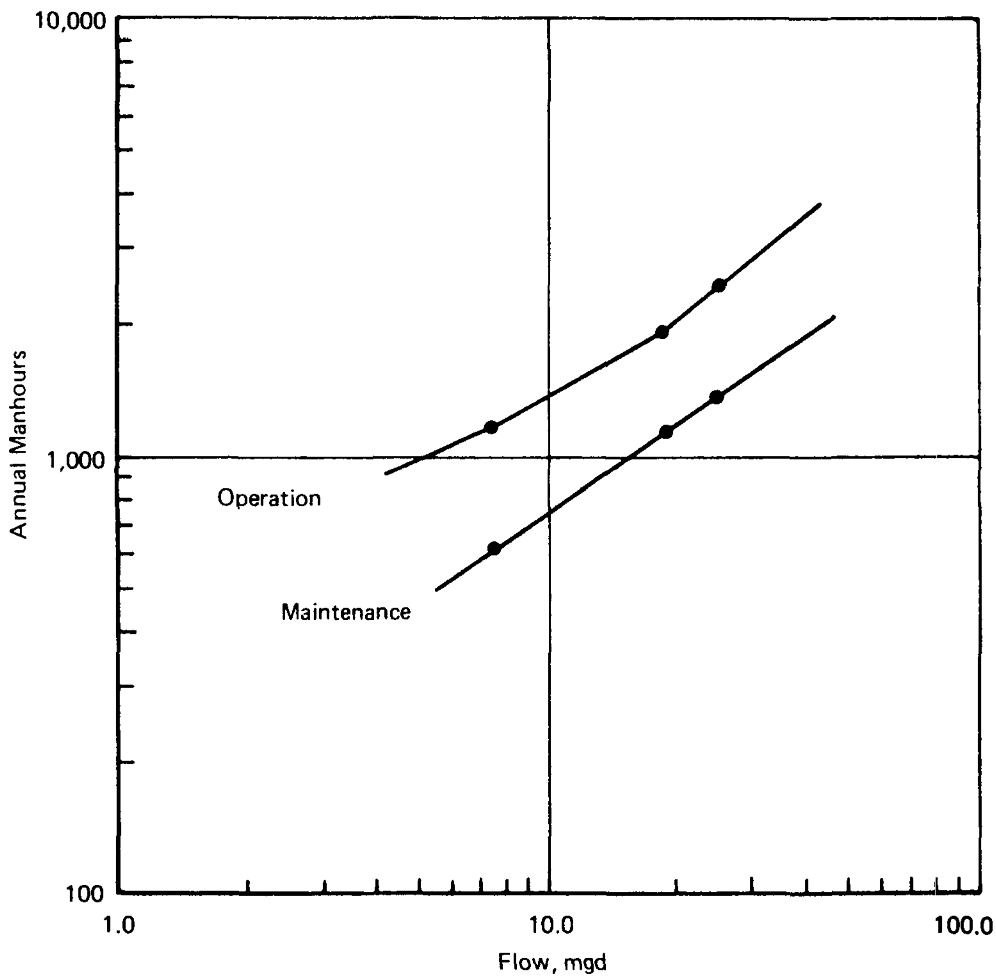


Figure 17
Clarifier, Annual Operation
and Maintenance Labor

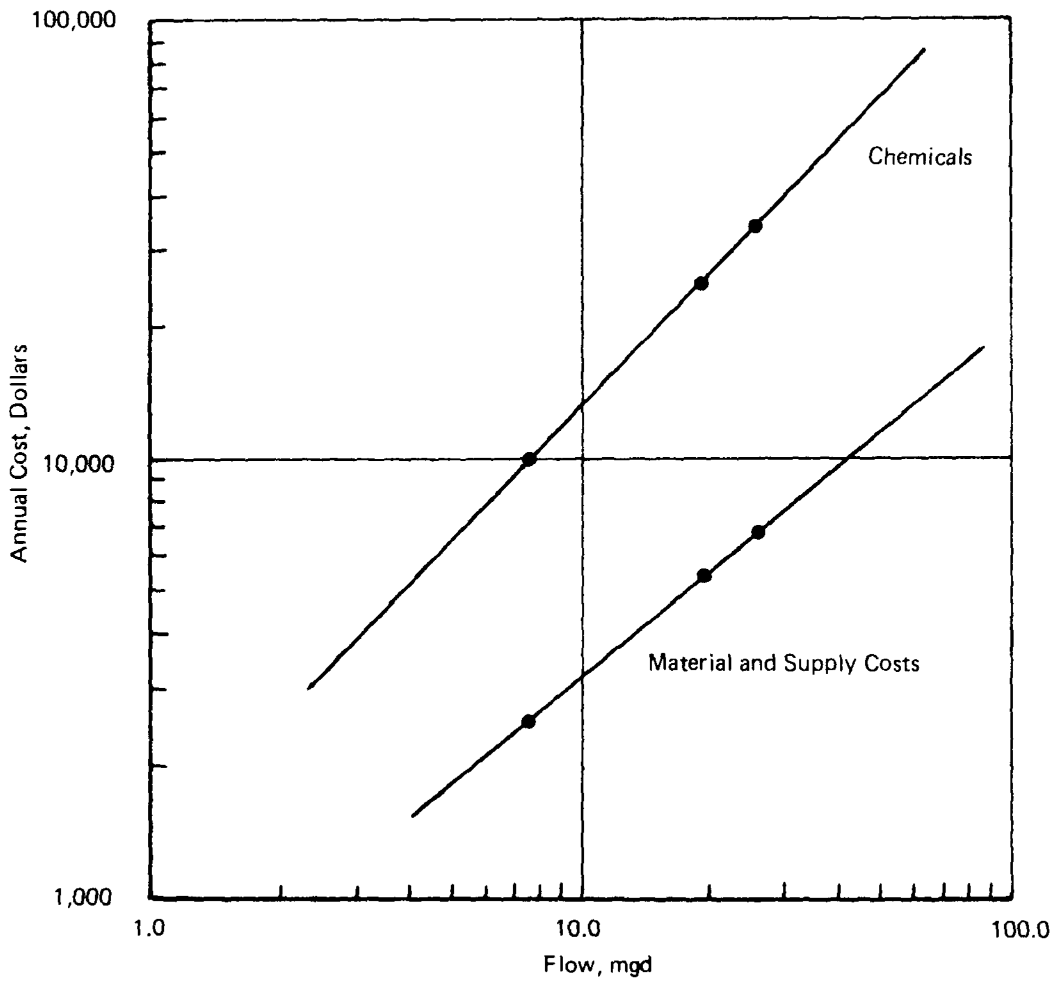


Figure 18

Clarifier
(Material and Supply Costs, Annual)
(Major Chemical Costs)

Cost Effectiveness of Treatment Alternatives

Alternative A - No Waste Treatment or Control

Costs - None

Reduction Benefits - None

Alternative B - Preliminary and Biological Treatment

This alternative includes preliminary screening, primary clarification (wool scouring only) and biological treatment.

Costs - The total capital investment cost is estimated to range from $10,200 to $336,000 for the model plants. The annual treatment cost is estimated to range from $3,900 to $88,000.

Reduction Benefits - Alternative B represents about a 95 percent reduction in BOD_5 compared with Alternative A. There are also significant reductions in TSS and some reduction of COD. Oils and grease are reduced from wool scouring operations.

Alternative C - Multi-media Filtration

This alternative consists of a filtration process that is compatible with biological treatment (Alternative B).

Costs - Alternative C represents a total capital investment of from $10,000 to $140,000 over Alternative B costs and an increased annual cost estimated to range from $3,000 to $41,300.

Reduction Benefits - Alternative C represents a further reduction in BOD_5 and TSS due to solids removal and optimum control over the biological treatment system.

Alternative D - Activated Carbon Adsorption

Alternative D includes an activated carbon adsorption system including carbon regeneration facilities. This system is compatible with biological treatment (Alternative B) and may require filtration (Alternative C). It may also be used for total effluent treatment.

Costs - Alternative D represents a total capital investment which ranges from $385,000 to $1,050,000 over Alternatives B or C and an increased annual cost from $113,100 to $404,800.

Reduction Benefits - Through Alternative D, there are some reductions in BOD_5 and TSS. There are significant reductions in COD, TOC, and color.

Alternative E - Multiple Effect Evaporation and Incineration

Alternative E includes a multiple effect (three stage) evaporator and a fluid bed incinerator. Residual solids are disposed of by landfill.

Costs - The capital investment is estimated to range from $196,000 to $3,148,00 and annual costs are estimated to range from $95,000 to $2,210,000.

Reduction Benefits - There would be complete removal of all waste water constituents. There would be no waste water discharge.

Impact of Waste Treatment Alternatives on Finished Product

Tables 13-25 illustrate the probable increases in finished product prices for small and medium size plants in the seven textile subcategories required to pay for waste water treatment. Each Table lists the increased cost attributable to biological treatment (Alternative B) and the additional cost increases in finished product prices for multi-media filtration (Alternative C), activated carbon adsorption (Alternative D) and multiple effect evaporation and incineration (Alternative E). Several conclusions are apparent from this economic analysis.

(1) The estimated increase in final product costs for the best practicable control technology currently available (Alternative B) are economically feasible for small and large plants in all seven subcategories. The estimated final product cost increases range from 0.1 to 0.8 cents per kilogram of product (0.2 to 1.8 cents per pound of product) for various subcategories. The average increase is less than 0.4 cents per kilogram (0.9 cents per pound).

(2) The estimated increase in final product costs for multi-media filtration (Alternative C) are significantly less than costs for Alternative B. These costs are not excessive and should be economically achievable for all plant sizes in each subcategory. The maximum cost for any industry model plant is less than 0.4 cents per kilogram of product (0.8 cents per pound of product).

(3) The price increases attributable to activated carbon adsorption appear to create an unequal economic impact. Variations in unit costs for small industry plants as compared with medium sized plants are reflected in an average price increase for a

small plant of 4.2 cents per kilogram of product (1.9 cents per pound of product) as compared with an average price increase for a medium sized plant of 2.3 cents per kilogram (1.0 cents per pound). The diseconomy of scale with the associated unequal economic impact resulted (as discussed in Section IV and later in Sections IX and X) in further segmentation. Different effluent limitations have been established for small plants than for medium or large sized plants in six subcategories.

(4) The estimated price increase in final product costs for evaporation and incineration (Alternative E) appear to be excessive for all industry subcategories except wool scouring (subcategory 1). The average price increase for all model plants is 7.5 cents per kilogram product (16.5 cents per pound of product). However, the average price increase for wool scouring plants is 1.8 cents per kilogram (4.0 cents per pound). Thus, no discharge of pollutants via evaporation and incineration is a feasible alternative treatment for wool scouring plants.

Tables 13-25 indicated the additional price increases for the best available technology economically achievable range from 0.05 to 0.4 cents per kilogram (0.1 to 0.8 cents per pound) product processed by all plants in subcategory 3 and by small plants in subcategories 1,2,4,5,6 and 7 with capacities less than 6,500 kg/day (14,300 lb/day), 900 kg/day (1,980 lb/day), 1,000 kg/day (2,200 lb/day), 3,450 kg/day (7,590 lb/day), 3,450 kg/day (7,590 lb/day), and 3,100 kg/day (6,280 lb/day) respectively. For larger plants in the industry, the price increases ranged from 0.4 cents per kilogram (0.8 cents per pound) to a high of 2.0 cents per kilogram (4.5 cents per pound). The overall costs of best practicable and best available technology is estimated to range between 0.3 and 1.1 cents per kilogram (0.6 and 2.5 cents per pound) produced from small plants and between 0.5 and 2.5 cents per kilogram (1.0 and 5.4 cents per pound) for products from larger plants.

TABLE 13

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 1-(SMALL)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	6.1	6.1	6.1	6.1
(1000 lb product/day)	13.3	13.3	13.3	13.3
Average Water Usage				
l/kg product	12.5	12.5	12.5	12.5
(gal/lb product)	1.5	1.5	1.5	1.5
Estimated Investment Cost (1) ($1000)	41.0	15.0	385.0	392.0
Estimated Annual Cost ($1000)	16.0	4.4	113.1	190.0
Estimated Product Cost				
$/kg product	0.002	0.0005	0.015	0.026
($/lb product)	0.005	0.001	0.034	0.057

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 14

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 1-(MEDIUM)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	30.3	30.3	30.3	30.3
(1000 lb product/day)	66.7	66.7	66.7	66.7
Average Water Usage				
l/kg product	12.5	12.5	12.5	12.5
(gal/lb product)	1.5	1.5	1.5	1.5
Estimated Investment Cost (1) ($1000)	103.0	38.0	480.0	768.0
Estimated Annual Cost ($1000)	30.0	11.2	135.6	398.0
Estimated Product Cost				
$/kg product	0.001	0.0002	0.004	0.011
($/lb product)	0.002	0.001	0.008	0.024

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 15

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 2-(SMALL)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	8.2	8.2	8.2	8.2
(1000 lb product/day)	18.1	18.1	18.1	18.1
Average Water Usage				
l/kg product	115.1	115.1	115.1	115.1
(gal/lb product)	13.8	13.8	13.8	13.8
Estimated Investment Cost (1) ($1000)	164.0	60.0	450.0	1,316.0
Estimated Annual Cost ($1000)	46.0	17.7	132.8	759.0
Estimated Product Cost				
$/kg product	0.005	0.002	0.013	0.076
($/lb product)	0.010	0.004	0.029	0.168

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 16

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 2-(MEDIUM)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	24.7	24.7	24.7	24.7
(1000 lb product/day)	54.3	54.3	54.3	54.3
Average Water Usage				
l/kg product	115.1	115.1	115.1	115.1
(gal/lb product)	13.8	13.8	13.8	13.8
Estimated Investment Cost (1) ($1000)	336.0	135.0	910.0	2,991.0
Estimated Annual Cost ($1000)	84.0	39.8	292.5	2,087.0
Estimated Product Cost				
$/kg product	0.003	0.001	0.010	0.070
($/lb product)	0.006	0.003	0.022	0.154

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 17

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 3-(AVERAGE)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	1.5	1.5	1.5	1.5
(1000 lb product/day)	3.3	3.3	3.3	3.3
Average Water Usage				
l/kg product	12.5	12.5	12.5	12.5
(gal/lb product)	1.5	1.5	1.5	1.5
Estimated Investment Cost (1) ($1000)	10.2	10.0	--	196.0
Estimated Annual Cost ($1000)	3.9	3.0	--	95.0
Estimated Product Cost				
$/kg product	0.002	0.001	--	0.044
($/lb product)	0.004	0.003	--	0.100

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 18

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 4-(SMALL)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	2.5	2.5	2.5	2.5
(1000 lb product/day)	5.6	5.6	5.6	5.6
Average Water Usage				
l/kg product	150.1	150.1	150.1	150.1
(gal/lb product)	18.0	18.0	18.0	18.0
Estimated Investment Cost (1) ($1000)	103.0	38.0	450.0	768.0
Estimated Annual Cost ($1000)	30.0	11.2	145.8	398.0
Estimated Product Cost				
$/kg product	0.008	0.003	0.039	0.107
($/lb product)	0.018	0.007	0.087	0.237

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 19

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 4-(MEDIUM)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	12.6	12.6	12.6	12.6
(1000 lb product/day)	27.8	27.8	27.8	27.8
Average Water Usage				
l/kg product	150.1	150.1	150.1	150.1
(gal/lb product)	18.0	18.0	18.0	18.0
Estimated Investment Cost (1) ($1000)	254.0	102.0	860.0	2,197.0
Estimated Annual Cost ($1000)	74.0	30.1	372.7	1,472.0
Estimated Product Cost				
$/kg product	0.004	0.002	0.020	0.080
($/lb product)	0.009	0.003	0.045	0.177

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 20

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 5-(SMALL)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	6.8	6.8	6.8	6.8
(1000 lb product/day)	15.0	15.0	15.0	15.0
Average Water Usage				
l/kg product	166.8	166.8	166.8	166.8
(gal/lb product)	20.0	20.0	20.0	20.0
Estimated Investment Cost (1) ($1000)	160.0	74.0	480.0	1,496.0
Estimated Annual Cost ($1000)	44.0	21.8	135.6	960.0
Estimated Product Cost				
$/kg product	0.004	0.002	0.014	0.097
($/lb product)	0.010	0.005	0.030	0.213

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 21

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 5-(MEDIUM)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	18.2	18.2	18.2	18.2
(1000 lb product/day)	40.0	40.0	40.0	40.0
Average Water Usage				
l/kg product	166.8	166.8	166.8	166.8
(gal/lb product)	20.0	20.0	20.0	20.0
Estimated Investment Cost (1) ($1000)	327.0	140.0	910.0	3,148.0
Estimated Annual Cost ($1000)	88.0	41.3	267.5	2,210.0
Estimated Product Cost				
$/ kg product	0.003	0.002	0.010	0.084
($/ lb product)	0.007	0.003	0.022	0.184

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 22

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 6-(SMALL)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	5.4	5.4	5.4	5.4
(1000 lb product/day)	11.9	11.9	11.9	11.9
Average Water Usage				
l/kg product	70.1	70.1	70.1	70.1
(gal/lb product)	8.4	8.4	8.4	8.4
Estimated Investment Cost (1) ($1000)	103.0	38.0	400.0	768.0
Estimated Annual Cost ($1000)	30.0	11.2	116.0	398.0
Estimated Product Cost				
$/ kg product	0.004	0.001	0.015	0.051
($/ lb product)	0.008	0.003	0.032	0.111

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 23

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 6-(MEDIUM)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	43.2	43.2	43.2	43.2
(1000 lb product/day)	95.2	95.2	95.2	95.2
Average Water Usage				
l/kg product	70.1	70.1	70.1	70.1
(gal/lb product)	8.4	8.4	8.4	8.4
Estimated Investment Cost (1) ($1000)	327.0	140.0	1,050.0	3,148.0
Estimated Annual Cost ($1000)	88.0	41.3	404.8	2,210.0
Estimated Product Cost				
$/ kg product	0.001	0.0006	0.006	0.035
($/ lb product)	0.003	0.001	0.014	0.077

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 24

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 7-(SMALL)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	4.1	4.1	4.1	4.1
(1000 lb product/day)	9.1	9.1	9.1	9.1
Average Water Usage				
l/kg product	183.5	183.5	183.5	183.5
(gal/lb product)	22.0	22.0	22.0	22.0
Estimated Investment Cost (1) ($1000)	125.0	59.0	400.0	1,132.0
Estimated Annual Cost ($1000)	35.0	17.4	116.0	638.0
Estimated Product Cost				
$1 kg product	0.006	0.003	0.019	0.106
($1 lb product)	0.013	0.006	0.042	0.234

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

TABLE 25

WASTE WATER TREATMENT COSTS
FOR SUBCATEGORY 7-(MEDIUM)

Parameter/Cost	ALTERNATIVE (2) B	C	D	E
Plant Finished Material Production				
1000 kg product/day	12.4	12.4	12.4	12.4
(1000 lb product/day)	27.3	27.3	27.3	27.3
Average Water Usage				
l/kg product	183.5	183.5	183.5	183.5
(gal/lb product)	22.0	22.0	22.0	22.0
Estimated Investment Cost (1) ($1000)	277.0	120.0	730.0	2,521.0
Estimated Annual Cost ($1000)	73.0	35.4	221.4	1,721.0
Estimated Product Cost				
$/ kg product	0.004	0.002	0.012	0.095
($/ lb product)	0.009	0.004	0.027	0.210

(1) Assumes treatment facilities sized to meet production with no allowance for growth.

(2) Alternative B = Preliminary and Biological Treatment
Alternative C = Multi-Media Filtration
Alternative D = Activated Carbon Adsorption
Alternative E = Multiple Effect Evaporation and Incineration

Alternative Treatment Systems

It has been assumed in the economic analysis that an extended biological stabilization process will be utilized for the biological treatment. However, aerobic-anaerobic lagoons or trickling filters or activated sludge can be designed to provide the same degree of biological treatment. These systems require less area and can only be utilized where land is not readily available near the textile facility. Activated sludge may result in additional annual costs of as much as $200,000 over those costs presented for Alternative B.

It is also assumed that wool scouring plants (Subcategory 1) with capacities greater than 6,500 kg/day (14,300 lb/day) will utilize activated carbon adsorption. Table 13 indicates that evaporation/incineration is a feasible alternative for large wool scouring plants. Costs could be as much as 0.6 cents per kilogram of product (1.4 cents per pound product) higher.

Electrical Energy Requirements

The energy requirements (electric power and fuel) for textile facilities vary considerably based upon reported data. This variation is due to the following factors:

1. Type of fiber processed.
2. Type of extent of cleaning and finishing operations.
3. Degree of mechanization within the textile facility.
4. Climate of the textile location.

It is estimated that the contribution of waste treatment is considerably less than 10 percent of the total industry energy consumption at present and is not likely to exceed 10 percent in the future.

Thermal Energy Requirements

Thermal energy costs are considerably less than electrical energy costs for operations within the industry. Waste treatment systems impose no significant addition to the thermal energy requirements of plants. Wastewater can be reused in cooling and condensing service if it is separated from the process waters in non-barometric type condensers. These heated waste waters improve the effectiveness of ponds which are best maintained at 90°F or more. Improved thermal efficiencies are coincidentally achieved within a plant with this technique.

Wastewater treatment costs and effectiveness can be improved by the use of energy and power conservation practices and techniques in each plant. The waste load increases with increased water use. Reduced water use therefore reduced the waste load, pumping costs, and heating costs, the last of which can be further reduced by water reuse as suggested previously.

Solid Wastes

The disposal of solid wastes from the textile industry are generally disposed of by landfill. The solid materials, separated during waste water treatment, containing organic and inorganic materials, including those added to promote solids separation, is called sludge. Typically, it contains 95 to 98 percent water prior to dewatering or drying. Some quantities of sludge are generated by both primary and secondary treatment systems with the type of system influencing the quantity. The following table illustrates this:

Treatment System	Sludge Volume as Percent of Raw Wastewater Volume
Dissolved air flotation	Up to 10%
Anaerobic lagoon	(Sludge accumulation in these
Extended Aeration	(lagoons is usually not sufficien
Aerobic & Aerated Lagoons	(to require removal at any time)
Activated sludge	10 - 15%
Extended aeration	5 - 10%
Anaerobic contact process	approximately 2%

The raw sludge can be concentrated, digested, dewatered, dried, incinerated, land-filled, or spread in sludge holding ponds. Sludge from secondary treatment systems is normally dewatered or digested sufficiently for hauling to a land fill. The final dried sludge materials can be safely used as an effective soil builder. Prevention of runoff is a critical factor in plant-site sludge holding ponds. Costs of typical sludge handling techniques for each secondary treatment system generating enough sludge to require handling equipment are already incorporated in the costs for these systems. All other non-water quality environmental impacts of the alternative treatment and control technologies described appear minor.

SECTION IX

EFFLUENT REDUCTION ATTAINABLE THROUGH THE APPLICATION OF THE BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE EFFLUENT LIMITATIONS GUIDELINES

INTRODUCTION

The effluent limitations which must be achieved July 1, 1977, are to specify the degree of effluent reduction attainable through the application of the Best Practicable Control Technology Currently Available. Best Practicable Control Technology Currently Available is generally based upon the average of the best existing performance by plants of various sizes, ages, and unit processes within the industrial category and/or subcategory. This average is not based upon a broad range of plants within the textile industry, but based upon performance levels achieved by exemplary plants.

Consideration must also be given to:

The total cost of application of technology in relation to the effluent reduction benefits to be achieved from such application;

The size and age of equipment and facilities involved;

The processes employed;

The engineering aspects of the application of various types of control techniques;

Process changes;

Non-water quality environmental impact (including energy requirements).

Also, Best Practicable Control Technology Currently Available emphasizes treatment facilities at the end of a manufacturing process, but includes the control technologies within the process itself when the latter are considered to be normal practice within an industry.

A further consideration is the degree of economic and engineering reliability which must be established for the technology to be "currently available". As a result of demonstration projects, pilot plants and general use, there must exist a high degree of confidence in the engineering and economic practicability of the technology at the time of start of construction of installation of the control facilities.

EFFLUENT REDUCTION ATTAINABLE THROUGH THE APPLICATION OF BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE

Based on the information contained in Section III through VIII of this report, a determination has been made that the quality of effluent attainable through the application of the Best Pollution Control Technology Currently Available is as listed in Table 26. A number of plants in the industry which have biological treatment systems for which effluent quality data were available are meeting these standards.

A biological treatment system which is permitted to operate at a constant food to microorganism ratio throughout the year and with minimum operational changes would have a natural variation of 50 percent as explained in Section VII and as shown by the solid line in Figure 19. A similar system with careful operational control and proper design can be operated within 25 percent of the average on a monthly operating basis. A system without optimum operational control has been used to account for normal treatment variation. Thus, a factor of 50 percent has been used to calculate the maximum 30 day effluent limitation. A further allowance of 100 percent has been applied to a maximum 30 day effluent limitation in order to develop the maximum daily effluent limitation.

TABLE 26

MAXIMUM THIRTY DAY AVERAGE
RECOMMENDED EFFLUENT LIMITATION
GUIDELINES FOR JULY 1, 1977

Plant Subcategory	Effluent Limitations (1) BOD5 kg/1000kg (lb/1000lb)	TSS kg/1000kg (lb/1000lb)	COD kg/1000kg (lb/1000lb)
1. WOOL SCOURING (2)			
Plant capacity less than 6,500 kg/day (14,300 lb/day)	3.7	3.7	NA
Plant capacity greater than 6,500 kg/day (14,300 lb/day)	3.7	3.7	24
2. WOOL FINISHING			
Plant capacity less than 900 kg/day (1,980 lb/day)	7.5	7.5	NA
Plant capacity greater than 900 kg/day (1,980 lb/day)	7.5	7.5	56
3. GREIGE MILLS			
All plant sizes	0.45	0.45	
4. WOVEN FABRIC FINISHING			
Plant capacity less than 1,000 kg/day (2,200 lb/day)	2.2	6.9	NA
Plant capacity greater than 1,000 kg/day (2,200 lb/day)	2.2	6.9	33
5. KNIT FABRIC FINISHING			
Plant capacity less than 3,450 kg/day (7,590 lb/day)	1.8	8.0	NA
Plant capacity greater than 3,450 kg/day (7,590 lb/day)	1.8	8.0	24
6. CARPET MILLS			
Plant capacity less than 3,450 kg/day (7,590 lb/day)	4.3	4.3	NA
Plant capacity greater than 3,450 kg/day (7,590 lb/day)	4.3	4.3	30
7. STOCK AND YARN DYEING AND FINISH-ING			
Plant capacity less than 3,100 kg/day (6,820 lb/day)	3.5	9.2	NA
Plant capacity greater than 3,100 kg/day (6,820 lb/day)	3.5	9.2	47

NA MEANS NOT APPLICABLE

(1) Plant capacities and discharge limitations are stated for Subcategories 1 and 2 per weight of raw wool received at the wool scouring or wool finishing operation and are stated for Subcategories 3, 4, 5, 6 and 7 per weight of final material produced by the facility.

For all subcategories pH should range between 6.0 to 9.0 at any time.

For all subcategories Most Probable Number (MPN) of Fecal Coliforms should not exceed 400 counts per 100 ml.

(2) For all Wool Scouring plants (Subcategory 1) Oils and Grease should not exceed 1.9 kg (lb)/1000 kg (lb) grease wool.

Figure 19

TYPICAL SEASONAL VARIATION
FOR BIOLOGICAL TREATMENT

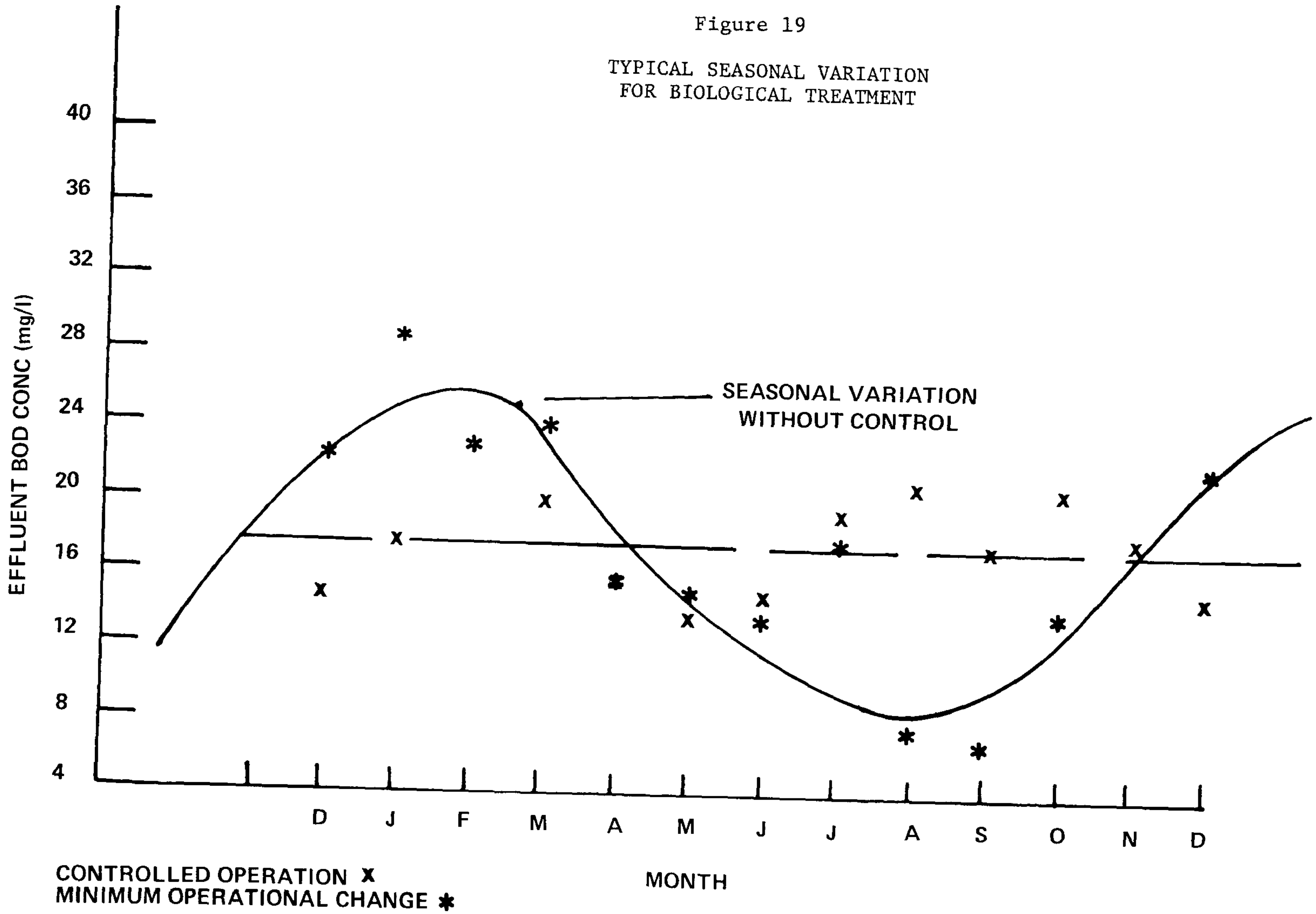


TABLE 27

PERFORMANCE OF BIOLOGICAL TREATMENT SYSTEMS

Plant Code	Waste Character	Production 1000 kg/day (1000 lb/day)	Influent BOD kg/1000 kg (lb/1000lb)	BOD Removal Efficiency (Percent)
J	Woven Fabric	50.8 (113)	66.0	97.8
K	Woven Fabric	103 (228)	22.2	96.5
L	Woven Fabric	68.4 (152)	108.0	95.0
M	Woven Fabric	158 (350)	40.6	97.6
N	Woven Fabric	78.8 (175)	66.2	92.8
O	Woven Fabric	60.8 (134)	40.0	96.9
P	Woven Fabric	197 (434)	138.0	96.9
Q	Woven Fabric	73 (161)	52.3	98.5
R	Woven Fabric	90.8 (200)	37.1	92.4
S	Woven Fabric	25.7 (56.6)	49.3	97.7
U	Woven Fabric	22.5 (50)	20.9	90.0
EE	Stock and Yarn	15.9 (35)	38.7	93.9
GG	Stock and Yarn	9.1 (20)	47.2	92.3
II	Stock and Yarn	44.0 (96.5)	14.9	92.5
W	Knit Fabric	17.2 (37.8)	49.8	93.0
X	Knit Fabric	27.0 (59.5)	19.0	97.0
Y	Knit Fabric	62.1 (137)	80.3	97.0
Z	Knit Fabric	17.9 (39)	16.6	94.0
	Average	62.3 (137)	50.4	95.1

IDENTIFICATION OF BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE

Best Practicable Control Technology Currently Available for the textile manufacturing industry includes preliminary screening, primary settling (wool scouring only), coagulation (carpet mills only), secondary biological treatment and chlorination. Strict management control over housekeeping and water use practices result in raw wastes loads which can be treated biologically to the effluent levels listed in Table 26. No special in-plant modification is required. The performances of eighteen different biological treatment systems that achieve these effluent limits are given in Table 27.

Wool Scouring and Wool Finishing

The stated guidelines for subcategory 1 (wool scouring) and subcategory 2 (wool finishing) can be achieved by applying the best practicable control technology to the appropriate subcategory raw waste load. The best practicable control technology for wool scouring includes screening, settling, biological treatment and chlorination; best practicable control technology for wool finishing includes screening biological treatment and chlorination. The average raw waste BOD_5 load resulting from wool scouring is almost 50 kg(lb) of BOD_5 per 1000 kg (lb) of grease wool as received and weighed at the plant. The average raw waste BOD_5 load resulting from wool finishing is estimated at 100 kg(lb) of BOD_5 per 1000 kg (lb) of dry wool received at the plant. The basis of this number is a single facility which is a 100 percent wool finishing operation. It is further substantiated by estimates of knowledgeable textile consultants. The recommended effluent limitation guidelines for July 1, 1977, for the wool scouring and wool finishing subcategories are based on results from eighteen exemplary biological treatment systems (see Table 27). These systems treat textile waste waters from dyeing and finishing of broadwoven cotton and cotton-synthetic blends, knits and stock and yarn.

TABLE 28

PERFORMANCE OF EFFLUENT TREATMENT SYSTEMS
SUBCATEGORY 1: Wool Scouring (1)

Plant Code	Production 1000kg/day (1000lb/day)	BOD Discharge kg/1000kg (lb/1000lb)	TSS Discharge kg/1000kg (lb/1000lb)	COD Discharge kg/1000kg (lb/1000lb)	Grease Discharge kg/1000kg (lb/1000lb)
A	45.4 (100)	2.3	1.5	15	1.5
B	74.9 (165)	2.4	2.0	18	0.1
AB (2)	45.4 (100)	0	0	0	0

(1) Production and discharge quantities are recorded per weight on raw grease wool as received and weighed at the plant.

(2) Total waste water containment.

The average BOD5 removal efficiency of these eighteen systems is greater than 95 percent. The BOD5 effluent limitation is calculated by applying this average BOD5 removal efficiency (95 percent) to the appropriate subcategory raw waste load, and allowing 50 percent to account for normal operational variation. Thus, the BOD5 effluent limitation for subcategory 1 (wool scouring) is 3.7 kg/kkg (lb/1000lb) of grease wool and the BOD5 effluent limitation for subcategory 2 (wool finishing) is 7.5 kg/kkg (lb/1000lb) of dry wool.

The subcategory 1 effluent limitations are substantiated by data given in Table 28 for a full-scale biological treatment system at Mill A and a pilot project at Mill B. The treatment system at Mill A can achieve sufficient effluent reduction to meet the effluent limitations. This is based on normal water usage and production at Mill A and average 30 day effluent BOD5 concentration of 150 mg/l. These results are confirmed by several months of effluent data. Results from Mill B indicate this biological treatment system can also meet the effluent limitations. This is confirmed by several months of effluent data during both warm and cold weather operation. The subcategory 2 effluent limitation is substantiated by water usage and waste water treatment data from a study supported by the American Textile Manufacturers Institute, Inc., and the Carpet and Rug Institute.

The total suspended solids (TSS) effluent limitations are identical to the BOD5 effluent limitations. Results from the exemplary biological treatment systems as well as from Mills A and B indicate that the suspended solids can be consistently reduced to at least this level. Thus the TSS effluent limitation for subcategory 1 (wool scouring) is 3.7 kg/kkg (lb/1000lb) of grease wool and the TSS effluent limitation for subcategory 2 (wool finishing) is 7.5 kg/kkg (lb/1000lb) of dry wool.

Much of the chemical oxygen demand (COD) in the effluent from the exemplary biological treatment systems and Mills A and B is associated with the suspended solids in the effluent. The COD effluent limitations are based on an average COD effluent concentrations of 1250 mg/l for subcategory 1 and 325 mg/l for subcategory 2. Using the mean water usages of 12.5 l/kg (1.5 gal/lb) for subcategory 1 and 12.5 l/kg (1.5 gal/lb) for subcategory 1 and 115 l/kg (13.8 gal/lb) for subcategory 2, the COD effluent limitations are 24 kg/kkg (lb/1000lb) of grease wool for subcategory 1 (wool scour) and 56 kg/kkg (lb/1000lb) of dry wool for subcategory 2 (wool finishing). Effluent data from biological treatment systems at Mills A and B confirm that these systems can meet the COD limitation.

COD limitations for subcategories 1 and 2 are applicable only to plants with capacities greater than 6,500 kg/day (14,300 lb/day) and 900 kg/day (1,980 lb/day) respectively. As discussed in Sections IV and VIII severe diseconomies of scale create economic impacts which require different limitations for small plants.

Grease is a serious problem in the wool scouring subcategory. Effluent levels observed especially at Mill B indicate the grease is recoverable and treatable to levels less than 100 mg/l in the final effluent. Applying this concentration to the mean water usage the grease effluent limitation is 1.9 kg/kkg (lb/1000lb) of grease wool.

Effluent limitations for subcategories 1 and 2 include pH and fecal coliforms. Control of pH in the range of 6.0-9.0 is commonly encountered in treated effluents and control of fecal coliforms to less than 400 per 100 ml is readily accomplished by chlorination.

Greige Goods

The stated guidelines for subcategory 3 (greige goods Mills) can be achieved by applying the best practicable control technology to the greige goods raw waste load. The best practicable control technology include screening, biolcgical treatment and chlorination.

As described in Section IV, greige Mills 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 an industry 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 20 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.

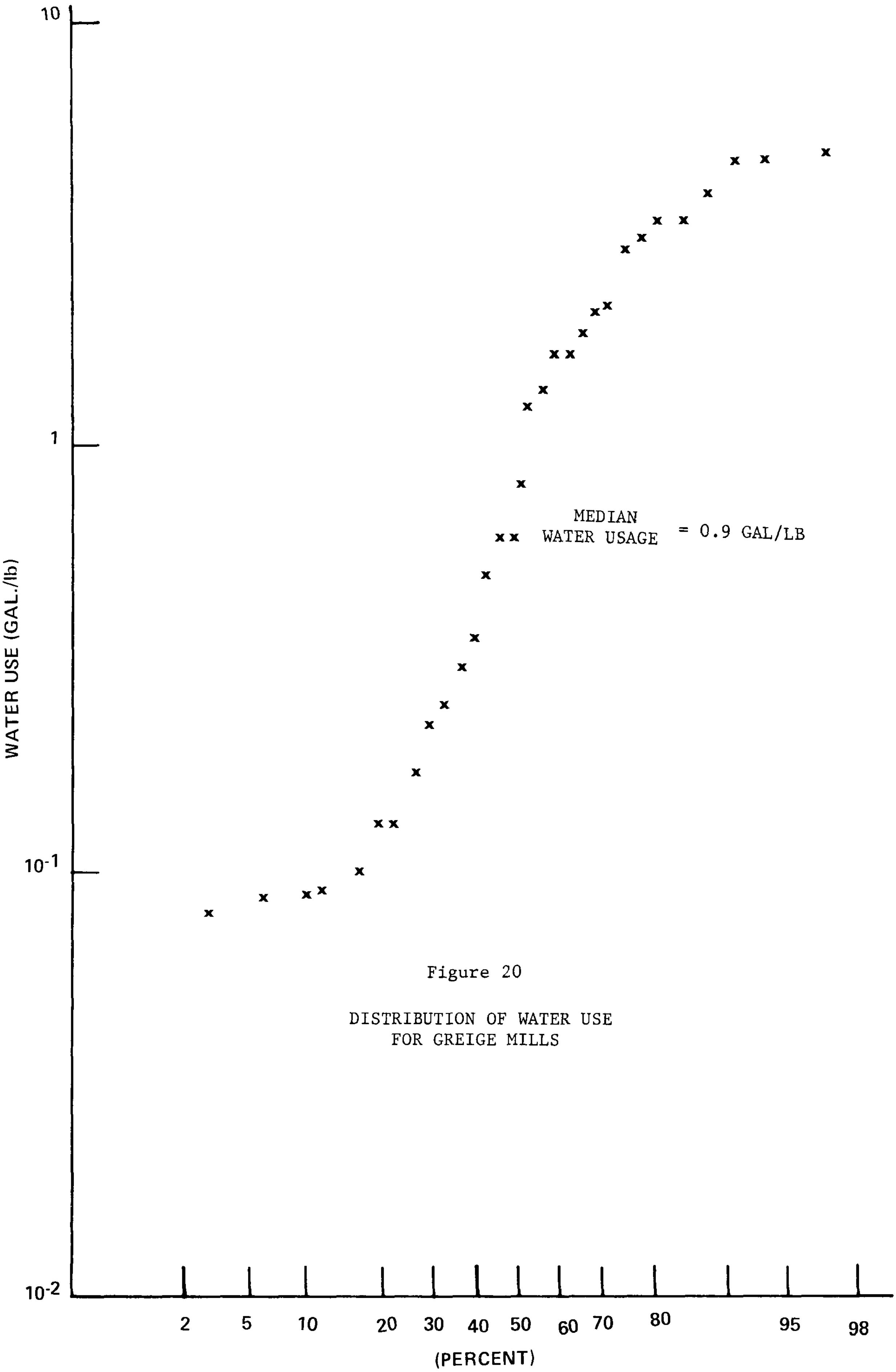


Figure 20

DISTRIBUTION OF WATER USE
FOR GREIGE MILLS

From the water usage distribution presented, it can be seen that the median water use value is 7.5 l/kg (0.9 gal/lb). It has been demonstrated that BOD_5 from a greige mill can be reduced to a low level. Because of this high treatability and the influence of sanitary waste, the best practicable control technology should consistently attain 40 mg/l BOD_5. The BOD_5 effluent limitation can be computed by applying this concentration factor to the median water usage and allowing a 50 percent increase to account for normal operations variation. Thus, the BOD_5 effluent limitation for greige Mills (subcategory 3) is 0.45 kg/kkg(lb/1000 lb) of product.

The total suspended solids (TSS) effluent limitations are identical to the BOD_5 effluent limitations. Results from the exemplary biological treatment systems indicated that TSS can be consistently reduced to at least this level. Thus, the TSS effluent limitation for greige Mills is 0.45 kg/kkg (lb/1000 lb) of product.

These BOD_5 and TSS effluent limitations are substantiated by plant I. Two years of data indicate a BOD_5 and TSS effluent discharge of less than 0.1 kg/kkg (lb/1000lb).

Effluent limitations for subcategory 3 (greige Mills) also include control of pH within the range of 6.0-9.0 and chlorination to control fecal coliforms to a level of 400 per 100 ml or less.

Woven Fabric Finishing

The effluent guidelines for July 1, 1977, subcategory 4 (woven fabric finishing) are the average of data from exemplary biological systems treating wastes from the dyeing and finishing of broadwoven cotton and cotton-synthetic blends. The BOD_5 effluent limitation is calculated from data tabulated in Table 29 from the average of the BOD_5 discharge from the biological treatment systems at Mills J, K, M, O, Q, R, S and U; the TSS effluent limitation is based on the average of treatment systems at Mills K, Q, and S; and the COD effluent limitation is based on the average of treatment systems at Mills M, O, S, and U. The effluent guidelines for subcategory 4 (woven fabric finishing) are as follows: BOD_5 limitation is 2.2 kg/kkg (lb/1000lb); TSS limitation is 6.9 kg/kkg (lb/1000lb).

Effluent limitations also include control of pH within the range of 6.0 to 9.0 and chlorination to control fecal coliforms below 400 per 100 ml.

TABLE 29

PERFORMANCE OF EFFLUENT TREATMENT SYSTEMS
SUBCATEGORY 4: Woven Fabric Finishing

Plant Code	Production 1000kg/day (1000lb/day)	BOD Discharge kg/1000kg (lb/1000lb)	TSS Discharge kg/1000kg (lb/1000lb)	COD Discharge kg/1000kg (lb/1000lb)
J	50.8 (113)	1.5	-	-
K	103 (228)	0.8	0.8	-
M	158 (350)	1.3	-	14.5
O	60.8 (134)	1.3	-	19.6
Q	73 (161)	0.7	6.9	-
R	90.8 (200)	2.8	-	-
S	25.7 (56.6)	1.1	6.1	23.6
U	22.5 (50.0)	2.1	-	29.7
	Average	1.5	4.6	22
	Average Plus 50 Percent	2.2	6.9	33

TABLE 30

PERFORMANCE OF EFFLUENT TREATMENT SYSTEMS
SUBCATEGORY 5: Knit Fabric Finishing

Plant Code	Production 1000kg/day (1000lb/day)	BOD Discharge kg/1000kg (lb/1000lb)	TSS Discharge kg/1000kg (lb/1000lb)	COD Discharge kg/1000kg (lb/1000lb)
X	27.0 (59.5)	0.5	8.6	-
Y	62.1 (137)	2.1	3.8	-
Z	17.9 (39)	1.0	3.6	-
	Average	1.2	5.3	16 (1)
	Average Plus 50 Percent	1.8	8.0	24

(1) COD = 2.60 + 11.2 (BOD)

Knit Fabric Finishing

The effluent guidelines for July 1, 1977 for subcategory 5 (knit fabric finishing) are the average of data from exemplary biological treatment systems. The BOD_5 and TSS effluent limitations are calculated from the average of the BOD_5 and TSS discharges from the biological treatment systems at Mills X, Y, and Z (see Table 30). The BOD_5 and TSS effluent limitations are based on these plants allowing a 50 percent increase to account for treatment plant variation: BOD_5 is 1.8 kg/kkg (lb/1000lb) and TSS is 8.0 kg/kkg (lb/1000lb). The COD effluent discharge is developed from data at Mills W and Y. Approximately 70 percent of the COD is removed by treatment plants at these Mills. The following correlation was developed between monthly average COD and BOD_5 in the effluent: BOD_5 limitation is 3.5 kg/kkg (lb/1000 lb) and TSS limitation is 9.2 kg/kkg (lb/1000 lb). The COD effluent limitation is based on three months effluent data in which COD averaged 13 times the BOD. The COD effluent guidelines is 47 kg/kkg(lb/1000lb).

Effluent limitations also include control of pH within the range of 6.0-9.0 and control of fecal coliforms to allow no more than 400 per 100 ml of discharge.

Carpet Mills

The effluent guidelines for July 1, 1977 for subcategory 6 (carpets) are the average of data from exemplary biological systems treating carpet mill wastes. The BOD_5, TSS and COD effluent limitations are based on the average BOD_5, TSS and COD discharges listed in Table 31 for systems treating waste water from Mills, MC, BS, CC and BB. The effluent limitations for carpet Mills (subcategory 6) are as follows: BOD_5 is 4.3 kg/kkg (lb/1000 lb); TSS is 4.3 kg/kkg (lb/1000 lb); and COD is 30 kg/kkg (lb/1000 lb).

Effluent limitations also include control of pH within the range of 6.0-9.0 and control of fecal coliforms to allow no more than 400 per 100 ml of waste water discharge.

TABLE 31

PERFORMANCE OF EFFLUENT TREATMENT SYSTEMS
SUBCATEGORY 6: Carpet Mills

Plant Code	Production 1000kg/day (1000lb/day)	BOD Discharge (kg/1000kg) (lb/1000lb)	TSS Discharge kg/1000kg (lb/1000lb)	COD Discharge kg/1000kg (lb/1000lb)
MC	19.2 (42.2)	5.0	3.2	24.7
BS	23.1 (50.9)	0.8	2.5	11.6
CC	49.9 (110)	4.9	4.1	36.4
BB	81.0 (178.5)	0.7	1.3	8.0
	Average	2.9	2.8	20
	Average Plus 50 Percent	4.3	4.2	30

TABLE 32

PERFORMANCE OF EFFLUENT TREATMENT SYSTEMS
SUBCATEGORY 7: Stock and Yarn Dyeing

Plant Code	Production 1000kg/day (1000lb/day)	BOD Discharge kg/1000kg (lb/1000lb)	TSS Discharge kg/1000kg (lb/1000lb)	COD Discharge kg/1000kg (lb/1000lb)
EE	15.9 (35)	2.4	3.5	-
GG	9.1 (20)	3.6	12.3	-
II	44.0 (96.5)	1.1	2.6	-
	Average	2.4	6.1	31 (1)
	Average Plus 50 Percent	3.5	9.2	47

(1) COD = 13 (BOD)

Stock and Yarn Dyeing and Finishing

The effluent guidelines for July 1, 1977, for subcategory 7 (stock and yarn) are the average of data from exemplary biological systems treating wastes from dyeing and finishing stock and yarn. The BOD5 and TSS effluent limitations are based on the average BOD5 and TSS discharges listed in Table 32 for biological treatment systems at Mills EE, GG and NS. The effluent guidelines for subcategory 7 are as follows: BOD5 limitations is 3.5 kg/kkg (lb/1000 lb) and TSS limitation is 9.2 kg/kkg effluent data in wich COD averaged 13 times the BOD5;. The COD effluent guidelines is 47 kg/kkg (lb/1000 lb).

Effluent limitations also include control of pH within the range of 6.0-9.0 and control of fecal coliforms to allow no more than 400 per 100 ml of discharge.

COD limitations for subcategories 4,5,6, and 7 are applicable only to plants with capacities greater than 1000 kg/day (2,200 lb/day), 3,450 kg/day (7,590 lb/day), 3,450 kg/day (7,590 lb/day) and 3,100 kg/day (6,820 lb/day) respectively. As discussed in Sections V and VIII severe diseconomies of scale create economic impacts which require different limitations for small plants.

RATIONALE FOR THE SELECTION OF BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE

Age and Size of Equipment and Facility

The industry has generally modernized its plants as new methods that are economically attractive have been introduced. No relationship between age of production plant and effectiveness of its pollution control was found. Size was shown in Section IV to require separate limitations for small facilities because of severe diseconomies of scale. Differences in effluent limitations have resulted.

Total Cost of Application in Relation to Effluent Reduction Benefits

Based on information contained in Section VIII of this report, the estimated increase in final product costs required to achieve the best practicable effluent reductions range from small and large plants in the seven subcategories from 0.1 cents per kilogram product (0.2 cents per pound product) to a high of 0.8 cents per kilogram (1.8 cents per pound). The average price increase is less than 0.4 cents per kilogram (0.9 cents per pound).

Engineering Aspects of Control Technique Applications

The specified level of technology is practicable because it is being practiced by plants representing a wide range of plant sizes and types. Eighteen exemplary biological treatment systems have been utilized to develop the effluent limitations (see Table 27). These systems treat textile waste waters from knit fabric finishing, dyeing and finishing of broadwoven cotton and cotton-synthetic blends, carpet manufacturing, and stock and yarn dyeing and finishing. The average BOD_5 removal efficiency of these systems is greater than 95 percent, this efficiency has been utilized to develop limitations in subcategories without exemplary treatment operations. In the subcategories there are treatment systems that should be capable of meeting those limitations with some modification in operation, perhaps the presence of a knowledgeable operator. In general, some minor plant design changes along with cooperation from management and plant personnel will be required.

Process Changes

Significant in-plant changes will not be needed by textile plants to meet the specified effluent limitations. Some plants may need to improve their water conservation practices and housekeeping, both responsive to good plant mangement control.

Non-Water Quality Environmental Impact

The major impact when the option of a biological treatment process is used to achieve the limits will be the problem of sludge disposal. Nearby land for sludge disposal may be necessary. Properly operated biological systems would permit well conditioned sludge to be placed in small nearby soil plots for drying without great difficulty.

It is concluded that no new kinds of impacts will be introduced by application of the best current technology.

Factors to be Considered in Applying Level I Guidelines

1. Limitations are based on 30 day averages. Based on performances of biological waste treatment systems, the maximum daily limitations for BOD_5,TSS,COD and oils and grease should not exceed the 30 day average limitations by more than 100 percent. The maximum 30 day and daily limitations for pH and fecal coliforms are identical.

2. If a plant produced materials in more than one subcategory, for instance wool and synthetics, the effluent limitations should be set by proration on the basis of the percentage of fiber being processed to a product.

SECTION X

EFFLUENT REDUCTION ATTAINABLE THROUGH THE APPLICATION OF THE BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE EFFLUENT LIMITATIONS GUIDELINES

INTRODUCTION

The effluent limitations which must be achieved no later than July 1, 1983, are not based on an average of the best performance within an industrial category, but are determined by identifying the very best control and treatment technology employed by a specific point source within the industrial category and subcategory, or by one industry where it is readily transferable to another. A specific finding must be made as to the availability of control measures and practices to eliminate the discharge of pollutants, taking into account the cost of such elimination.

Consideration must also be given to:

The age of the equipment and facilities involved;

The process employed;

The engineering aspects of the application of various types of control techniques;

Process changes;

The cost of achieving the effluent reduction resulting from application of the technology;

Non-water quality environmental impact (including energy requirements).

Also, Best Available Technology Economically Achievable emphasizes in-process controls as well as control or additional treatment techniques employed at the end of the production process.

This level of technology considers those plant processes and control technologies which, at the pilot plant, semi-works, and other levels, have demonstrated both technological performances and economic viability at a level sufficient to reasonably justify investing in such facilities. It is the highest degree of control technology that has been achieved or has been demonstrated to be capable of being designed for plant scale operation up to and including "no discharge" of pollutants. Although economic factors are considered in this development, of current technology, subject to limitations imposed by economic and engineering feasibility.

EFFLUENT REDUCTION ATTAINABLE THROUGH APPLICATION OF THE BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE

Based on the information contained in Section III through VIII of this report, a determination has been made that the quality of effluent attainable through the application of the Best Available Technology Economically Achievable is as listed in Table 33. The technology to achieve these goals is generally available, although the advanced treatment techniques may not have yet been applied at full scale to plants within each subcategory.

IDENTIFICATION OF THE BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE

Best available control technology economically achievable for the textile manufacturing industry includes the preliminary screening, primary settling (wool scouring only), coagulation (carpet mills only), secondary biological treatment and chlorination listed under the Best Practicable Control Technology Currently Available. In addition, it includes advanced treatment techniques such as multi-media filtration and/or activated carbon adsorption following biological treatment.

Management controls over housekeeping and water use practices will be stricter than required for 1977. However, no additional in-plant controls will be required to achieve the specified levels of effluent reduction. There are several in-plant controls and modifications that provide alternatives and trade-offs to additional effluent treatment. For example, a scouring bowl train designed for complete counter-current operation can significantly reduce water usage at wool scouring facilities.

The stated guidelines for July 1, 1983, for small plants in six subcategories (wool scouring, wool finishing, woven fabric finishing, knit fabric finishing carpet Mills and stock and yarn dyeing and finishing) and both small and large plants in subcategory 3 (greige goods) can be achieved by adding a multi-media filtration system to the best practicable control technology. This advanced technology can insure that operational variability is minimized. The recommended effluent limitations are based on the effluent reduction attainable with the best practicable control technology without an allowance for operational variability.

TABLE 33

MAXIMUM THIRTY DAY AVERAGE
RECOMMENDED EFFLUENT LIMITATION
GUIDELINES FOR JULY 1, 1983

Plant Subcategory	Effluent Limitations (1) BOD5 kg/1000kg (lb/1000lb)	TSS kg/1000kg (lb/1000lb)	COD kg/1000kg (lb/1000lb)
1. WOOL SCOURING (2)			
Plant capacity less than 6,500 kg/day (14,300 lb/day)	2.5	2.5	NA
Plant capacity greater than 6,500 kg/day (14,300 lb/day)	2.5	2.5	64
2. WOOL FINISHING			
Plant capacity less than 900 kg/day (1,980 lb/day)	5.0	5.0	NA
Plant capacity greater than 900 kg/day (1,980 lb/day)	5.0	5.0	14.9
3. GREIGE MILLS			
All plant sizes	0.3	0.3	NA
4. WOVEN FABRIC FINISHING			
Plant capacity less than 1,000 kg/day (2,200 lb/day)	1.5	4.6	NA
Plant capacity greater than 1,000 kg/day (2,200 lb/day)	1.5	4.6	8.8
5. KNIT FABRIC FINISHINC			
Plant capacity less than 3,450 kg/day (7,590 lb/day)	1.2	5.3	NA
Plant capacity greater than 3,450 kg/day (7,590 lb/day)	1.2	5.3	6.4
6. CARPET MILLS			
Plant capacity less than 3,450 kg/day (7,590 lb/day)	2.9	2.9	NA
Plant capacity greater than 3,450 kg/day (7,590 lb/day)	2.9	2.9	8.0
7. STOCK AND YARN DYEING AND FINISH-ING			
Plant capacity less than 3,100 kg/day (6,820 lb/day)	2.3	6.1	NA
Plant capacity greater than 3,100 kg/day (6,820 lb/day)	2.3	6.1	12.5

NA MEANS NOT APPLICABLE

(1) Plant capacities and discharge limitations are stated for Subcategories 1 and 2 per weight of raw wool received at the wool scouring or wool finishing operation and are stated for Subcategories 3, 4, 5, 6 and 7 per weight of final material produced by the facility.

For all subcategories pH should range between 6.0 to 9.0 at any time.

For all subcategories Most Probable Number (MPN) of Fecal Coliforms should not exceed 400 counts per 100 ml.

(2) For all Wool Scouring plants (Subcategory 1) Oils and Grease should not exceed 1.9 kg (lb)/1000 kg (lb) grease wool.

The guidelines for large plants in six subcategories (wool scouring, wool finishing, woven fabric finishing, knit fabric finishing, carpet Mills and stock and yarn dyeing and finishing) can be achieved by adding an activated carbon adsorption system to the best practicable control technology. This advanced technology has been shown to effectively (greater than 90 percent) remove COD from textile wastes. In some plants where large quantities of dispersed dyes or materials with poor adsorptive capacity are discharged, a multi-media filtration system may also be needed. The recommended effluent limitations are based on the best effluent reduction attainable with the best practicable control technology and include an additional reduction on the order of 60 percent of the remaining COD.

RATIONALE FOR THE SELECTION OF BEST AVAILABLE CONTROL TECHNOLOGY ECONOMICALLY ACHIEVABLE

Age and Size of Equipment and Facilities

The industry has generally modernized its plants as new methods that are economically attractive had been introduced. No relationship between age of production plant and effectiveness of its pollution control was found. Size was shown in Section IV to require separate limitations for small plants because of severe diseconomies of scale. Significant differences in effluent limitations have resulted.

Total Cost of Application in Relation to Effluent Reduction Benefits

Based on information contained in Section VIII of this report, the estimated increase in final product costs required to achieve the best available effluent reductions range from 0.05 to 0.4 cents per kilogram (0.1 to 0.8 cents per pound) product processed by all plants in subcategory 3 and by small plants in subcategories 1, 2, 4, 5, 6, and 7 with capacities less than 6,500 kg/day (14,300 lb/day), 900 kg/day (1,980 lb/day), 1,000 kg/day (2,250 lb/day), 3,450 kg/day (7,590 lb/day), 3,450 kg/day (7,590 lb/day), and 3,100 kg/day (6,820 lb/day) respectively. For larger plants in the industry, the price increases ranged from 0.4 cents per kilogram (0.8 cents per pound) to a high of 2.0 cents per kilogram (4.5 cents per pound). The estimated costs required to achieve best practicable and best available effluent reductions range between 0.3 and 1.1 cents per kilogram (0.6 and 2.5 cents per pound) product from small plants and 0.5 to 2.5 cents per kilogram (1.0 and 5.4 cents per pound) product from larger plants.

Engineering Aspects of Control Technique Application

The specified level of technology is achievable. Biological treatment is practiced throughout the textile industry and activated carbon adsorbtion is practiced at four textile plants. The use of activated carbon to treat textile wastes was pioneered at a Pennsylvania carpet mill and at least one synthetic knit goods plant (mill HH) is installing activated carbon.

Multi-media filtration has been used effectively in various EPA applications including Lebanon, Ohio, and Washington, D.C. Filtration is also used as pretreatment before carbon adsorption at a Virginia textile mill.

Process Changes

No in-plant changes will be needed by most plants to meet the limits specified. Some in-plant techniques are available as alternatives to effluent treatment techniques.

Non-Water Quality Environmental Impact

The non-water quality environmental impact will essentially be those described in Section IX. It is concluded that no new serious impacts will be introduced.

Factors to be Considered in Applying Level II Guidelines

1. Limitations are based on 30 day averages. Based on performances of biological waste treatment systems, the maximum daily limitations for BOD_5, TSS, COD and oils and grease should not exceed the 30 day average limitations by more than 100 percent. The maximum 30 day and daily limitations for pH and fecal coliforms are identical.

2. If a plant produced materials in more than one subcategory for instance wool and synthetics, the effluent limitations should be set by proration on the basis of the percentage of fiber being processed to a product.

SECTION XI

NEW SOURCE PERFORMANCE STANDARDS

INTRODUCTION

The effluent limitations that must be achieved by new sources are termed performance standards. The New Source Performance Standards apply to any source for which construction starts after the publication of the proposed regulations for the Standards. The Standards are determined by adding to the consideration underlying the identification of the Best Practicable Control Technology Currently Available, a determination of what higher levels of pollution control are available through the use of improved production processes and/or treatment techniques. Thus, in addition to considering the best in-plant and end-of-process control technology, New Source Performance Standards are based on an analysis of the process itself. Alternative processes, operating methods or other alternatives are considered. However, the end result of the analysis is to identify effluent standards which reflect levels of control achievable through the use of improved production processes (as well as control technology), rather than prescribing a particular type of process or technology which must be employed. A further determination made is whether a standard permitting no discharge of pollutants is practicable.

Consideration must also be given to:

Operating methods;

Batch, as opposed to continuous, operations;

Use of alternative raw materials and mixes of raw materials;

Use of dry rather than wet processes (including substitution of recoverable solvents for water);

Recovery of pollutants as by-products.

EFFLUENT REDUCTION ATTAINABLE FOR NEW SOURCES

The effluent limitation guidelines for new sources are identical to those for the Best Available Control Technology Economically Achievable (See Section X). This limitation is achievable in newly constructed plants. In-plant controls and waste treatment technology identified in Section X are available now and applicable to new plants.

The new source technology is the same as that identified in Section X: preliminary screening, primary settling (wool scouring only), coagulation (carpet mills only), biological treatment and multi-media filtration and/or activated carbon adsorption. The conclusion reached in Section X with respect to Total Cost of Application in Relation to Effluent Reduction Benefits, the Engineering Aspects of Control Technique Application, Process Changes, Non-Water Quality Environmental Impact and Factors to be Considered in Applying Level II Guidelines, apply with equal force to those New Performance Standards.

PRETREATMENT REQUIREMENTS

Three constituents of the waste water from plants within the textile industry have been found which would interfere with, pass through, or otherwise be incompatible with a well designed and operated publicly owned activated sludge or trickling filter waste water treatment plant. Waste water constituents include grease from wool scouring operations, latex from carpet mills and heavy metals such as chromium used in dyes. Adequate control methods can and should be used to keep significant quantities of these materials out of the waste water. Dye substitutes are available for many dyes containing heavy metals.

SECTION XII

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Special acknowledgment is made of the contributions of industry personnel who provided information to the study. Their active response, cooperation and assistance is greatly appreciated.

SECTION XIII

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.

(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 Wastewate
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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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 rcller 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. As 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 cn 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 cellulcse. 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.

METRIC UNITS

CONVERSION TABLE

MULTIPLY (ENGLISH UNITS) by TO OBTAIN (METRIC UNITS)

ENGLISH UNIT	ABBREVIATION	CONVERSION	ABBREVIATION	METRIC UNIT
acre	ac	0.405	ha	hectares
acre - feet	ac ft	1233.5	cu m	cubic meters
British Thermal Unit	BTU	0.252	kg cal	kilogram - calories
British Thermal Unit/pound	BTU/lb	0.555	kg cal/kg	kilogram calories/kilogram
cubic feet/minute	cfm	0.028	cu m/min	cubic meters/minute
cubic feet/second	cfs	1.7	cu m/min	cubic meters/minute
cubic feet	cu ft	0.028	cu m	cubic meters
cubic feet	cu ft	28.32	l	liters
cubic inches	cu in	16.39	cu cm	cubic centimeters
degree Fahrenheit	F°	0.555(°F-32)*	°C	degree Centigrade
feet	ft	0.3048	m	meters
gallon	gal	3.785	l	liters
gallon/minute	gpm	0.0631	l/sec	liters/second
horsepower	hp	0.7457	kw	killowatts
inches	in	2.54	cm	centimeters
inches of mercury	in Hg	0.03342	atm	atmospheres
pounds	lb	0.454	kg	kilograms
million gallons/day	mgd	3,785	cu m/day	cubic meters/day
mile	mi	1.609	km	kilometer
pound/square inch (gauge)	psig	(0.06805 psig +1)*	atm	atmospheres (absolute)
square feet	sq ft	0.0929	sq m	square meters
square inches	sq in	6.452	sq cm	square centimeters
tons (short)	t	0.907	kkg	metric tons (1000 kilograms)
yard	y	0.9144	m	meters

* Actual conversion, not a multiplier