Water Requirements of the Rayon- and Acetate-Fiber Industry

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1330-D

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By ORVILLE D. MUSSEY

WATER REQUIREMENTS OF SELECTED INDUSTRIES

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A study of the manufacturing processes with emphasis on present water use and future water requirements

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PREFACE

This report is one of a series describing the water requirements of selected industries that are of national importance. It was prepared at the request of and in consultation with the Water and Sewerage Industry and Utilities Division, Business and Defense Services Administration, Department of Commerce, and is designed to serve the dual purpose of providing basic information for national defense planning and at the same time of providing assistance to business and industry.

Special acknowledgment is given to the many officials of the companies manufacturing rayon and acetate fiber who supplied information concerning the water used at their plants.

The author is indebted to Ernest H. Sieveka, chemical engineer of the Geological Survey, who planned the scope of the reports on the use of water in industry and has guided and aided the author during the study of the water requirements of the rayon- and acetate-fiber industry.

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WATER REQUIREMENTS OF THE RAYON- AND ACETATE-FIBER INDUSTRY

By Orville D. Mussey

ABSTRACT

Water is required for several purposes in the manufacture of rayon and acetate fiber. These water requirements, as indicated by a survey of the water used by the plants operating in 1953, are both quantitative and qualitative.

About 300 mgd (million gallons per day) of water was used in 1953 in the preparation of purified wood cellulose and cotton linters, the basic material from which the rayon and acetate fiber is made. An additional 620 mgd was used in the process of converting the cellulose to rayon and acetate fiber. The total, 920 mgd, is about 1 percent of the total estimated withdrawals of industrial water in the United States in 1953.

The rayon- and acetate-fiber plants are scattered through eastern United States and generally are located in small towns or rural areas where there are abundant supplies of clean, soft water. Water use at a typical rayon-fiber plant was about 9 mgd, and at a typical acetate-fiber plant about 38 mgd.

About 110 gallons of water was used to produce a pound of rayon fiber—32 gallons per pound was process water and the remainder was used largely for cooling in connection with power production and air conditioning. For the manufacture of a pound of acetate fiber about 170 gallons of water was used. However, the field survey on which this report is based indicated a wide range in the amount of water used per pound of product. For example, in the manufacture of viscose rayon, the maximum unit water use was 8 times the minimum unit water use. Water use in summer was about 22 percent greater than average annual use. About 8 mgd of water was consumed by evaporation in the manufacture of rayon and acetate fiber.

More than 90 percent of the water used by the rayon and acetate industry was withdrawn from surface-water sources, about 8 percent from ground water, and less than 2 percent from municipal water supplies.

All available analyses of the untreated waters used by the rayon and acetate industry were collected and studied. The untreated waters were generally cool, low in content of calcium and magnesium, and very low in iron and manganese. At many plants, water was obtained from more than one source, and thus had different quality characteristics. Dissolved solids in all the untreated waters analyzed ranged between 14 and 747 ppm (parts per million) but in those waters used in processing the dissolved solids content was less than 200 ppm.

The cooling water used by the industry is also generally of very high quality, principally because the requirements for a high-quality process water necessitate location of the plants in areas where such water is available.

INTRODUCTION

PURPOSE AND SCOPE

The results of a survey of the quantitative and qualitative water requirements of the rayon- and acetate-fiber manufacturers are presented in this report. Such information will aid in planning the location of new plants using large amounts of industrial water for the production of either rayon or acetate fiber or of other material.

The literature was carefully studied to gather as much information as possible about the use of water in rayon- and acetate-fiber manufacture, particularly how much and what kind of water was required for economical operation. Plants that prepared the special purified wood cellulose and cotton linters used as a raw material in cellulosic-fiber manufacture also are included in this study.

A field survey of the rayon- and acetate-fiber plants was made to determine the amount and quality of the water used at each plant, the way the water was used, the amount of water that was reused, and the total consumptive water use. Similar information for two cellophane plants was obtained because it was found that water requirements for the manufacture of viscose-rayon fiber and the manufacture of cellophane were nearly identical. The information obtained included source or sources of supply, adequacy of the supply, temperature of the water, treatment given the water, and particularly any unusual practices in water use and the reasons for such practices. The source of water used for cooling, washing, process, boiler feed, sanitary, and chemical recovery was also sought. The type of raw material used and the amount and kind of fiber produced at each plant were ascertained to determine the relation to water use. All water used at the plants was part of the ordinary operation of cellulosic-fiber plants and thus was considered a part of the plant use.

Any estimate of the future water requirements of these industries would normally be based on an estimate of the future production of rayon and acetate fiber. Therefore, a brief history of the growth of the industries has been included to explain past changes in production rates and assist in estimating the future rates of production.

HISTORY

Nearly 300 years ago Robert Hooke envisioned the possibilities of creating artificial silk by chemical means. It seemed possible to him that, if a silkworm could spew out a fiber produced from a diet of mulberry leaves, man could discover how to make similar fibers from vegetable matter. However, it was not until 1884 that the nitrocellulose process for making artificial silk was patented. The viscose process was patented in 1892 and the acetate process in the following year. The first cuprammonium yarn was made commercially in Germany in 1898.

The early history of the manufacture of artificial silk is one of bankruptcies and reorganizations of companies that did not exist long enough to solve the problem of economically producing and selling a product that could compete with natural fibers. The first artificial silk was coarse and harsh and only the lustrous sheen of real silk was attained. The fibers produced by the cuprammonium process were the only ones that had what William Haynes (1953) described as "the sensuous feel and the soft, clinging drape of silk," but these fibers were physically weak; machines designed for use with silk or cotton could handle the knitting and weaving of cuprammonium fibers only by slowing down their operation. The cuprammonium fibers remained weak until a process for strengthening the filaments by stretching them was adopted in 1919. Gradually the producers of viscose and acetate fiber learned to make finer and stronger fibers, until these artificial-silk fibers rivaled natural silk.

No commercially successful artificial silk plants had been established in America before 1910, but in that year the English firm of Courtaulds constructed at Marcus Hook, Pa., the first plant of what was to become the American Viscose Corporation. The success of this enterprise resulted from the acquirement of the American rights to a group of patents that previously were held by competitive companies. From 1910 to 1920 production was doubled and redoubled and new plants were built, but the supply lagged behind demand. After 1920, when the patents expired, many other companies established plants in the United States until, in 1923, this country was producing one-third of the world's artificial silk, twice as much as any other country.

In 1924 the entire product of this industry was renamed rayon. The 15 years following the adoption of the new name showed a rapid increase in production in the United States, but the world picture so changed that by 1939 the United States was producing only one-sixth of the world supply; Germany, Italy, and Japan were producing nearly two-thirds of the supply; and the rest of the world was producing the remaining one-sixth. During this period many changes took place in the American industry. One of the most significant changes occurred in 1938 when the first continuous-process rayon plant was placed in commercial operation, and established new standards of uniform quality for the entire industry.

Cellulose acetate was only about 3 percent of the total rayon and acetate production for 1925, but by 1940 nearly one-third of the production was acetate. As early as 1934 high-tenacity rayon filaments suitable for automobile tires, belting, and other heavy duty fabrics were introduced and replaced, for the most part, the costly long-fiber cottons that had been used previously.

Rayon and acetate staple fiber (filament cut into short lengths for thread and textile manufacture by the same methods used for cotton and wool) and tow (a rope of parallel filaments from which such staple can be readily produced) now (1953) constitute about a quarter of our total cellulosic-fiber production.

DEFINITIONS OF RAYON AND ACETATE

The literature dealing with manmade fibers of cellulosic origin is somewhat confusing because of the changes in nomenclature of the product. For many years before 1924 such fibers were generally described as artificial silk. In 1924, the Federal Trade Commission ruled that any fiber of cellulosic origin should be called rayon in marketing and advertising. Later, however, the Federal Trade Commission (1951) defined rayon as "manmade textile fibers and filaments composed of regenerated cellulose, and yarn, thread, or textile fabric made of such fibers and filaments." At the same time it defined acetate as "manmade textile fibers and filaments composed of cellulose acetate, and yarn, thread, or textile fabric made of such fibers and filaments."

PROPERTIES OF RAYON AND ACETATE FIBERS

Viscose and cuprammonium rayons are somewhat alike, but acetate differs from the others in several respects. Cuprammonium rayon generally is composed of filaments of smaller diameter than viscose rayon and usually is woven into a sheer fabric called bemberg. Acetate fabrics have a suppleness that results in a more pleasing drape and a finer "feel" than rayon fabrics made from yarn of the same denier. The denier is a measure of the size of filaments or yarn; it is the weight in grams of 9,000 meters of filament or yarn—the finer the yarn the smaller the denier.

Rayon may be dyed using selected dyes that have an affinity for cotton, but special acetate dyes generally are used for acetate fibers. Acetate blends well with other synthetic and natural fibers; this permits some interesting color effects as the fibers may be affected differently by a single dyeing process. Acetate is thermoplastic and may be pleated permanently or given a moire effect by the use of heat.

The regular grade of viscose rayon is not quite as strong as cuprammonium rayon but is stronger than the regular grade of acetate. Saponified acetate fiber (cellulose acetate fiber which has been chemically transformed into cellulose) is stronger than high-tenacity viscose fiber.

The different properties of the various kinds of cellulosic fibers have strongly affected the trends in their production.

MANUFACTURING PROCESSES

The brief descriptions of the manufacturing processes that follow are based on reports by Mauersberger (1952) and Shreve (1945) and on information obtained from visits to the rayon and acetate plants. Only enough process description is presented to enable the reader to understand where water enters into the processes and the water quality requirements for the different uses.

Although the manufacturers of rayon and acetate were quite willing to discuss the use of water in a general way, details of the flow of water through the plants were not available. Large amounts of water are used for washing and process but most of the water is used for power production, temperature control of process, factory air conditioning, and chemical recovery.

PURIFIED WOOD CELLULOSE

Purified wood cellulose (high in alpha-cellulose content) is made by methods similar to those used in producing wood pulp for paper manufacture (Mussey, 1955, p. 7–15). The basic difference is that considerable effort is made to separate a large part of the beta and gamma cellulose (low molecular weight) from the alpha cellulose (high molecular weight). The alpha-cellulose derivatives dissolve to form solutions suitable for rayon and acetate manufacture. Purified wood cellulose is produced from wood chips that are first treated with acid and then with caustic soda or other strong alkalis.

In the sulfite process, a mixture of sulfurous acid and calcium and magnesium bisulfite breaks down the lignins into a soluble product of lignin and sulfuric acid and partially hydrolyzes the beta and gamma cellulose to sugar. The beta and gamma cellulose are removed later with caustic soda. Knots, bark fragments, and pieces of unpulped chips are removed by screening. This is followed by bleaching (with chlorine or hypochlorite) and purification.

The cellulose is thoroughly washed using multistage, countercurrent backwashing at each stage of the process, for which large quantities of pure water are needed. As the wood cellulose acts as a filter and removes many of the substances in suspension in the water, the wash water should be almost entirely free of suspended matter and salts of such metals as copper, iron, and manganese.

Some purified wood cellulose is prepared by a modified sulfate process in which the wood chips are treated with dilute sulfuric acid followed by the conventional sulfate process which involves cooking in a liquor containing sodium sulfide and caustic soda. The cooking is followed by washing, screening, and bleaching similar to that followed in the sulfite process.

After bleaching and purification, the fibers are formed on a Fourdrinier papermaking machine into sheets that resemble blotting paper. These sheets are then shipped either in bales of flat sheets or in rolls to the rayon- and acetate-fiber plants.

PURIFIED COTTON LINTERS

Cotton linters are the very short cellulose fibers that cling to the cotton seed after the ginning process. These short fibers are cut from the seeds in preparing them for the oil press. Natural impurities and foreign matter are removed from the fibers by cooking in dilute caustic soda in steel digesters under steam pressure. The linters are then washed and bleached with chlorine in multiple stages with close control of pH, temperature, and time. Enormous amounts of high-quality water must be used for washing after each stage of bleaching. Cotton linters, like wood cellulose, act as a filter and will retain any impurities in the wash water. Such impurities may make the product unusable. Processed chemical cotton may be either dried and baled or processed, by the use of standard papermaking machinery, into sheets that resemble blotting paper.

VISCOSE RAYON

Sheets of purified wood cellulose (or cotton linters) are placed in steeping presses where they are soaked 2–4 hours in an 18 percent caustic soda solution at controlled temperatures. Much of the remaining beta and gamma cellulose goes into solution in the caustic, and the alpha cellulose is converted to alkali cellulose. The caustic soda solution containing nearly all of the dissolved beta and gamma cellulose is pressed from the cellulose sheets and sent to chemical recovery.

Sheets of alkali cellulose are reduced to small crumbs in a water-jacketed shredder at carefully controlled temperatures. The crumbs are aged for variable periods also at very definite temperatures; this results in a change in the molecular structure. After the aging is completed, the crumbs are placed in a barratte, which is a hexagonal horizontal iron-drum mixer. One pound of carbon disulfide is added for each 10 pounds of crumbs. In 2 or 3 hours the alkali cellulose is converted to cellulose xanthate. The excess carbon disulfide is exhausted, and the cellulose xanthate is dissolved in a dilute solution of caustic soda in a water-jacketed mixer.

Several batches are blended, and the blend is aged or ripened until it is about ready to coagulate. The temperature is very carefully controlled. When the viscosity is suitable, the solution is filtered, and the filtrate is placed under vacuum for 24 hours. The viscose solution is then pumped to the spinning machine where it is filtered again and extruded through minute holes in a spinneret into an acid bath where it coagulates to form filaments of regenerated cellulose.

The bath consists of warm water that contains 8–12 percent sulfuric acid, $13\frac{1}{4}$–20 percent sodium sulfate, 1 percent zinc sulfate or magnesium sulfate, and 4–10 percent glucose. The quality of the bath is kept uniform by continuous circulation to a large supply tank. Because the bath loses acid and gains water and sodium sulfate, sulfuric acid is added to the bath, and from time to time withdrawals of liquid from the solution are made to a lead-lined evaporator where the excess water is removed by evaporation and the concentrated solution is cooled. This causes the excess sodium sulfate to settle out as Glauber salt, and the remaining liquid is returned to the spinning bath.

Three different systems are used for processing the thread after it leaves the spinning bath.

(1) Most rayon is produced by passing the gathered filaments into the center of the top of a bucket revolving at 6,000–10,000 revolutions per minute. The coils of rayon threads collected in the bucket are called cakes. Considerable water is used in completing the treatment of the cakes. A warm alkaline-water rinse is used first to deacidify the filaments; next a dilute sodium sulfide wash is used to remove the yellow color that results from the residual sulfur; and then the cakes receive a thorough warm-water rinse which is followed by a cold-water rinse. If it is desired to bleach the thread completely it is next subjected to a weak solution of sodium hypochlorite followed by a bath of dilute hydrochloric or sulfuric acid which stops the bleaching action, after which another thorough rinse in warm water is followed by a cold-water rinse. The final bath is an emulsion of water and oil or soap which improves the softness and pliability of the yarn. The cakes are then slowly dried 60–72 hours at temperatures of 160°–180°F allowing the cakes to shrink sufficiently to relieve tensions in the yarn. The whole process from spinning to cured cake takes about 90 hours.

(2) In a system using bobbins the filaments are wound, without twisting, on a perforated core. The wound bobbins are removed from the machine, deacified, desulfured, and rinsed in a bobbin-washing machine as were the cakes.

(3) A continuous system of viscose manufacture has been developed which permits production of a yarn of more uniform quality than can be manufactured by processing the rayon in cakes or spools. One method involves a series of thread-advancing reels offset horizontally and vertically like stairs. On each reel the thread receives a special chemical or washing treatment, each step representing one of the series of treatments described in the first, or bucket, system. Thread is dried on the last reel or reels, twisted by passage over cap twisters, and wound on bobbins holding several pounds of dry yarn. The entire process from spinning bath to bobbin requires about 6 minutes. Several other methods for continuous production by the viscose process also have been developed.

All the buildings (even ones used for packaging) are usually air conditioned, with control over both temperature and humidity. This extensive air conditioning was found desirable to facilitate the operation of the yarn-handling machinery. Large amounts of cooling water are used in air conditioning and also in maintaining desirable temperatures within narrow limits at some points in the process.

CUPRAMMONIUM RAYON

Cuprammonium rayon is manufactured by first dissolving cotton linters or purified wood pulp in Schweitzer's reagent, which is an ammoniacal solution of copper hydroxide. After passing through filters this spinning solution is pumped from the spinnerets into spinning funnels through which deaerated water is flowing. This water removes about a third of the copper and most of the ammonia causing a mild coagulation of the cellulose. During spinning, the fibers are stretched until they have a cross section that is only about one five-thousandth of the area of the spinneret holes.

The thread then is passed into a bath of dilute sulfuric acid which completes the hardening of the threads by converting the remaining ammonia to ammonium sulfate and the remaining copper to copper sulfate. The untwisted thread is wound on reels to form skeins that are laced to prevent tangling during washing. Copper sulfate, ammonium sulfate, and excess acid are washed out, and lubricants are introduced to soften the threads; and then the skeins are dried. A second bath contains an emulsion of soap and oil to further soften the thread and may contain tints for temporarily coloring the material for identification. After a second drying, the skeins are packaged to suit the customer.

ACETATE

Purified cellulose is selected from several different batches to help in maintaining uniform quality in the final product. Most, but not all, of the moisture normally present in the cellulose is first removed in a tunnel dryer at low temperatures.

The cellulose is dissolved in a mixing tank called an acetylator, which is equipped with a stirring device and is jacketed for control of temperature by a liquid medium that has a range from 20° to 120°F. The cellulose is introduced slowly into a mixture of glacial acetic acid mixed with a small amount of sulfuric acid. During this time the mix is agitated, and the temperature is kept below 45°F. Acetic anhydride, with sufficient sulfuric acid to act as a catalyst, is added; the temperature is kept below 68°F during the first hour and then raised to 86°F. After several hours the acetylation is complete, and a heavy viscous clear solution results. Exact time, temperature, and catalyst control are important factors in producing a desirable end product. The output of the acetylator is cellulose triacetate which is soluble only in costly solvents and is too impervious to moisture and dyes. Therefore, cellulose triacetate is converted to diacetate, which is soluble in acetone.

This conversion is accomplished by placing the cellulose triacetate into an aging tank where water and acetic acid are added and the temperature is maintained at higher levels than in the acetylator. Hydrolysis of the cellulose triacetate occurs and acetic acid is liberated. When samples indicate the desired acetyl content has been reached, the secondary acetate in the aging tank is precipitated in the form of flakes by discharging it into a large volume of water. The flakes are washed several times by decanting, centrifuging, and rewashing, after which they are dried in a centrifuge and a steam drier.

A spinning solution is prepared by dissolving flakes from different batches in acetone and a small amount of water. After repeated filtering and deaerating, the spinning solution is ready for the spinning machine.

Acetate fibers are produced by discharging the spinning fluid through a spinneret into a cabinet through which air at about 134°F is passing. This air, which is slightly above the boiling point of acetone, removes the acetone by evaporation. At the end of the cabinet the filaments are gathered together, lubricated, and wound in a suitable package.

A very strong saponified acetate, which has very important military and industrial uses, may be produced by saponification with caustic soda or other alkalis while the material is under high tension. Saponified acetate fiber may be dyed with viscose-rayon dyes. A partially saponified acetate that takes on some of the properties of both acetate and rayon is generally used as staple fiber. Both of these processes require additional water for process and subsequent washing.

WASTES

RAYON

In viscose-rayon manufacture, four different types of waste from the plants are emptied into sewers: (1) sanitary sewage; (2) wastes from that part of the plant where the viscose syrup is produced—these wastes are strongly alkaline on the pH scale; (3) wastes that result from regeneration of the viscose, including the first washing of the regenerated fiber—these wastes are strongly acid; and (4) acid wastes from final treatment of the rayon fibers. Each of these wastes generally is kept separate to facilitate treatment.

At their Front Royal, Va., plant (Roetman, 1944), the American Viscose Corporation treats the sanitary sewage in Imhoff tanks and trickling filters. The effluent from this process is mixed with the effluent from a biochemical treatment of the sodium sulfide wastes from desulfuring the fiber in the aftertreatment. The alkaline wastes from the production of viscose solution are added to acid wastes from the spinning and aftertreatment departments, and the combined waste, which is always acid, is neutralized by the addition of a lime slurry. Wastes from the biochemical treatments are added, after which the mixture of all the liquid wastes passes to a settling and retention basin where the suspended matter settles out and the effluent is returned to the South Fork Shenandoah River.

Very little information could be found regarding cuprammonium-rayon waste, but one authority (Besselievre, 1952) indicates that cuprammonium-rayon waste has a biochemical oxygen demand of only about 4 percent of that of viscose-rayon waste per pound of end product. Cuprammonium-rayon waste appears to be a very minor problem, although American Bemberg, only cuprammonium-rayon manufacturer in the United States, took the lead in Tennessee in equipping its plant with facilities for treatment of industrial wastes (Norman, 1948).

ACETATE

Most of the waste from the manufacture of acetate fiber results from the recovery of dilute acetic acid and the conversion of some of the recovered acetic acid to acetic anhydride (Roznoy, 1954). The waste contains small amounts of acetic acid, acetate, cellulose-acetate fines, sugars resulting from hydrolysis of the cellulose, and appreciable amounts of sulfate. One troublesome feature of this waste is its relatively high biochemical oxygen demand.

In recent laboratory scale tests, the biochemical oxygen demand has been reduced as much as 93 percent by aerobic biologic treatment methods. Testing on a pilot-plant scale is planned, but results are not yet available. However, this would not reduce the sulfate content.

WATER REQUIREMENTS FOR PREPARATION OF RAW MATERIAL

Large amounts of water are used for the manufacture of purified wood cellulose, but the only figure obtained for unit water use was 200,000 gallons per ton of purified wood cellulose at an unidentified pulp mill (Technical Association of the Pulp and Paper Industry, 1942). No figures were obtained as to the quantity of water used for the purification of cotton linters, the other basic raw material, but a comparison of the process used in purifying cotton linters with that used in refining wood cellulose reveals that the unit water use is perhaps about half that for purified wood cellulose.

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An estimated 300 mgd, based on 200,000 gallons per ton of purified wood cellulose and about half that amount per ton of refined cotton linters, was used in 1953 for the preparation of special cellulose for rayon- and acetate-fiber manufacture. This is a water requirement for the plants that refine the purified wood cellulose and cotton linters and not for the rayon- and acetate-fiber plants.

The quality of the water used in manufacturing purified wood cellulose must be quite high; suggested maximum allowable concentrations for several of the ordinary constituents of process water are shown in table 1. If these constituents are present in

Table 1.—*Suggested maximum allowable concentrations of dissolved and suspended constituents in process water used for making purified wood cellulose for viscose-rayon fiber*

[Modified from American Water Works Association, 1950, p. 67]

Constituent	Ppm	Constituent	Ppm
Turbidity	5	Total solids	100
Color (units)	5	Alkalinity as $CaCO_3$	50
Hardness as $CaCO_3$	8	Aluminum oxide (Al_2O_3)	8
Iron and manganese (together)	.05	Silica (SiO_2)	25
Manganese (Mn)	.03	Copper (Cu)	5
Iron (Fe)	.05		

the process water in amounts greater than those suggested, they may cause difficulties of two types: undesirable colors in the finished synthetic fibers may result from three of the constituents—color, iron, and manganese—becoming concentrated in the pulp by being filtered out of the process water; increased ash content of the cellulose, which makes it unsuitable for use as a raw material for rayon and acetate fiber, may occur if all of the constituents shown in table 1 are filtered out of the wash water.

Although no quality requirements were obtained for water for purifying cotton linters, the similarity in processes for purifying them and for manufacturing purified wood cellulose suggests that the specifications for the chemical quality of the water used should be similar to those given in table 1.

QUANTITATIVE WATER REQUIREMENTS

REVIEW OF LITERATURE

The most recent figures compiled by the American Water Works Association (1953, p. 8) indicate that the water used in production of rayon is 45–100 gallons per pound of yarn.

According to H. R. Mauersberger (1952), 1 pound of viscose-rayon yarn requires about 30–60 gallons of water and 1 pound of cellulose-acetate fiber requires about 10 gallons of processing water. This 10 gallons per pound for processing water is consistent with a total water requirement of 1,000 gallons per pound, as nearly all of the water used in manufacturing acetate fiber is used for steam-power production, temperature control of process, factory air conditioning, and chemical recovery.

E. R. Riegel (1949) stated that 100–200 gallons of pure water is required to produce 1 pound of viscose-rayon yarn and about 1,000 gallons is used to produce 1 pound of cellulose acetate.

Two figures for quantity of water used per unit produced are given in Chemical and Metallurgical Engineering (1947). Notes on the flow sheets state that 45–80 gallons of water is used to produce 1 pound of cuprammonium rayon and 90–100 gallons to produce 1 pound of viscose rayon.

The U. S. Tariff Commission (1944, p. 92) stated that rayon manufacture requires large quantities of clean, soft water; about 150–200 gallons to produce 1 pound of viscose rayon and 1,000 gallons to produce 1 pound of acetate.

Only those quantitative water-requirement values that appear reasonable have been quoted in this section; some previously published figures of water use in these industries appear to be grossly in error.

FIELD SURVEYS

UNIT WATER-USE REQUIREMENTS

During the survey of plants conducted in late 1952 and early 1953 (a few plants were visited in 1951), unit water-use figures were obtained; these figures varied considerably. At three of the rayon-fiber plants it was necessary to estimate daily production to compute unit water use because company policy was opposed to release of production figures. During the investigation it was discovered that the water requirements for cellophane production were equivalent to those for viscose-rayon production. Data on unit water requirements obtained for two cellophane plants also were included. One rayon plant supplied the water requirements for a company town in addition to the water required for production. The municipal use was equivalent to 6.5 gallons per pound of rayon fiber produced. This amount for municipal use was subtracted from total water use in computing unit water used for that particular installation.

All of the unit water-use data obtained in the survey of the rayon plants are listed in table 2. The maximum was 240 gallons per pound of rayon fiber, 8 times the minimum; the median was 110 gallons.

At eight of the viscose-rayon plants, data on unit use requirements for process water (called soft water in the industry) were obtained. These process-water requirements (table 2) range from about 10 to about 80 gallons per pound of product. The median use was 32 gallons of process water per pound of viscose-rayon fiber.

Acetate fiber is made at seven plants in the United States. At one plant, acetate fiber is made from cellulose acetate, but at the other plants the raw cellulose material is either purified wood cellulose or cotton linters. Unit water-use values obtained from the six acetate-fiber plants using the complete process are shown in table 2. Unit use ranged from about 40 to nearly 500 gallons

Table 2.—*Gallons of water per pound of product, arranged by product, use, and magnitude*

[Compiled from data obtained at the plants, November 1952–January 1953]

Rayon[1]			Acetate	
Viscose and cuprammonium	Viscose			
Total use	Process use	Consumptive use	Total use	Consumptive use
30	[2]10.6	0.18	41	0.3
42	13.3	.18	[2]112	4.5
[2]50	15.6	.18	[2]140	5.0
[2]60	28.2	.24	209	
73	36.2	.58	360	
74	43.3	.75	494	
84	49.9	.84		
88	82.0	.91		
102		1.06		
[2]106		2.65		
109		2.97		
109		3.27		
[2]110		3.36		
112		3.65		
112		3.72		
114		4.11		
128		10.2		
130		12.0		
132		12.5		
132				
137				
160				
166				
178				
178				
[2]186				
240				

[1]Includes 2 cellophane plants.
[2]Value obtained in 1951.

per pound of acetate produced; the maximum was slightly more than 12 times the minimum and the median was 170 gallons per pound.

Both summer and mean annual water-use values were obtained at 12 rayon- and acetate-fiber plants. Summer use ranged from 2 to 50 percent greater and averaged 22 percent greater than mean annual water use because cooling requirements for air conditioning were greater and the water available for cooling was usually warmer.

Table 3 shows the total water used in the United States for rayon- and acetate-fiber manufacture, by source of water used.

Table 3.—*Source of water used in rayon- and acetate-fiber manufacture in the United States, 1952–53 survey*

Source	Rayon		Acetate	
	Million gallons per day	Percent	Million gallons per day	Percent
Private supply:				
Surface water	257.3	89	299.2	92
Ground water	27.2	9	23.9	7
Municipal supply	6.3	2	2.4	1
Total	290.8	100	325.5	100

Most of the water was derived from surface-water supplies. Although surface water generally requires treatment, this is not particularly disadvantageous because the surface water available at the plant sites selected is generally of good quality, and the treatment methods are inexpensive. An advantage of surface water is its generally low mineral content as compared with ground water in the same locality. Ground water constituted the major source of supply at five plants. It was also used at a few plants for cooling in summer and at one plant the ground water used for this purpose was saline. At this plant sea water was used for cooling in winter.

The median use of water for all purposes at a rayon-fiber plant was 9 mgd and at an acetate-fiber plant was 38 mgd.

CONSUMPTIVE WATER USE

Water is used consumptively in the manufacture of viscose-rayon fiber: by evaporation to maintain humidity in the air-conditioning system; in the operation of cooling towers used in power production and air cooling; and to rejuvenate the spinning solution.

Water losses also result from evaporation of the many water solutions used at the plant and from drying the finished product. Not all the viscose-rayon plants visited in the 1952–53 survey indicated what their consumptive losses were, but the consumptive water use in gallons per pound of product for 19 plants was obtained (see table 2). The median consumptive water use was 1.7 gallons per pound. The largest consumptive water use per pound of fiber was about 70 times the minimum. No relation appears to exist between the total unit water use and the consumptive unit water use at the viscose-rayon plants.

Water loss in the manufacture of cuprammonium-rayon fiber results principally from drying the finished fibers and from evaporation of water solutions used in processing. As there is only one cuprammonium rayon plant operating in the United States, consumptive use of water is not reported.

In producing acetate fiber, water losses result from evaporation to maintain humidity in air conditioning; in the operation of cooling towers used in power production and air cooling; and from evaporation from water solutions used in processing. In addition, water is lost in chemical-recovery processes and in drying the cellulose-acetate flakes. Three of the acetate-fiber plants estimated their consumptive water use at 0.3, 4.5, and 5.0 gallons per pound (table 2). The estimates cover a considerable range; the largest of the three values is about 17 times the smallest. There is no apparent relation between the total water use per pound of acetate fiber and the consumptive water use per pound.

When computed from the unit consumptive water use as determined by the survey, total consumptive water use in the rayon-fiber industry in 1953 was a little more than 4 mgd and in the acetate-fiber industry a little less than 4 mgd. Combined consumptive water use in the two industries was a little less than 8 mgd.

QUALITATIVE WATER REQUIREMENTS

PUBLISHED DATA

PROCESS WATER

Many references in the technical literature indicate that pure, cool water, free from injurious chemicals, is desirable for rayon- and acetate-fiber manufacture. The earliest water-quality specifications that were found were given by Moore (1940) and are presented in table 4. These specifications have been widely quoted.

Table 4.—*Suggested maximum concentrations of dissolved and suspended constituents and range of recommended threshold of process water for the manufacture of viscose-rayon fiber.*

[Data modified from Moore, 1940]

Constituent or property	Limiting values (ppm)
Iron	0.0
Manganese	.0
Total hardness (as $CaCO_3$)	55
pH	7.8 - 8.3
Turbidity	.3

Habbart (1945), in a discussion of the American Viscose Company, stated that the water for rayon-fiber manufacture should be cool, relatively free from iron, manganese, and industrial waste, and low in calcium, magnesium, silica, and color. He pointed out that magnesium hydroxide and residual alum, because of their gelatinous properties, tend to adhere to textile fibers and may affect dyeing, and suggested an upper limit of 0. 4 ppm (parts per million) for residual alum. Iron and manganese cause stains and interfere with bleaching and dyeing. Iron precipitates as ferric hydroxide and attaches easily to the fibers, and iron in any form will be deposited on the surface of a filament by adsorption. In addition, manganese is very detrimental in the mercerizing process because of its catalytic reaction. In some operations, iron (as Fe) under 0. 2 ppm and manganese (as Mn) under 0. 1 ppm will give little trouble, but it is advisable to keep the sum of the two well under 0. 1 ppm. Ordinary methods of controlling the Crenothrix-type bacteria that use iron or manganese in their life processes cannot be used. The copper in the copper sulfate frequently used to control algae cannot be tolerated in the process water. Habbart also stated that free chlorine acts more rapidly and is more economical than chloramine or sodium pentachlorophenate for retarding biologic growth with the plan of operation generally used in plants manufacturing rayon fiber.

Miller (1946) presented specifications for water quality for rayon-fiber manufacture that permit much higher mineral content than those given by Moore in 1940. However, he did indicate that for some operations in which the water comes in contact with the product a lower mineral content would be required. On the other hand he stated that water of higher mineral content could be used for other operations. In general, the specifications that he gave would permit satisfactory operation. (See table 5.)

Process water for manufacture of acetate fiber must be very low in color, turbidity, and iron (Mauersberger, 1952).

Table 5.— *Specifications for water quality for rayon-fiber manufacture*

[Data modified from Miller, 1946]

Constituent or property	Permissible upper limits (ppm)
Silica (as SiO_2)	10
Aluminum (Al)	.25
Iron (Fe)	.05
Manganese (Mn)	.02
Heavy metals[1]	.01
Dissolved solids	200
Total hardness (as $CaCO_3$)	10
Alkalinity (as $CaCO_3$)	75
Color (in platinum units)	5
Turbidity (as SiO_2)	1
Nonliving organic matter	5
Microbiological growths	0 or sterile

[1]Reporting unit is not given; apparently does not include iron or manganese.

BOILER-FEED WATER

Large amounts of boiler-feed water are used to produce steam as it is economical to operate the system only partly closed and use the steam for two purposes. Usually the steam, at high pressure from the boiler plant, is first used to operate turbines that drive electric generators. Low-pressure steam discharged from the turbines is used for process heating, of which a large part is used by mixing with process water and thus is lost to the boiler system. The ratio of boiler-water makeup to total steam output is therefore quite high compared with a closed system.

Untreated water generally is unsatisfactory for boiler-feed water. Its proper treatment is so specialized that for large installations consultants ordinarily are employed to revise the treatment whenever it is necessary due to quality changes in the available raw water. The use of unsuitable water can result in heavy maintenance and replacement costs as a result of excessive corrosion, scale formation, and even caustic embrittlement.

Suggested limits of tolerance for boiler-feed water proposed by Moore (1940) are given in table 6. These values were prepared by the Committee on Water Quality Tolerances for Industrial Uses of the New England Water Works Association and have been widely quoted.

COOLING WATER

Water may be used for cooling or heat transfer either in a recirculating or a once-through system. In a recirculating system,

Table 6.—*Suggested water-quality tolerance for boiler-feed water*

[After Moore, 1940. Allowable limits in parts per million]

Pressure........ lb per sq in...	0-150	150-250	250-400	Over 400
Oxygen consumed	15	10	4	3
Dissolved oxygen[1]	1.4	.14	.0	.0
Hydrogen sulfide (H_2S)	[2]5	[2]3	0	0
Total hardness as $CaCO_3$	80	40	10	2
Aluminum oxide (Al_2O_3)	5	.5	.05	.01
Silica (SiO_3)	40	20	5	1
Bicarbonate (HCO_3)[1]	50	30	5	0
Carbonate (CO_3)	200	100	40	20
Hydroxide (OH)	50	40	30	15
Total solids[3]	3,000-500	2,500-500	1,500-100	50
Color	80	40	5	2
pH value (minimum)	8.0	8.4	9.0	9.6
Turbidity	20	10	5	1
Sulfate-carbonate ratio[4] (Na_2SO_4 : Na_2CO_3)	1:1	2:1	3:1	3:1

[1]Limits applicable only to feed water entering boiler, not to original water supply.
[2]Except when odor in live steam would be objectionable.
[3]Depends on design of boiler.
[4]American Society of Mechanical Engineers standards.

the water acquires heat from the process and loses the heat in a cooling tower or spray pond. The only water needed in a recirculating cooling system is that needed to compensate for evaporation and spray losses and to drain off excessive mineral concentrations. A once-through system uses the water only once for cooling after which it is either wasted or used in process.

Cooling water should be of a satisfactory quality to keep corrosion, scale formation, and the growth of micro-organisms at a minimum. Achievement of this goal ordinarily requires water treatment, at least for recirculating systems. Cooling water that is used only once must be of a suitable temperature. Generally in once-through use it is advisable to chlorinate to prevent the growth of slimes and iron or manganese bacteria. Scale formation sometimes may be prevented by adding small amounts of sulfuric acid. This converts some of the carbonates to sulfates, which are more soluble than the carbonates and so will not precipitate as scale when the water temperature is raised. The addition of small doses of polyphosphates will prevent precipitation of calcium, magnesium, and iron, if the pH of the water is not too high and the water temperature is not raised excessively (Nordell, 1951).

If the cooling water is to be used subsequently for process, it is generally advisable to complete the necessary treatment before using it as a coolant. Such water is ordinarily very satisfactory for cooling.

FIELD SURVEYS

All the rayon- and acetate-fiber plants in the United States were visited during the survey (1951–53). The type of treatment and the use of treated water at each plant were inventoried.

The management of the various plants supplied a considerable amount of data on the chemical and physical characteristics of their untreated water supplies. However, more than 60 percent of the water-quality data presented in this report were obtained by the U. S. Geological Survey as a part of its program of investigation of the quality of water of the United States.

A little more than one-half of the rayon- and acetate-fiber plants obtain all their water from a single source, about one-third of the plants find it advantageous to obtain water from two sources, and about one-seventh use three or more sources. In the majority of plants where water was obtained from more than one source, one quality of water was used for process and another quality for cooling.

QUALITY OF UNTREATED WATER

Data were obtained on the chemical and physical characteristics of the untreated water supplies as shown in tables 7–8. The information was separated into four groups based on the intended use of the water. The data on the quality of the untreated water used for cooling in viscose-rayon manufacture are given in table 7. At some plants, cooling water was used without treatment; at other plants all or part of the cooling water was treated before use. The minimum, lower quartile, median, upper quartile, and maximum were determined for each constituent and characteristic for which a sufficient number of samples was available. The characteristics of the untreated water used to furnish process water in viscose-rayon manufacture are also given in table 7. A comparison of the two groups shows that all the minimum values and the maximum, median, and quartile values for silica, aluminum, iron, manganese, free carbon dioxide, carbonate, fluoride, nitrate, pH, turbidity, suspended matter, and average temperature are nearly identical. However, the maximum, median and quartile values for the other constituents and characteristics for process water are generally lower than the values for the same constituents in cooling water.

Table 8 shows the chemical and physical characteristics of the untreated waters used to furnish cooling water and process water,

Table 7.—*Quality characteristics of untreated water used for cooling and processing in the manufacture of viscose-rayon fiber, based on available analyses* [1]

[Results expressed in parts per million unless otherwise indicated. These are based on individual observations and are not balanced analyses]

Constituent or property	Cooling[1]						Processing					
	Number of samples	Minimum	Lower quartile	Median	Upper quartile	Maximum	Number of samples	Minimum	Lower quartile	Median	Upper quartile	Maximum
Silica (SiO_2)	22	0	4.2	6.5	9.3	16	23	0	3.6	6.7	9.5	16
Aluminum (Al)	3	.3	....	....	....	3.4	3	.3	....	....	....	3.4
Iron (Fe)	23	.01	.04	.07	.18	2.5	24	.01	.04	.07	.13	.7
Manganese (Mn)	6	.00	....	.00	....	.7	7	.00	....	.00	....	.7
Calcium (Ca)	23	.7	9	19	32	55	24	.7	5	14	25	39
Magnesium (Mg)	23	.4	1.9	4.3	9	29	24	.4	1.4	3.2	6.8	11
Sodium and potassium (as Na)	16	1.7	2.8	4.6	7.8	9.8	19	.7	2.2	4.0	6.8	9.8
Free carbon dioxide (CO_2)	5	1.8	....	....	....	38	5	1.8	....	....	....	38
Carbonate (CO_3)	7	0	0	0	0	0	11	0	0	0	0	0
Bicarbonate (HCO_3)	21	6	24	56	95	172	22	6	16	42	90	119
Sulfate (SO_4)	22	0	5	15	28	108	23	0	3.5	7	20	40
Chloride (Cl)	23	.5	2.0	4.3	10	285	24	.5	1.8	3.8	8	20
Fluoride (F)	16	.0	.04	.1	.16	.4	17	0	.1	.1	.1	.2
Nitrate (NO_3)	19	.1	.3	1.0	2.5	6.1	20	.1	.3	.6	1.7	9.3
Dissolved solids	21	14	53	92	140	747	22	14	41	84	115	186
Hardness as $CaCO_3$:												
Total	26	3	33	70	117	197	26	3	20	55	92	132
Noncarbonate	12	0	8	21	35	43	15	0	5	12	32	43
Alkalinity as $CaCO_3$	6	8	....	78	....	145	7	8	....	41	....	114
Color	21	0	4	7.2	10	50	22	0	3	5	10	50
pH	23	4.8	6.8	7.3	7.6	8.0	23	4.8	6.8	7.2	7.5	8.0
Specific conductance (in micro-mhos at 25°C)	10	52.0	90	150	270	1,260	12	40.8	70	120	200	298
Turbidity	6	4	....	30	....	150	7	3	....	20	....	150
Suspended matter	4	2	....	....	....	51	4	2	....	....	....	51
Average temperature (°F)	23	55	57	60	63	69	23	55	57	60	62	69

[1] One plant using sea water is nor included.

Table 8.—*Quality characteristics of untreated water used for cooling and processing in the manufacture of acetate fiber, based on available analyses*

[Results expressed in parts per million unless otherwise indicated. These are based on individual observations and are not balanced analyses]

Constituent of property	Cooling				Processing			
	Number of samples	Minimum	Median	Maximum	Number of samples	Minimum	Median	Maximum
Silica (SiO_2)	4	4.5	7	18	4	4.2	6	18
Iron (Fe)	4	.02	.25	1.8	3	.02	....	.10
Manganese (Mn)	1	....	0	....	1	....	0	....
Calcium (Ca)	7	3.6	16	36	6	3.6	13	36
Magnesium (Mg)	6	.8	7	18	5	.8	5.5	10
Sodium and potassium (as Na)	4	1.7	3	18.4	4	1.7	10	20.8
Free carbon dioxide (CO_2)	1	....	2.5	....	1	....	2.5	....
Carbonate (CO_3)	1	....	0	....	2	0	....	0
Bicarbonate (HCO_3)	4	58	70	124	4	58	65	124
Sulfate (SO_4)	8	2	8	65	6	2	8	41
Chloride (Cl)	8	.5	3	7.5	6	.5	2.5	7.5
Fluoride (F)	3	.1	.1	.1	3	.1	.1	.1
Nitrate (NO_3)	4	.25	1.4	15	4	.25	2	15
Dissolved solids	7	47	100	199	6	47	96	199
Hardness as $CaCO_3$:								
Total	7	13	70	152	5	13	50	131
Noncarbonate	2	9	....	29	3	0	....	29
Total alkalinity as $CaCO_3$	5	11	60	136	3	27	....	86
Color	6	0	10	115	5	0	8	115
pH	6	6.3	7.1	7.8	5	7.0	7.1	7.8
Specific conductance (in micromhos at 25°C)	3	123	....	312	3	123	....	312
Turbidity	4	1	6	60	4	1	2.5	60
Average temperature (°F)	6	54.2	57	59	5	54.2	56	58.5

respectively, for acetate-fiber manufacture. However, the number of samples was too small to permit the computation of quartiles. Comparison of the two groups indicates that untreated process water is of slightly better quality than untreated cooling water. Water is almost always treated for process use and may be treated for cooling use. This difference in quality is greater in water used in the viscose-rayon industry than in the acetate industry.

More detailed information on the occurence of iron, dissolved solids, and total hardness in the untreated water used for process in viscose-rayon manufacture is shown by means of frequency distribution charts in figure 24. Similar data on color, pH, turbidity, and average temperature are shown in figure 25.

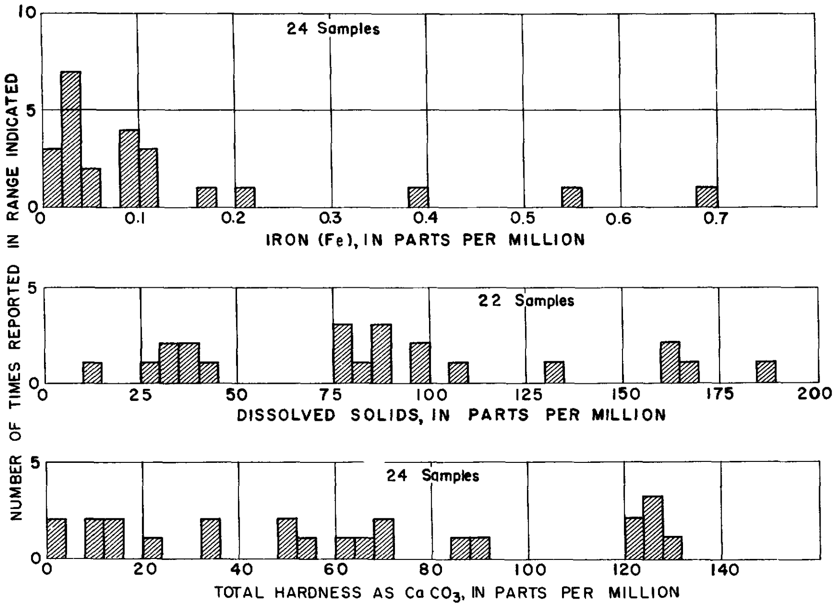

Figure 24. —Frequency distribution of chemical characteristics in untreated water supplies used for process water in the manufacture of viscose-rayon fiber, based on available analyses.

A graphical representation of the chemical composition of a typical untreated water for process in the manufacture of viscose-rayon fiber is shown in figure 26. Silica is shown as a percentage by weight of the sum of all the constituents. The cations are shown in two categories, expressed as a percentage of equivalents per million of strong and weak bases, and the anions are shown as a percentage of equivalents per million of strong and weak acids.

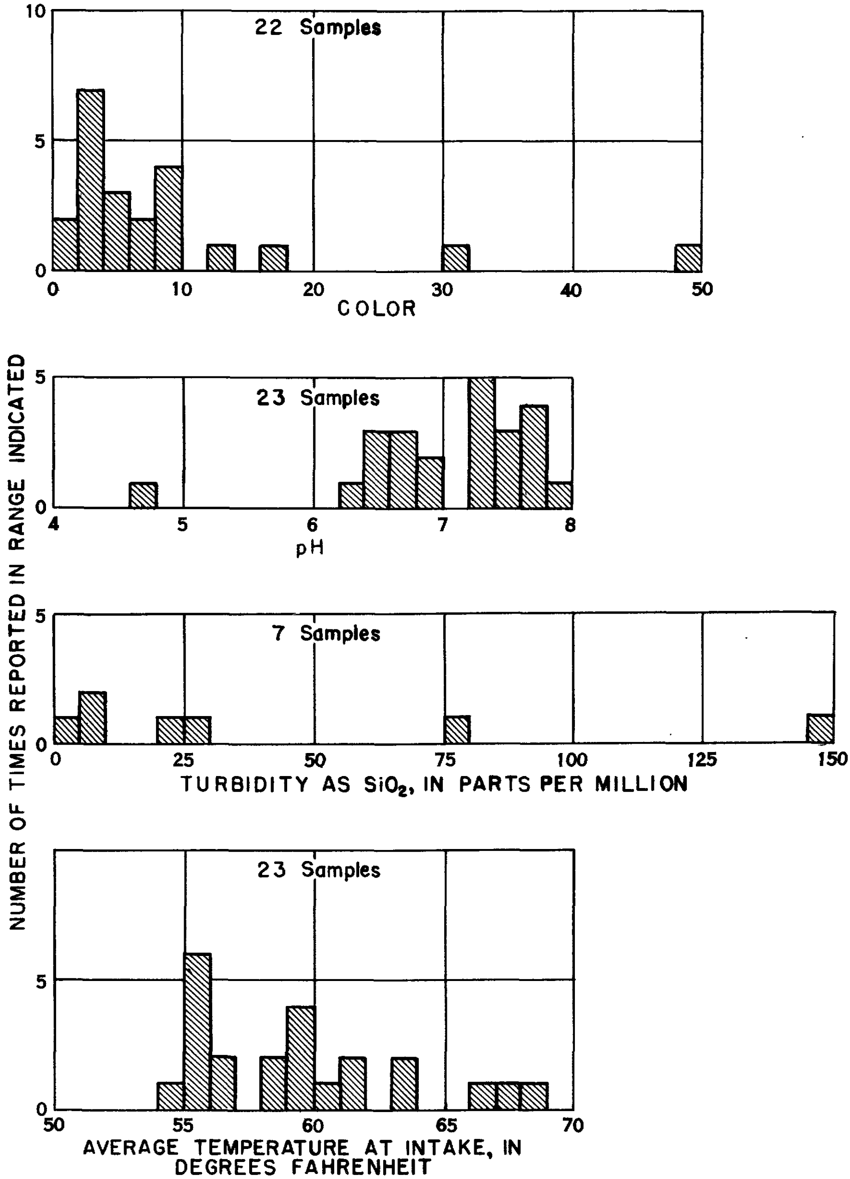

Figure 25. —Frequency distribution of physical characteristics in untreated water supplies used for process water in the manufacture of viscose-rayon fiber, based on available analyses.

A summary of the properties of the untreated water used for cooling and for process in the manufacture of both viscose-rayon and acetate fiber is given in table 9. The maximum, minimum, and mean values, of the total cations expressed in equivalents per

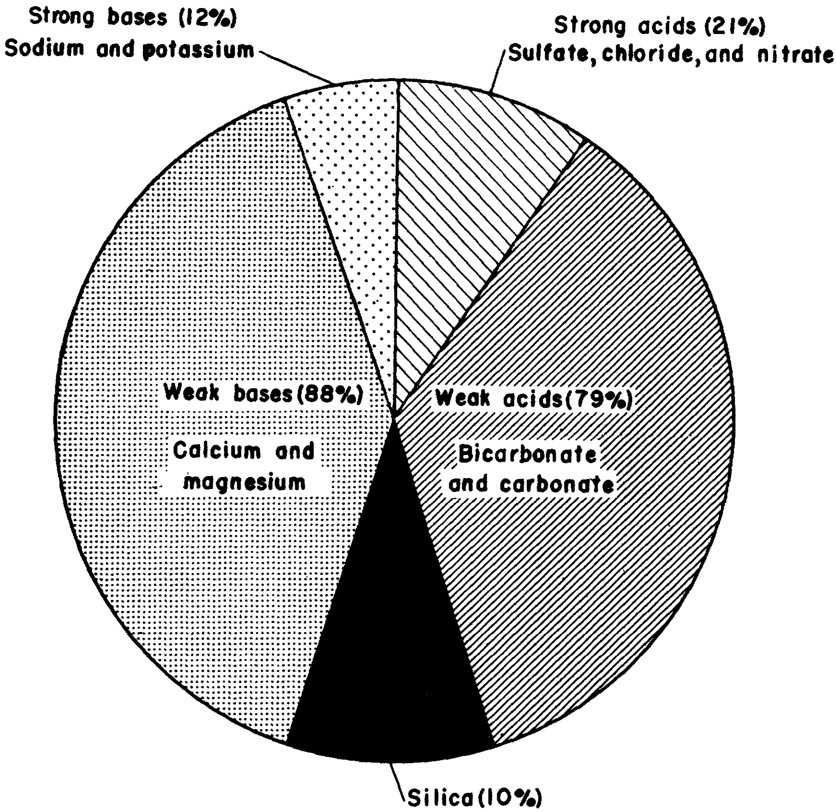

Figure 26. —Chemical composition of a typical untreated water used for process water in the manufacture of viscose-rayon fiber.

(Silica equals perçentage composition by weight; all other constituents indicate percentages of equivalents per million of total cations or anions.)

million (epm), the ratio of calcium (epm) to magnesium (epm), and the ratio of calcium (epm) to total cations (epm) for each of four groups of waters are given. Mean values of the ratios of calcium to magnesium ranged from 1.89 to 2.43, and mean values of the ratios of calcium to total cations ranged from 0.48 to 0.57 for the groups. No ratios of calcium to magnesium greater than 4.2 were found.

In summation it can be said that the raw waters for cooling and process were generally low in content of calcium and magnesium (with calcium comprising about one-half the total cations), were very low in iron and manganese, and had an average temperature of 58°F.

Table 9.—*Properties of untreated water used for the manufacture of viscose-rayon and acetate fiber based on available analyses*

Fiber	Use of water	Number of analyses	Total cations (equivalents per million)			Calcium : magnesium[1]			Calcium : total cations[1]		
			Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Viscose rayon...	Cooling........	16	3.50	0.13	1.69	4.20	1.00	2.34	0.76	0.23	0.55
Do............	Process (Soft water).	19	2.97	.13	1.41	4.20	1.00	2.43	.76	.23	.56
Acetate.........	Cooling.......	3	3.43	1.32	2.04	2.20	1.70	1.89	.61	.52	.57
Do...........	Process.........	3	3.43	1.32	2.13	2.20	1.78	2.04	.61	.30	.48

[1]Ratio of constituents in equivalents per million.

WATER TREATMENT

In the rayon-fiber industry much of the plant capacity has been constructed or modernized during recent years. As a result, operations at the various plants are quite similar and the treated water used at all rayon-fiber plants is similar. The situation is the same in the acetate-fiber industry. Table 10 shows the water-treatment methods used at the various rayon- and acetate-fiber plants. The type of water treatment differs more with the quality of the raw water than with variations in the process of manufacture. Because most of the water is obtained from surface supplies, the principal types of water treatment consist of coagulation, sedimentation, filtration, pH adjustment, chlorination, and softening, in the order named. Only a scattering of other types of treatment are employed.

The quality requirements for process water at rayon and acetate plants are such that general-purpose water for drinking and other domestic service usually can be supplied by using process water. However, nearly half of the plants purchase at least a small part of their water from public supplies.

Table 10.—*Water-treatment methods at rayon- and acetate-fiber plants*

[Does not include prior treatment of purchased water]

Type of treatment	Number of plants	
	Rayon	Acetate
Coagulation........	22	4
Sedimentation........	22	4
Filtration........	22	5
pH adjustment........	21	3
Chlorination........	18	6
Softening........	15	4
Iron and manganese stabilization........	1	1
Addition of activated carbon........	1	1
Deionization........	....	1
No treatment........	1	....

FUTURE WATER REQUIREMENTS

Many factors must be considered in estimating the total water requirements of the rayon- and acetate-fiber industry in future years. Some of these factors, such as the extent to which rayon and acetate fibers may replace or be replaced by other natural or synthetic fibers, are rather uncertain; other factors may be more accurately determined. Reasonably accurate estimates can be made of the amounts of water that will be required at individual plants of feasible size and in what section of the country such plants probably will be located.

LOCATION OF INDUSTRY

The locations of the rayon- and acetate-fiber plants in operation at the time of the 1952–53 survey are shown in figure 27. The 25 rayon-fiber and 7 acetate-fiber plants are scattered from Alabama to Vermont and, with few exceptions, are located in small towns or at sites several miles from any large city. One authority (Alderfer and Michl, 1950) stated, "The chief reasons for the wide geographical spread appear to be the search for areas where there is an abundant supply of clean, soft water and where taxes are low." Other factors of less importance in site selection are fuel prices and transportation costs. Large amounts of coal are used in producing the steam and electricity required, so points near coal mines mean lower freight costs for fuel. Much of the rayon and acetate fiber is shipped from the plants on reusable spools or bobbins designed to fit the textile machinery of the purchaser, so proximity to the rayon textile mills is desirable. Most of the textile industry is now located in the Southeast with the Northeast in second place. All of the cotton linters and much of the purified wood cellulose used in rayon-and acetate-fiber manufacture are also produced in the South.

GROWTH OF INDUSTRY

Production of rayon and acetate fiber in the United States and in the world increased about eightfold during the period 1930-53 as shown in figure 28 which shows domestic and foreign quantitative and percentage values of the total annual production of these fibers during the period. Foreign production, which, in 1939, was concentrated in Japan, Germany, and Italy, was drastically affected by World War II, but the principal effect on United States production was to stimulate output during the first 6 postwar years.

Manufacturing costs of rayon and acetate products are so high in relation to transportation costs that foreign production is

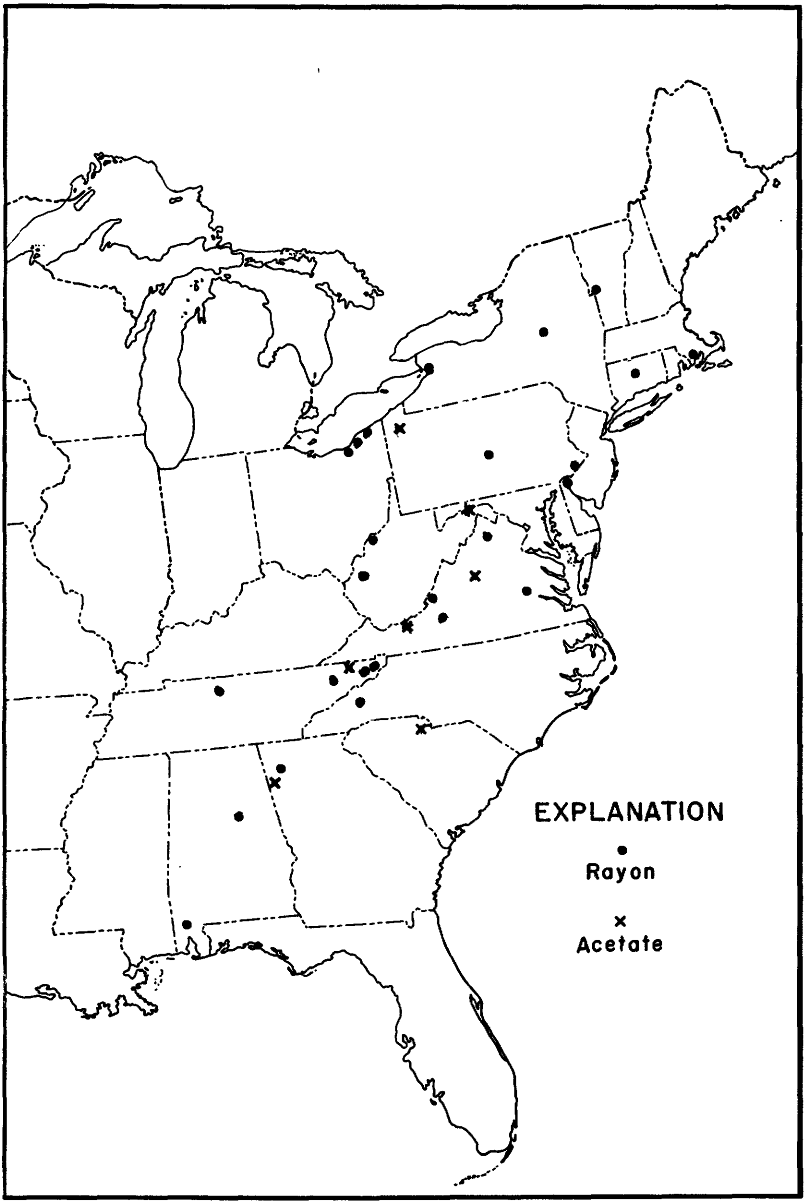

Figure 27. —Location of rayon- and acetate-fiber plants, 1952.

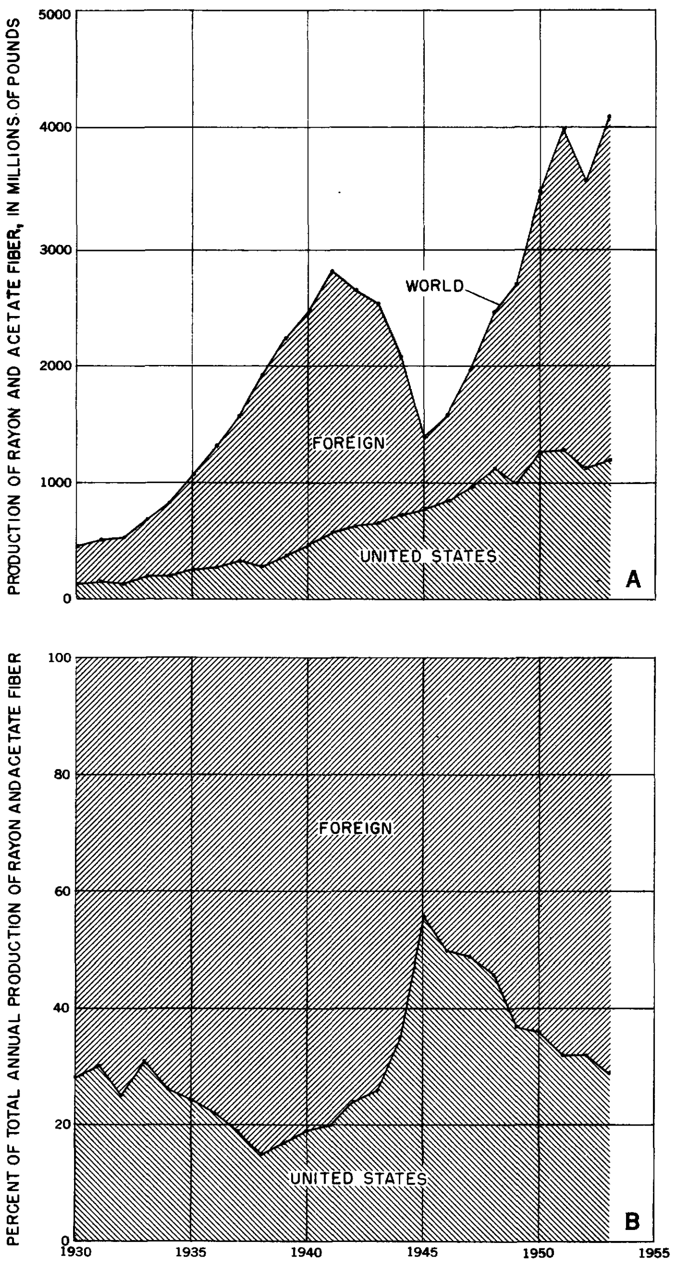

Figure 28. —United States and world production of rayon and acetate fiber by (A) quantity and (B) percent, 1930–53.

(Data for 1930–45, Mauersberger, 1952, p. 56, 58, 72; 1946–53, Textile Organon, 1954, no. 6, p. 89.)

intimately related to production in the United States. The export-import trade is sensitive to small price changes. Thus, for rayon and acetate fiber and yarn there was an import balance of 10 percent of domestic production in 1939; an export balance of 12 percent in 1949; and an import balance of 4 percent in 1951. Domestic production in some years may be much less and for others much more than domestic consumption, depending on the delicate balance of foreign trade.

Rayon and acetate are competitive with cotton, wool, silk, and the other manmade fibers. Figure 29 shows the annual mill consumption of each of these fibers, by both quantity and percent of total, for the years 1930–53. Of the fibers selected, cotton and wool are supplying a decreasing percentage of the total requirements. Since 1941 silk has almost completely vanished from the market. The use of rayon and acetate fibers is increasing rapidly but, since 1950, the use of other manmade fibers has increased even more rapidly.

Figure 30 shows the annual production of various types of rayon and acetate fibers by both quantity and percent of total for 1930–53. In 1930, textile-grade rayon filament constituted more than 90 percent of total rayon- and acetate-fiber production, but although total production of this type had about doubled during the period, percentagewise it had shrunk to 17 percent in 1953. The production of acetate filament during this same period increased more than twentyfold and rose from 8 percent to 19 percent of the total. The use of high-tenacity rayon filament for industrial fiber began in the midthirties and by 1953 had increased to 38 percent of the total, more than twice the production of any other classification. Production of rayon staple and tow began about 1930 and increased rapidly until, by 1953, it exceeded production of rayon filament. Manufacture of acetate staple and tow began in 1953 and output has amounted to about half the production of rayon staple and tow since 1950. The most rapid expansion in the manufacture of this type of fiber occurred in the 5 years following World War II.

PRESENT CAPACITY OF PLANTS

Most of the rayon- and acetate-fiber plants now in operation were constructed in comparatively small units and gradually expanded by the addition of similar or slightly improved units until they reached their present size. This type of expansion is apparently continuing and probably will continue. Occasionally, new plants are placed in operation or obsolete plants are abandoned, but most of the industry's growth has resulted from expansion of existing plants.

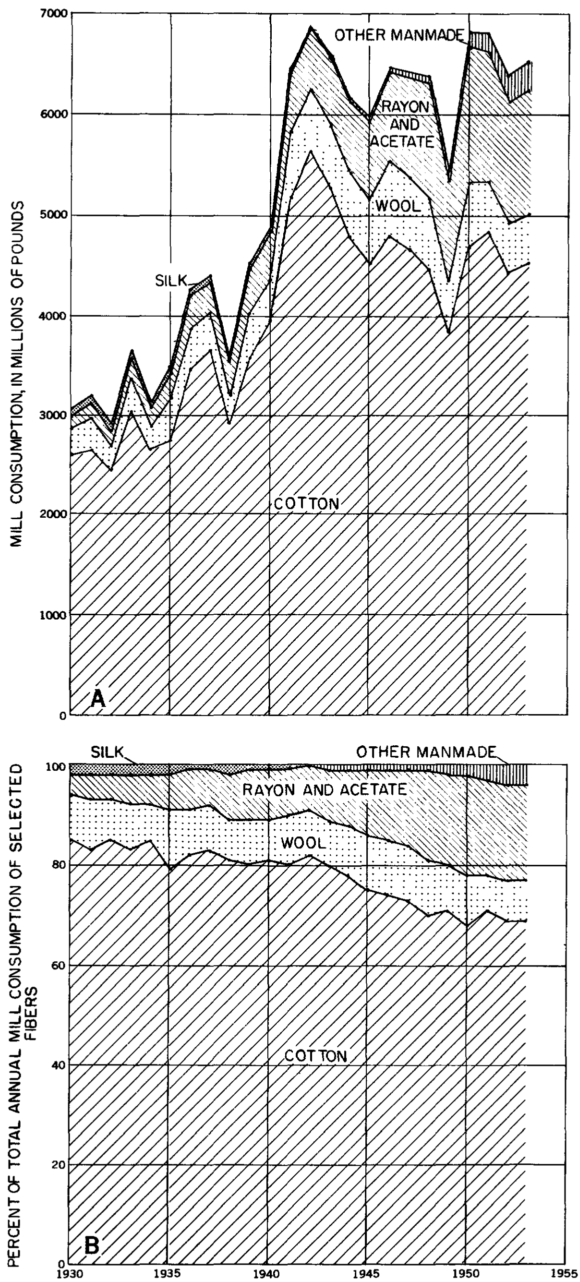

Figure 29.—Mill consumption of selected fibers in the United States by (A) quantity and (B) percent, 1930-53.

(Data for 1930-49, Textile Organon, 1952, no. 3, p. 74; 1950-53, Textile Organon, 1954, no. 3, p. 42.)

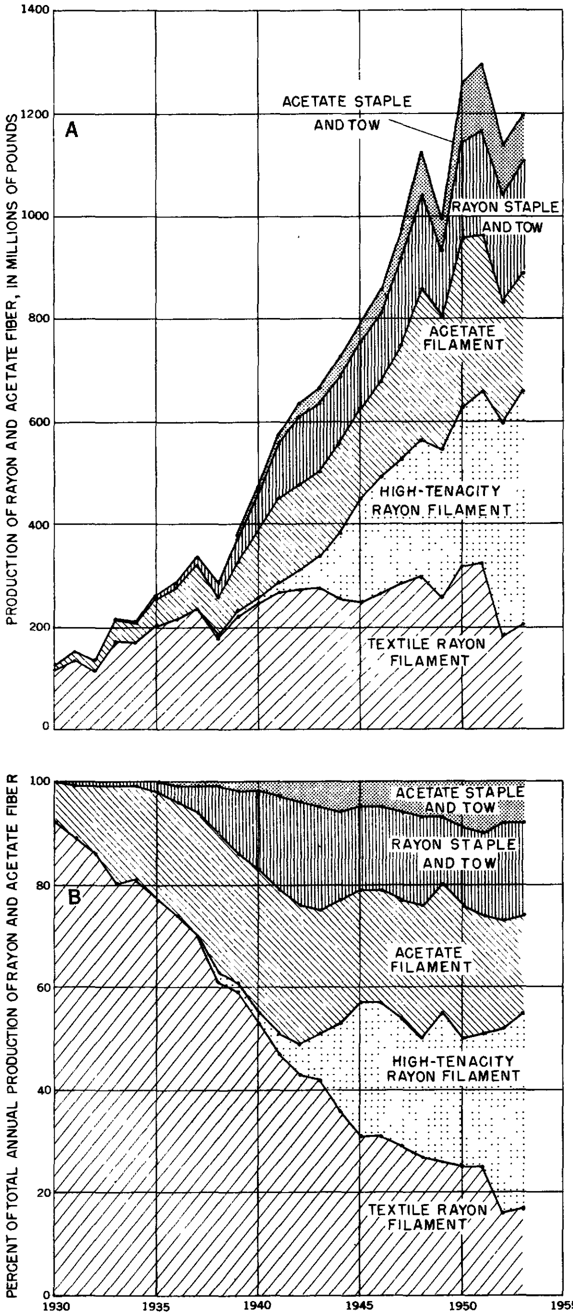

Figure 30.—Production of types of rayon and acetate fibers in the United States by (A) quantity and (B) percent, 1930–53.

(Data for 1930–48, Mauersberger, 1952, p. 58, 72; 1950–51, Textile Organon, 1952, no. 12, p. 212; 1949, 1952–53, Textile Organon, 1954, no. 12, p. 193.)

Rayon.—At the time of the 1952–53 survey, 25 rayon-fiber plants were in operation in the United States. The median capacity of these plants was 38 million pounds per year, and the upper and lower quartiles were 54 and 15 million pounds per year, respectively. The capacity of the newer mills averaged closer to the upper quartile than to the median value.

Acetate.—Only 7 acetate-fiber plants were in operation at the time of the water-use survey, and 1 of these employed only a partial process making practical a much smaller plant capacity than would be feasible for a complete process plant. The median capacity of the 6 complete process plants was 85 million pounds per year. The capacity of the largest plant was about 3½ times the capacity of the smallest plant.

TRENDS IN THE RAYON- AND ACETATE-FIBER INDUSTRY

Primarily because of the manufacturers' reluctance to change production practice to include synthetic materials and the consumers' hesitance to accept them, rayon and acetate fibers have yet to reach the limit of their potentialities. However, their prospects have been dimmed somewhat by the introduction of other synthetic fibers. Relative prices of rayon and acetate fibers and the newer synthetics probably will be an important factor in the extent of the market eventually controlled by each fiber (Alderfer and Michl, 1950). Price probably will be a more important factor in selection of fibers for commercial use than for such items as clothing where fashion or convenience may be a deciding factor.

It has been estimated that 1,200,000 tons of purified wood cellulose will be consumed by the rayon- and acetate-fiber industry in the United States in 1975 (Stanford Research Institute, 1954). This probably would be in addition to about 100,000 tons of cotton linters. As the quantity of water required to produce a pound of purified wood cellulose probably is double that required for refining cotton linters, the relation between the two sources of raw material may affect the total water requirements of the industry.

The President's Materials Policy Commisiion (1952) estimated that the 1975 production of rayon fiber in the United States would be 2,100 million pounds and the production of acetate fiber for that year would be 900 million pounds.

On the basis of 1953 unit water-requirements values, about 680 mgd would be required in 1975 for the preparation of special cellulose for rayon- and acetate-fiber manufacture, and about 1,050 mgd would be required for use at the rayon- and acetate-fiber plants. This would mean a total water requirement of about 1, 700 mgd in 1975, including preparation of the special cellulose.

SUMMARY

QUANTITATIVE WATER REQUIREMENTS

The primary aim of the survey conducted in 1952–53 was to determine the current water requirements of the rayon- and acetate-fiber plants rather than to determine the minimum amount of water that could be used in producing the materials.

Median unit water use was 110 gallons per pound in the rayon plants and 170 gallons per pound in the acetate plants. Median water requirements for all purposes at rayon and acetate plants in 1953 were 9 mgd and 38 mgd, respectively. Water requirements in summer were somewhat greater.

Total annual water use for rayon-fiber manufacture in the United States in 1953 averaged 290 mgd and for acetate-fiber manufacture averaged 330 mgd. The annual average total water use by the rayon- and acetate-fiber industry in 1953 was about 620 mgd. Because much of this water was used for cooling and air conditioning, the rate of use in summer was about 22 percent greater or about 760 mgd. In 1953, the estimated average total water requirements for rayon- and acetate-fiber manufacture, including water for cellulose preparation, amounted to about 920 mgd or about 1 percent of the estimated total withdrawal of industrial water in the United States.

Consumptive use of water in the rayon- and acetate-fiber industry is relatively insignificant; it averaged less than 8 mgd for the entire industry in 1953.

QUALITATIVE WATER REQUIREMENTS

The qualitative requirements for water used in the rayon- and acetate-fiber industry differ greatly with the use that is made of the water. At the typical plant, cooling water is withdrawn from a river and screened and chlorinated before being used only once. If the cooling water is reused, treatment may be more elaborate. Specifications for processing water for both rayon and acetate manufacture are quite strict; the water must be soft and very low in dissolved solids. Similar specifications apply to the process and wash water used in preparing the purified wood cellulose and cotton linters used as raw materials. Process water is usually suitable for domestic use including drinking. Frequently more than one source of raw or untreated water is available, in which case the water of higher quality is generally used for process water.

The minimum, median, and maximum values of the more important chemical and physical characteristics of the untreated waters used for process water in viscose-rayon manufacture are summarized in table 11. The untreated water used for process in acetate-fiber manufacture was of very similar character as indicated by the available analyses (Table 8).

Untreated cooling waters used for both rayon and acetate manufacture were, as a group, only slightly lower in quality than the process water. These waters somewhat resembled the untreated process waters and were generally cool, low in calcium and magnesium content, and very low in iron and manganese.

Table 11.—*Most important quality characteristics of untreated water used for process water in the manufacture of viscose-rayon fiber*

[Results expressed in parts per million unless otherwise indicated. These are based on individual observations and are not balanced analyses]

Constituent or property	Minimum	Median	Maximum
Silica (SiO_2)	0	6.7	16
Iron (Fe)	.01	.07	.7
Manganese (Mn)	.00	.00	.7
Calcium (Ca)	.7	14	39
Magnesium (Mg)	.4	3.2	11
Total hardness as $CaCO_3$	3	55	132
Color	0	5	50
Turbidity	3	20	150
Average temperature (°F)	55	60	69

TRENDS IN WATER REQUIREMENTS

The manufacture of rayon and acetate fiber constitutes a comparatively new industry, accustomed to change. Most of the plants, therefore, have been quick to adopt new methods that would result in savings, including those that might result from economies in water use. There is a tendency to use smaller amounts of water per pound of product and to increase the size of the plants.

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