EPA-600/2-76-060
March 1976

Environmental Protection Technology Series

HYPERFILTRATION FOR RENOVATION OF TEXTILE FINISHING PLANT WASTEWATER

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

EPA REVIEW NOTICE

This report has been reviewed by the U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policy of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-76-060
March 1976

HYPERFILTRATION FOR RENOVATION OF TEXTILE FINISHING PLANT WASTEWATER

by

Craig A. Brandon and John J. Porter

LaFrance Industries
Riegel Textile Corporation
LaFrance, South Carolina 29656

Grant No. S800929
ROAP No. 21AZT-006
Program Element No. 1BB036

EPA Project Officer: Thomas N. Sargent

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

CONTENTS

Sections		Page
I	Conclusions	1
II	Recommendations	3
III	Summary	5
	In-Plant Water Reuse	5
	Equipment Performance	6
	Summary of Plant Costs Projections	9
IV	Introduction	11
	Objective and Scope	11
	Program Plan	12
V	La France Plant Facility	14
	Fibers and Chemicals Used	14
	Wastewater Characterization	16
VI	Reuse in Production Dyeings	27
	Standard Dyeing Procedure	29
	Reuse of Concentrate Water	29
	Reuse of Product Water	33
VII	Equipment Performance	36
	Pilot Plant	37
	Tubular Cellulose Acetate (Westinghouse)	39
	Hollow Polyamide Fiber (DuPont)	44
	Spiral-Wound Cellulose Acetate (Gulf)	51
	Dynamic Zr(IV)-Polyacrylic Acid (Selas)	54
	Design Values for Cost Projections	58
VIII	Treatment Plant Cost Projections	61
	The Treatment System	61
	Equipment Description and Capital Cost Projections	63
	Operating Cost Projections	75
	Cost Projections for a Combined Membrane System	79
IX	References	82

CONTENTS (continued)

Sections		Page
X	Appendix A - Water Sampling Schedule, Procedure, and Chemical Analyses	83
	Sampling Schedule	84
	Collection and Storage of Samples	84
	Analytical Procedures	85
XI	Appendix B - Production Scale Reuse Dyeings	89
	Cycle #1	91
	Cycle #2	95
	Cycle #3	98
	Cycle #4	100
	Cycle #5	102
	Cycle #6	104
	Cycle #7	107
	Cycle #8	109
	Cycle #9	111
	Cycle #10	113
	Cycle #12	115
	Cycle #14	117
	Cycle #16	119
XII	Appendix C - Performance of Hyperfiltration Modules in the La France Pilot Plant	121

FIGURES

No.		Page
1	BOD of the composite wastewater	17
2	COD of the composite wastewater	18
3	Dissolved solids content of the composite wastewater	19
4	Calcium concentrations of the composite wastewater	20
5	pH of the composite wastewater	21
6	Color content of the composite wastewater	22
7	Turbidity of the composite wastewater	23
8	Schematic of pilot plant layout	38
9	Operating performance of Westinghouse module at La France	41
10	Operating evaluation of Westinghouse module during final 500 hours	46
11	Operating performance of DuPont hollow polyamide fiber module at La France	49
12	Operating performance of Gulf (U.O.P.) spiral cellulose acetate module at La France	53
13	Operating performance of Selas dynamic membrane module at La France	57
14	Simplified flow schematic of a textile dyewaste treatment system	62
15	Case 1 - Details of a membrane bank design	66

TABLES

No.		Page
1	Summary of performance of hyperfiltration modules in La France demonstration pilot plant	7
2	Summary of cost estimates for treatment of 7570 m^3/d of textile wastes at La France	10
3	Comparison of hyperfiltration module configurations	13
4	La France size characteristics	15
5	Characteristics of raw composite wastewater during the operation of the pilot project (March 1973 to May 1974)	24
6	Characteristics of process (tap water) water currently used in the La France plant	26
7	Production dyeings	28
8	Standard dyeing cycle	29
9	Reuse dyeings of cotton velour with concentrate water	30
10	Analyses of concentrated residues employed in reuse dyeing	32
11	Critical test dyeing formulation	33
12	Analyses of product water	35
13	Operating performance of tubular cellulose acetate Westinghouse module with La France composite wastewater	43
14	Operating performance of tubular cellulose acetate Westinghouse module with La France composite wastewater under variable conditions	45
15	Operating performance of hollow polyamide fiber DuPont module with La France dyehouse wastewater	48
16	Operating performance of spiral cellulose acetate Gulf module with La France wastewater	52
17	Operating performance of ceramic tube Zr(IV)-PAA Selas module with La France wastewater	56
18	Design values for cost projections	59

TABLES (continued)

No.		Page
19	Membrane module capital cost basis for projections	64
20	Details of capital cost projections for hyperfiltration module unit	68
21	Details of capital cost projections for pretreatment unit	71
22	Capital cost projection summary for hyperfiltration treatment of La France wastewater	74
23	Operating cost projections summary for hyperfiltration treatment of La France wastewater	76
24	Net operating cost projections summary including potential recycle credits	78

ACKNOWLEDGEMENTS

Any project of this scope obviously is indebted for its success to contributions of more than one or two individuals. Therefore, Dr. C. A. Brandon and Dr. J. J. Porter, consultants to the Riegel Textile Corporation as project director, and principle expert on reuse evaluations, respectively, acknowledge the following people.

The Texidyne pilot plant operators under the guidance of Dr. Ali El-Nashar, namely, Mr. Bob Adler, Mr. Charles Shuler, and Mr. Eric Snider have contributed significantly to the large degree of on-stream time for the pilot plant. The La France personnel including the plant engineers, Henry McAdory and Tom Foy, and foreman, John Byrum, have been largely responsible for the expeditious assembling of the pilot plant equipment and the maintenance thereof. Mr. Charles Smith and Mr. Bernard Thompson have cooperated to achieve and evaluate the full scale reuse test dyeings.

Several people less directly involved in the day-to-day operations have, however, made significant contributions, and are due acknowledgement and thanks for the consultations: Dr. R. L. Goldsmith and Mr. Sorab Hassain of ABCOR contributed to this report and to the progress and success of the pilot plant operations with their continued surveillance and advice. We also acknowledge the contributions of Dr. J. S. Johnson and Dr. R. E. Minturn of the Oak Ridge National Laboratory, along with the efforts of Mr. George V. Jordan and Mr. George L. Bartholomew, of Selas Corporation, for their on-going efforts in planning, testing, and preparation for the second phase of the pilot plant project. The guidance and direction of Mr. T. N. Sargent, EPA Project Officer, was most valuable during the course of this study.

SECTION I

CONCLUSIONS

Hyperfiltration (reverse osmosis) has been studied, on a pilot plant scale, for renovation of the composite wastewater from the textile dyeing and finishing plant of La France Industries. Both the purified product water and the residual concentrate were used in full scale production dyeings in a two-piece dye beck. The results of this study were presented in three categories; direct reuse, equipment performance, and cost projections. The conclusions based on the reuse evaluation results are:

(1) The quality of the product water, purified by passing through a hyperfiltration membrane, was satisfactory for direct reuse in all dyeing and finishing operations at La France.

(2) The technical feasibility of the reuse of the concentrate water, retained by the hyperfiltration membrane, was demonstrated by the production of first quality fabric in nine standard shades.

The conclusion drawn from the equipment performance results is:

(3) The four commercial membrane module configurations evaluated in the pilot plant were each capable of processing textile wastewater, when operated with proper pretreatment.

The conclusion that attains from the results of cost projections is:

(4) The cost projections for a full scale 2,000,000 gallons/day (7570 m^3/day) treatment facility combining two of the commercial membranes indicated a capital cost of $1,650,000, and a net operating saving of 43¢/1000 gallons (11.3¢/m^3), including credit for recycle of water, chemicals, and energy. However, amortization is not included in the operation cost projections, because the cost of money varies considerably from company to company. Amortization, a significant factor, can be determined with the information given.

SECTION II

RECOMMENDATIONS

The result of this investigation demonstrated the feasibility of hyperfiltration (reverse osmosis) membranes for the renovation of composite textile dyeing and finishing wastewater at La France Industries. The scope of the study was limited to the evaluation of performance of commercial membranes under manufacturer specifications. It was beyond the scope of this pilot plant investigation to determine optimum pretreatment for textile wastewater. Further, this study was limited to the consideration of plant composite wastewater and the total mixed dyehouse effluent. The following are recommendations directed toward the optimum utilization of membrane separations for the economic renovation of textile wastewater effluents, including direct recycle of single process effluents, waste treatment of any required system blow down, and modifications of the manufacturing process that may become economical because of recycling.

(1) The textile wet finishing industry employs a variety of processes that each have peculiar waste characteristics. A mobile hyperfiltration laboratory project is recommended to (a) determine the engineering performance of available hyperfiltration equipment, and (b) to evaluate potential for reuse at several plants selected to represent the major categories of dyeing and finishing. A part of this program should be the study of the treatability of the concentrate since complete reuse may not prove to be universally practical in the immediate future.

The favorable economics implied for a combined membrane system suggest the second and third recommendations.

(2) Basically hyperfiltration is a separation process. The objective of the application of hyperfiltration is direct recycle, both of the chemicals in the concentrate and of the product water. It may be more efficient in many manufacturing processes to make the application of membranes to individual effluents, rather than to a mixed composite. This is particularly true for the conservation of energy through direct recycle of hot water.

It is recommended that a study be made of the application of membranes

to the individual effluents of manufacturing processes. In particular, this study should examine in detail both batch and continuous operations in order to assess the potential impact of energy conservation, through recycle of hot process water and the reuse of reconcentrated chemical baths, upon the textile industry.

Since the potential for economic recovery, for certain processes where significant energy and chemical savings are possible, the acceptability of membrane separation technology for point source application is enhanced. The recovery of any process chemical by direct recycle will also obviously reduce the pollutional load in the remaining composite wastewater.

Because the economics are potentially conducive to early adoption by industry, and because the removal of expensive chemicals and energy by direct recycle achieve a significant reduction in the pollutional load (often of the more refractive constituents, e.g., PVA and vat dyes), it is further recommended that as a second phase of the study of point source recycle be a full scale demonstration. The full scale demonstration should involve closed cycle operation of a manufacturing process. Closed cycle will provide a necessary demonstration of the effects of recycle on the manufacturing process. In addition, it will permit the full scale evaluation of process modification.

(3) As the full scale demonstration of membrane separation for point source recycle is a second phase of an assessment study, the full scale demonstration of the renovation of composite wastewater is recommended as a second phase of this pilot plant project and the mobile hyperfiltration laboratory project recommended above. Closed cycle operation would provide information on (a) the equipment performance over an extended period, (b) the change in process water composition, and (c) the treatment of any blow down required. A full scale membrane system would also provide a useful test bed for the study of pretreatment to minimize the total cost of the treatment system.

The demonstration of the renovation of composite wastewater would be beneficial because there are a number of instances in which this could be

a useful intermin step to full scale totally closed cycle. For example, in a few cases, water availability and costs (supply and treatment) are such that recycle is a viable alternative to minicipal systems. Further full scale demonstration of the removation of composite wastewater would not be redundant in that application of point source recycle would only tend to optimize the performance of the integrated system and to maximize the rate of return from recycle.

Since the cost of the membrane modules is the significant factor in determination of the economic practicality of this separation technology, the following recommendations relate to improvement in the equipment performance with textile wastes.

(4) Development of washing procedures to prevent flux decline, i.e., fouling, or to restore flux periodically. Costs potentially may be reduced up to 50%.

(5) Development of pretreatment to reduce membrane fouling in order to both increase average flux and prolong membrane useful lifetime.

(6) Development of membranes tailored to the separation of the specific chemicals, e.g., for use with process solvents other than water.

(7) Development of membrane modules designs and determination of fluid dynamics to minimize horsepower requirements.

(8) Evaluation of the potential for the chemical recovery from concentrate as a raw material for a chemical process.

SECTION III

SUMMARY

This report describes the results of the hyperfiltration (reverse osmosis) demonstration pilot plant at La France Industries which was in operation during 1973-74. Both the purified product water and the concentrate water representing 65 - 95% water recovery have been recycled successfully in full scale test dyeings during the period of operation of this program.

IN-PLANT WATER REUSE

This pilot study was conducted to demonstrate the feasibility of reuse of treated textile wastewater in plant (full) scale dyeing operations. This method of treatment was hyperfiltration which yields a relatively pure fraction of water, referred to as product water, and an impure fraction containing most of the dyes and chemicals, referred to as concentrate water.

Sixteen different treatment cycles were performed during the course of the project. Thirteen of these cycles used the treated water in plant scale dyeing operations. Three cycles were devoted entirely to equipment performance determinations. The product water was used in five dyeing operations with standard dye formulations. The product water was used with the concentrate in five dyeing operations. Eight plant scale dyeings were made in which the concentrate was used as the initial dye bath with normal plant water used for all other process steps. A total of eighteen plant scale dyeings were performed. A total of eleven different dye formulations evaluated the success of using the product water and concentrate water for plant scale dyeings.

All of the plant dyeings were successful. No significant problems were encountered with the reuse of product or concentrate water. The light fastness wash tests performed on the fabric, as a quality control measure, established that the test dyeings were equal to normal production quality.

Test dyeings were conducted in the laboratory before plant scale dye formulations were chosen. The product water required no additional treatment and could be used interchangeably with plant water. Concentrate water samples from each cycle contained concentrations of different dyes. The dye formulation chosen for use with the concentrate water required minor additions of dye when the concentrate water contained compatible colors and major additions of dye when the recovered dye was different. This results in dye savings in some cases and an increase in dye requirements in other cases. The average reduction of dyes was 16%.

EQUIPMENT PERFORMANCE

Three types of hyperfiltration membranes were evaluated during the course of this demonstration pilot plant; polyamide, cellulose acetate, and Zr(IV)-polyacrylic acid. Cellulose acetate was evaluated in two membrane configurations. A total of four basic commercial module configurations were therefore investigated. These were:

(1) Tubular cellulose acetate on the internal wall of 13 mm diameter tubular channels,

(2) hollow-fine polyamide fibers,

(3) spiral-wound sheets of cellulose acetate, and

(4) external coating of Zr(IV)-PAA dynamically deposited on ceramic tube bundles.

The operation of these units is summarized in Table 1.

A single Westinghouse tubular cellulose acetate module was operated for over 1000 hours. Pretreatment employing 25 micron cartridge filters was employed. The pH was maintained in the range 5.2 - 7.0, and the temperature controlled below 90 F (32 C), as recommended by the manufacturer. The average rejections of COD, total solids, conductivity, and color range from 92 - 99+%. There was a decrease in product water flow rate from the unit with time of operation that was partially recoverable by washing.

Table 1. SUMMARY OF PERFORMANCE OF HYPERFILTRATION MODULES IN LA FRANCE DEMONSTRATION PILOT PLANT[a]

MANUFACTURER	Westinghouse	DuPont	Gulf[b]	Selas Flotronics
MEMBRANE	Cellulose Acetate	Polyamide	Cellulose Acetate	Zr(IV)-PAA
CONFIGURATION	internal tubular	hollow-fine fiber	spiral-wound	externally coated tube bundle
TEST DATE	12/73 - 1/74	2/74 - 3/74	4/74	6/74 - 7/74
HOURS OF TEST	1059	187	804	944
TEST CONDITIONS				
Prefiltration	25 micron cartridges	D.E.[c]	25 micron cartridges	250 micron screen
pH	5.6 - 7.0	6.2 - 8.3	5.8 - 7.0	6.6 - 8.5
Temperature, C	13 - 32	11 - 32	15 - 26	20 - 91
Pressure, Pa ($\times 10^{-6}$)	2.1 - 3.1	2.4	2.8	2.4 - 7.2
AVERAGE REJECTIONS, %				
Total Solids	95	95	96	90
Color	99+	99+	99+	98+
Conductivity	92	94	95	85
COD	96	92	94	95

[a] Total plant composite and dyehouse wastewaters used in this study.
[b] Now ROGA, a Division of Universal Oil Products
[c] Diatomaceous earth - Sears swimming pool filter - preceeded 25 micron and 1 micron cartridge filters.

Three DuPont permeators employing the hollow-fine polyamide fibers were operated, below 90 F (32 C), for a total of about 600 hours. After greater than 400 hours of operation on composite wastewater from the total plant, it was recommended by DuPont that further evaluations be made with wastewater from the dyehouse only, excluding all sanitary and finishing wastewaters. During the last 200 hours, a diatomaceous earth prefilter was used in addition to the 25 micron and 1 micron cartridge prefilters which were used for the initial 400 hours. The permeator evaluated during the last 200 hours, under these recommended conditions, performed satisfactorily. The average rejection of COD, total solids, conductivity, and color ranged from 92 - 99+%. It was possible to maintain the product water flow rate from the module by intermittent detergent washing.

The Gulf (now ROGA, Division of Universal Oil Products) spiral-wound cellulose acetate module was operated for 804 hours. The pH was maintained in the range 5.8 to 7.0, and the temperature controlled below 90 F (32 C). All wastewater was prefiltered through 25 micron cartridge filters. During the initial 163 hours an additional 1 micron cartridge filter was used in series with the 25 micron filter. The average rejections of COD, total solids, conductivity, and color ranged from 94 - 99+%. There was an initial decrease in product water flow rate of the unit, however, operation over the last 600 hours was at a stable rate.

Two types of units containing dynamic membranes were used during the course of this pilot plant project. Initially, dynamic membrane modules, prepared by consultants at the Oak Ridge National Laboratory, were used to generate sufficient product and concentrate to demonstrate full scale reuse. The performance of the commercial modules provided by Selas is summarized in this report.

The Selas dynamic membrane module contained eight, 19-tube bundles in series. The Zr(IV)-PAA membranes were deposited on these ceramic tubes and then operated for 944 hours. (This period included approximately 170 hours of operation with rinse water from an indigo dye range.)

The pH of the raw feed was not adjusted. The unit was operated with

40 mesh prefiltration over a temperature range from 68 - 195 F (20 - 90 C). The average rejections of conductivity, total solids, COD, and color ranged from 85 - 98+%. The product water flow rate from the unit decreased sharply initially but achieved a stable rate.

SUMMARY OF PLANT COSTS PROJECTIONS

The equipment performance data were used by each module vendor to prepare a cost projection for a complete 2 million gallon per day (7570 m^3/d) hyperfiltration wastewater plant for the La France facility. These projections include pretreatment costs for control of pH, temperature, and suspended solids, as required for each membrane configuration. These estimates do not include reservoir storage facilities, or treatment of the 10 to 20 percent make-up water required in the plant.

There is a wide variation in both the capital cost and the daily operating costs. Major daily cost items for the polyamide and cellulose acetate membrane systems are membrane replacement and electrical power costs. The major cost item for the dynamic membrane system is electrical power.

The capital cost and the operating power costs for each hyperfiltration plant are directly related to the number of module units required. Therefore, the pilot plant determinations of the product water flow rate from each module were critical to meaningful cost estimate determinations. A summary of cost estimates is given in Table 2.

It is very important to note that these cost data do not include the value of recyclable water, chemicals, or heat (energy). Using the estimated values of recycled materials and water as indicated in Table 2, the cost reduction for each of the polyamide and cellulose acetate membrane systems is 57¢/kgal (15¢/m^3). Because of the possibility of direct recycle of 25% of the water at process temperature, the dynamic membrane system may have a cost reduction of as much as 69¢/kgal (32¢/m^3). A system combining two membrane types may have a cost reduction of as much as 88.5¢/kgal (23.4¢/m^3), (see pages 79 f.f.).

Table 2. SUMMARY OF COST ESTIMATES FOR TREATMENT OF 7570 m^3/d OF TEXTILE WASTES AT LA FRANCE

MEMBRANE CONFIGURATIONS	Hollow-fiber	C. A. Spiral	C. A. Tubular	Dynamic	Combined
CAPITAL INVESTMENT, $	$1,777,435	$1,860,815	$4,086,315	$3,481,086	$1,650,000
DAILY OPERATING COSTS, $/d					
1. Pretreatment Chemicals					
a. Filter Aid	$ 30.00	$ .00	$ .00	$ .00	$ 22.50
b. Chemicals	20.00	45.00	45.00	5.00	15.70
2. Labor					
a. Operating	202.20	202.20	202.20	202.20	202.20
b. Maintenance	27.40	27.40	27.40	27.40	27.40
c. Supervision	22.96	22.96	22.96	22.96	22.96
3. Maintenance Materials	72.35	58.63	174.14	205.45	82.96
4. Electric Power	210.60	214.20	335.52	936.00	288.99
5. Membrane Replacement	328.77	455.48	1123.30	16.43	247.60
Total	$914.28	$1025.87	$1930.52	$1415.40	$910.11
DAILY OPERATING COSTS, ¢/m^3	12.10[a]	13.60[a]	25.50[a]	18.70[a]	12.10[a]
RECYCLE POTENTIAL, ¢/m^3					
1. Salt (80% recovery @ 4.4¢/kg)	1.50	1.50	1.50	1.50	1.50
2. Water (80% recovery @ 13¢/m^3)	10.60	10.60	10.60	10.60	10.60
3. Energy (25% hot water @ 1.9¢/10^7 J)	3.40	2.80	2.80	6.20	11.30
4. Total Cost Reduction (¢/m^3)	15.50	14.90	14.90	18.30	23.40

[a] Does not include amortization

SECTION IV

INTRODUCTION

Increasingly stringent requirements for treatment of wastewater, and significant surcharges which have been introduced by municipalities require that we evaluate wastewater treatment systems which provide recycle capabilities. Hyperfiltration[1,2] (reverse osmosis) is a technique for economical renovation of industrial wastewaters which may yield recovered chemicals, relatively pure product water, and energy where hot water can be directly recycled in a process.

Hyperfiltration is a membrane separation process that selectively filters soluble and insoluble chemicals from water. This technology has been used successfully in selected industrial applications where the recovered products have significant value. This study investigated the application of hyperfiltration for the recovery of water and chemicals from the wastewater of a textile plant. The purified product water and the concentrate water were directly recycled in full scale production dyeings.

The results from this study are in agreement with previous laboratory tests of hollow-fine fiber permeators and dynamic membrane hyperfiltration test sections.[3] This demonstration pilot plant was operated by La France Industries, a Division of Riegel Textile Corporation, in cooperation with participating equipment companies under an Environmental Protection Agency grant.[4] The characteristics of the La France facility and wastewater stream are summarized in this report.

OBJECTIVE AND SCOPE

The primary objective of this pilot plant project was to demonstrate the direct reuse of renovated textile wastewater in full scale production dyeing equipment using standard procedures. Additional goals were to demonstrate the practicality of hyperfiltration equipment and develop cost estimates for a full scale plant.

When a major portion of the wastewater is renovated and recycled a blow down stream will ultimately be required to prevent chemicals from accumulating to intolerable levels in a closed system. The composition and disposition of such a blow down were beyond the scope of this project.

There are several configurations of commercial hyperfiltration equipment. The characteristics of the types of systems available are presented in Table 3. The scope of this project was to demonstrate the performance of each of these commercial and prototype modules.[2,5-7]

PROGRAM PLAN

The program plan included 16 monthly test cycles. In thirteen cycles product water was used in plant scale dyeings. Operation over 16 months permitted a complete study of the seasonal production variations in the mill.

Before this project was started, tests were conducted on laboratory scale with hyperfiltration equipment to establish the feasibility of treating the waste stream at La France. Technical feasibility was indicated by these tests and the pilot plant was installed and full scale reuse tests were begun.

The size of the pilot plant equipment was selected to permit the full scale operation in the dyehouse of a production dyeing beck, with a capacity of 92 meters of fabric. The hyperfiltration unit was sized to accumulate, in each test cycle, approximately 17 m^3 of product water and 5.7 m^3 of concentrate. These volumes were sufficient to permit a full scale dyeing by standard procedures. The first week of each cycle was devoted to the collection of this purified water by the processing of approximately 22.7 m^3 of raw wastewater taken directly from the composite sewer main leaving the plant. During the latter stages of the project raw wastewater could be taken from either the composite sewer or the dyehouse drain.

The original period of investigation for this grant was for 20 months. The study began July 12, 1972, the initial operation of the pilot plant began on March 12, 1973, and was completed July 31, 1974.

Table 3. COMPARISON OF HYPERFILTRATION MODULE CONFIGURATIONS

	Spiral	Tubular	Hollow-Fine Fiber	Dynamic
Membrane Material	cellulose acetate	cellulose acetate	polyamide	hydrous Zr(IV) oxide-polyacrylate
Production Rate $m^3/m^3/day$	67 - 1000	13 - 200	27 - 2000	200 - 2000
Method of Membrane Replacement	module (on-site)	tubes (on-site)	module (on-site)	in-situ
High Pressure Limitation	membrane compaction	membrane compaction	fiber collapse	no problem
Particulates in Feed	filtration required	no problem	filtration required	no problem
Permissible Feed Range, pH	5.5 - 7.5	5.5 - 7.5	2 - 10	4 - 11
Maximum Temperature, F (C)	100 (38)	100 (38)	100 (38)	>195 (>90)

SECTION V

LA FRANCE PLANT FACILITY

The parameters describing the production capacity of the La France plant are shown in Table 4. These data provide a basis for comparison and evaluation of the results of this demonstration project. These factors are important in the ultimate estimation of the practicality of scale-up from the pilot plant.

The process water is from La France's own filter plant. Ninety-five percent of the 7570 m^3 per day total water usage is in the dyehouse. Allowing for considerable evaporation by drying, the composite waste stream is at least 85% by volume dyehouse wastewater. This is verified by the average total dissolved solids (TDS) measured in the composite waste. The 7600 lbs/day (3455 kg/d) of salt used are equivalent to 500 mg/ℓ of dissolved solids in the composite wastewater.

The materials involved in potential recycle with hyperfiltration are the water, the salt, and the unexhausted dyes. In the case of membranes that can withstand high temperatures, energy can also be recovered by direct recycle of renovated hot water. The economic potential for recovery of salt, water, and energy is greater than $1500/day. A significant cost item is the $800/day cost for water treatment which may be reduced by recycling water. An additional economic incentive is the recovery of dyes. These potential savings will reduce the net cost of this type of waste treatment and may pay for part or all of the operating cost.

FIBERS AND CHEMICALS USED

The dyeing and finishing processes at La France involve several different dyes and finishes. The dyeing is done in open-beck, piece dyeing machines. The principal classes of dyes employed are neutral pre-metallized, direct, and acid dyes. These account for about 95% of the total dye usage. Other dyes used in smaller quantity are disperse, basic, and

Table 4. LA FRANCE PRODUCTION CAPACITY PARAMETERS

QUANTITIES USED	
Materials:	
Water (total to plant), m^3/day (gallons/day)	7,197 (1,900,000)
Water (to dyehouse), m^3/day (gallons/day)	6,818 (1,800,000)
Dyes, kg/day (pounds/day)	225 (500)
Cloth, m/day (yards/day)	20,000 (22,000)
Salt, kg/day (pounds/day)	3,454 (7,600)
Energy:	
Fuel Oil (for process steam), joules/day (Btu/day)	1.05×10^{12} (1.0×10^{9})
UNIT COSTS	
Water, ¢/m^3 ($/1000 gallons)	13 (0.50)
Fuel Oil, ¢/10^7 joules ($/$10^6$ Btu)	1.9 (2.06)
Salt, ¢/kg ($/ton)	4.4 (42.70)
Dye, $/kg ($/pound)	8.0 (3.5)

reactive dyes. The finishes used include silicone, latex, wax dispersions, fluoro-chemicals, and flame retardants. These finishes represent, at most, a few parts per million in the composite waste stream.

The materials processed are nylon (30%), viscose (20%), and cotton (50%), with approximate weight percentages indicated.

WASTEWATER CHARACTERIZATION

The variety of dyes and finishes employed produce a complex and variable waste stream composition. The quantitative characterization of the waste stream is important in evaluation of the pilot plant. Daily samples of the composite waste stream were collected at random times and composited weekly for analyses. The results of typical analyses are tabulated in Table 5. The variation of several of the significant parameters is indicated in Figures 1 through 7. The sampling and analytical procedures are shown in Appendix A.

As shown in Figure 1, the BOD varied within the range 20 - 125 mg/ℓ with an average near 40 mg/ℓ. In Figure 2, approximately the same percentage variation is indicated for COD, from 125 - 900 mg/ℓ. No simple correlation between BOD and COD is apparent from these data. In Figure 3, the total dissolved solids average 1000 mg/ℓ, with a range from 600 - 1200 mg/ℓ. The calcium content, Figure 4, varies from 0.5 - 7.2 mg/ℓ. The pH, an important parameter for selection of hyperfiltration equipment (see Table 3) stays in the neutral range, Figure 5, during most of this period; the maximum values about 8. In some cases the pH was measured about 10; however, this level of pH was noted only rarely and could be adjusted by equalization or chemical neutralization.

The color of the waste stream shown in Figure 6 also varies widely. This was expected and is typical of dyehouse wastewater. The turbidity shown in Figure 7 is attributable mostly to small fibers from velvet fabrics sheared in the plant.

Values of selected parameters were determined by the pilot plant operators for each of the 600-gallon batches of raw feed collected for

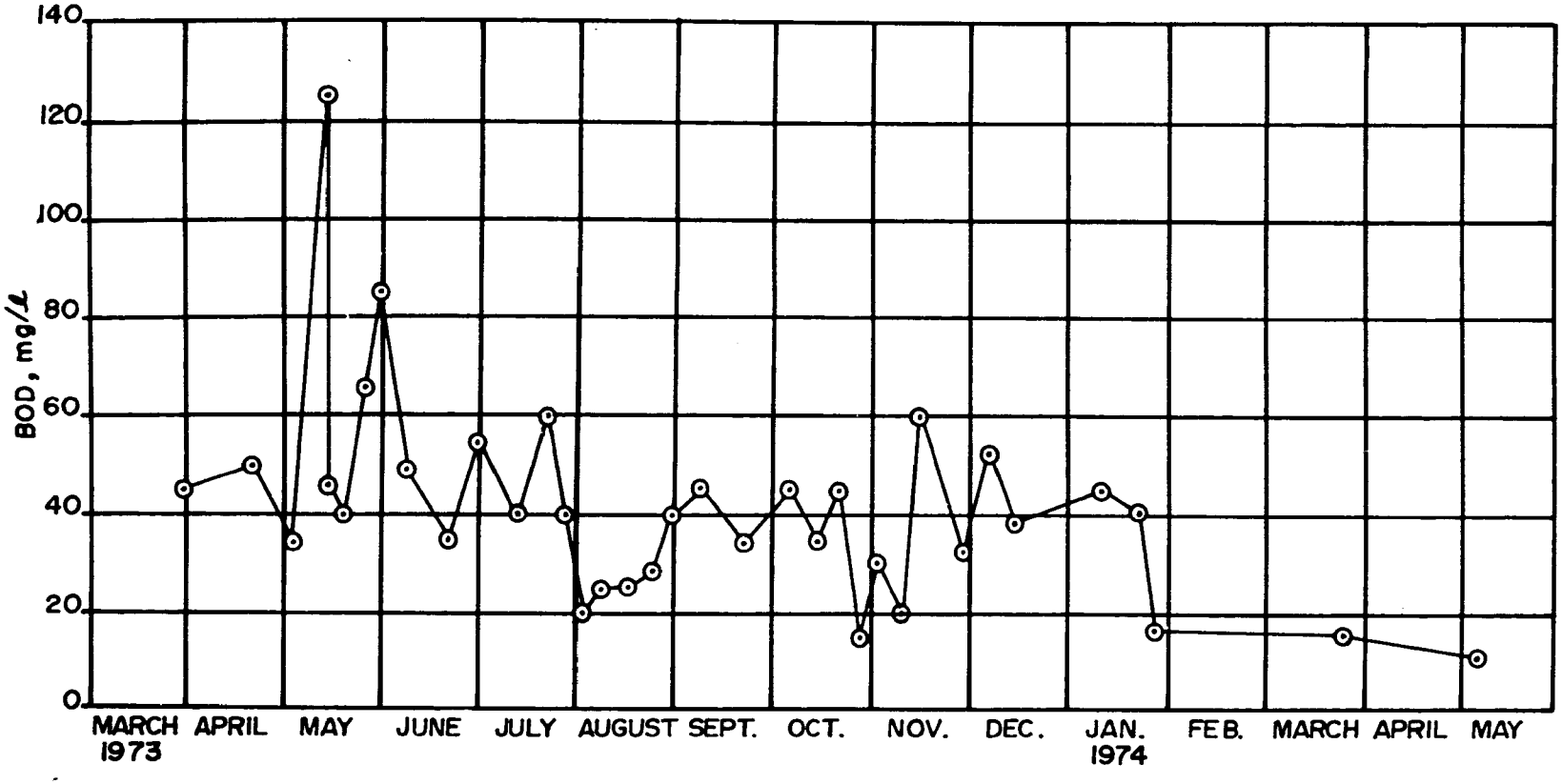

Figure 1. BOD of the composite wastewater.

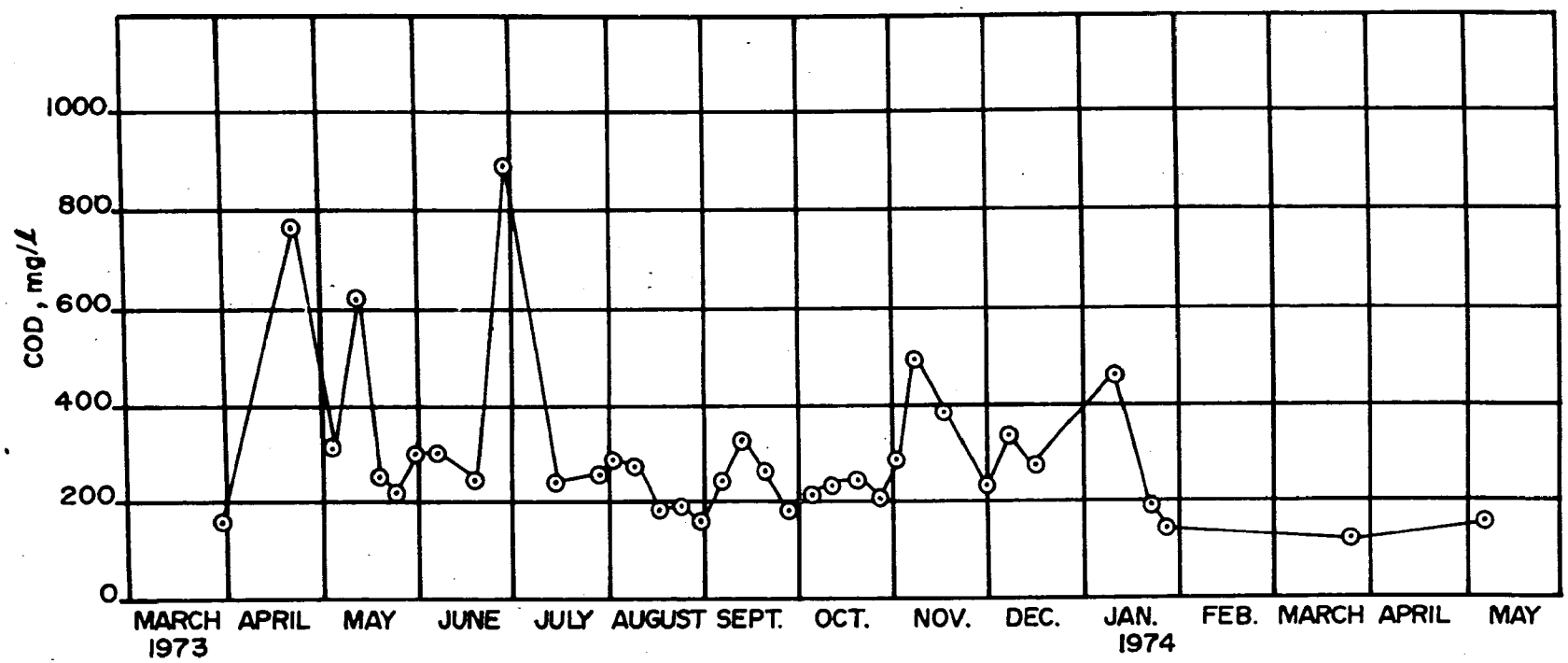

Figure 2. COD of the composite wastewater.

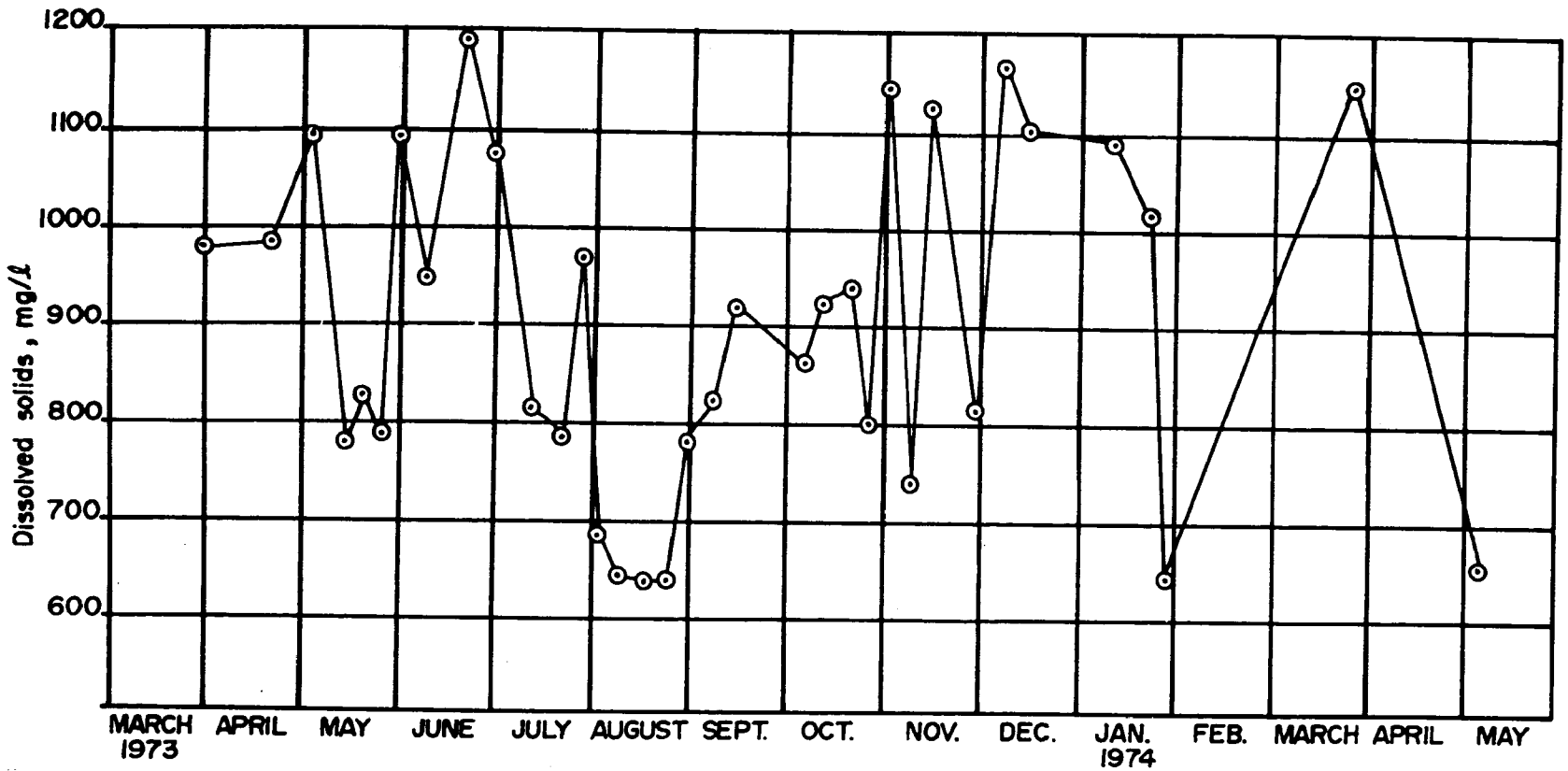

Figure 3. Dissolved solids content of the composite wastewater.

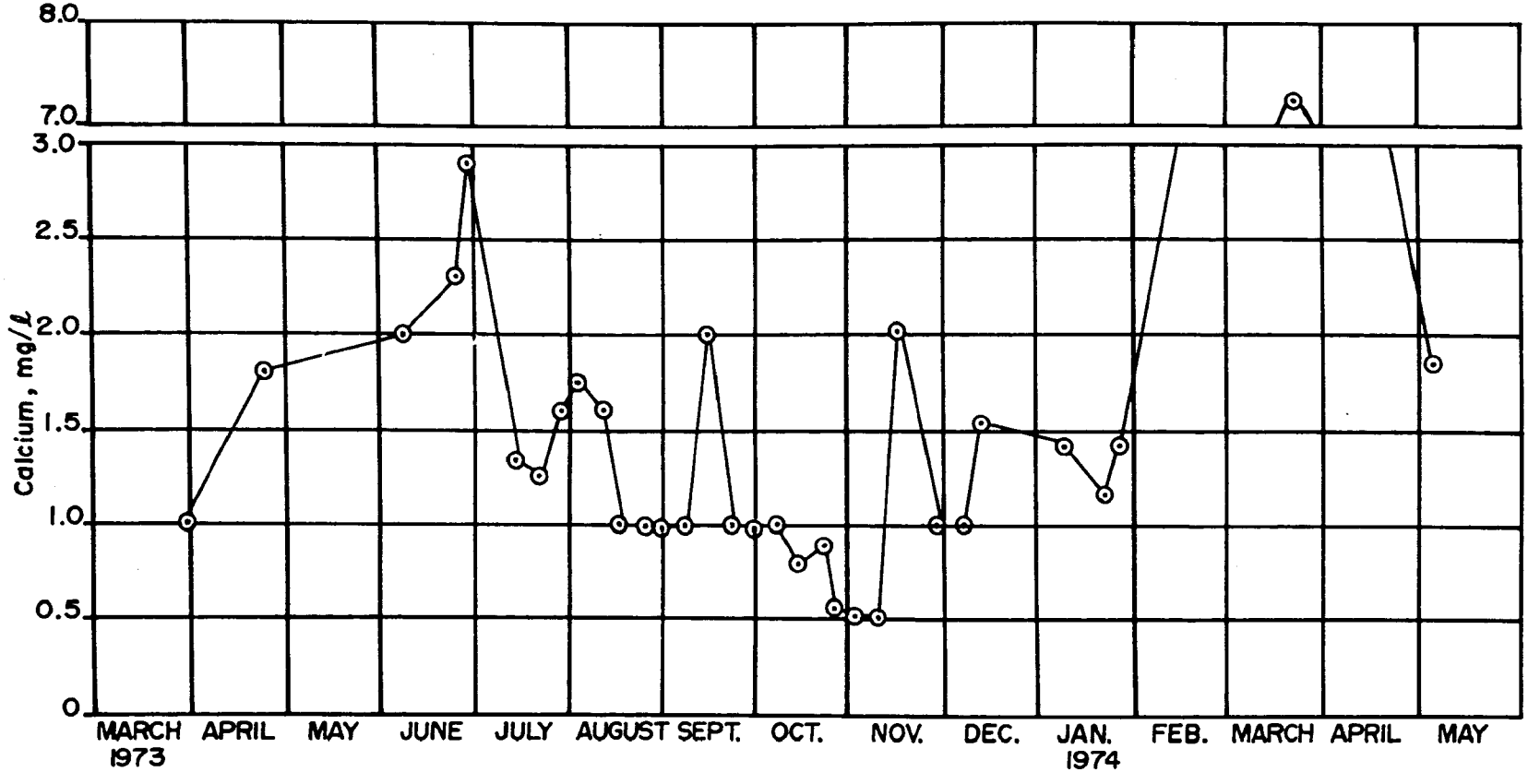

Figure 4. Calcium concentrations of the composite wastewater.

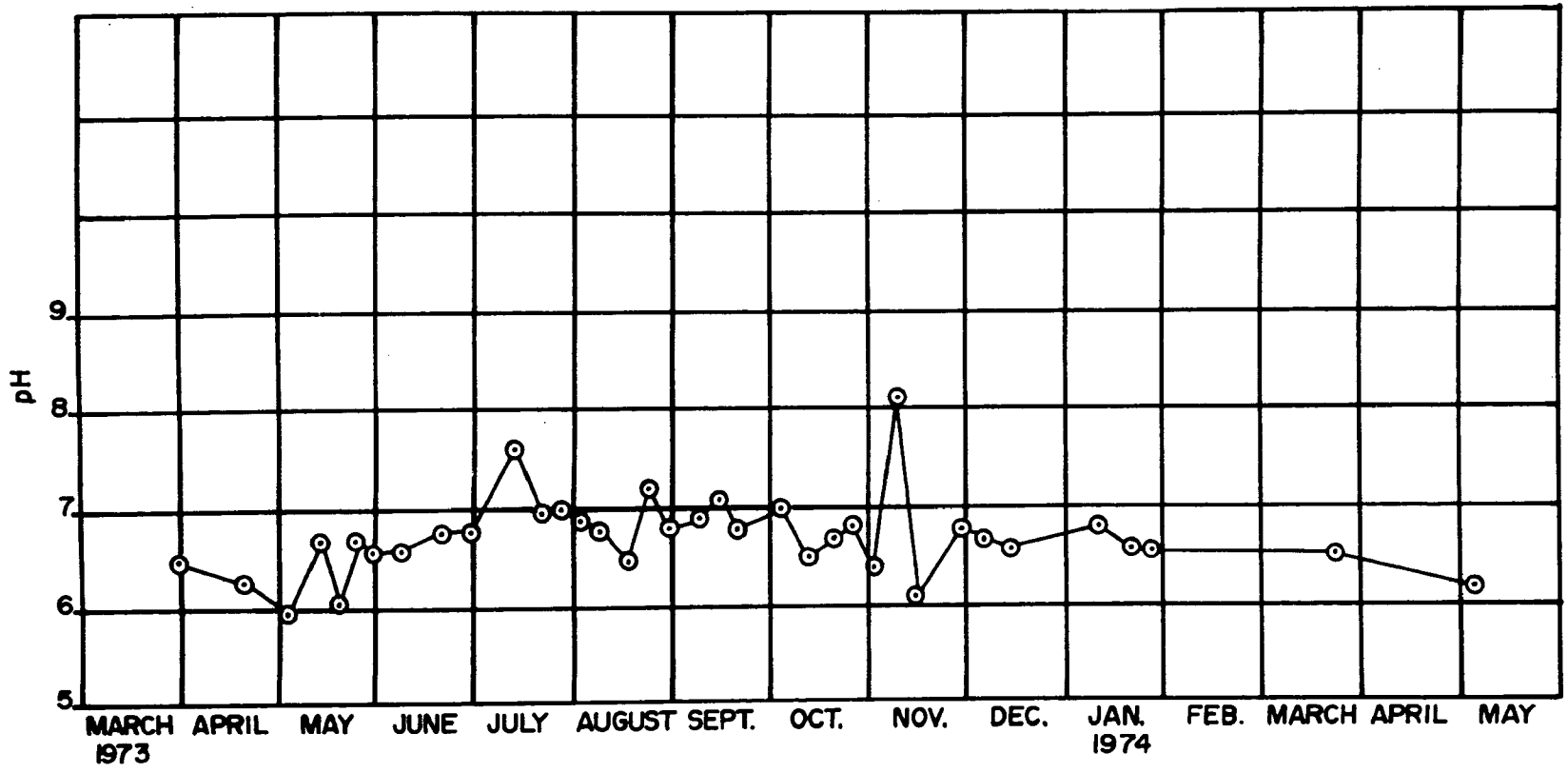

Figure 5. pH of the composite wastewater.

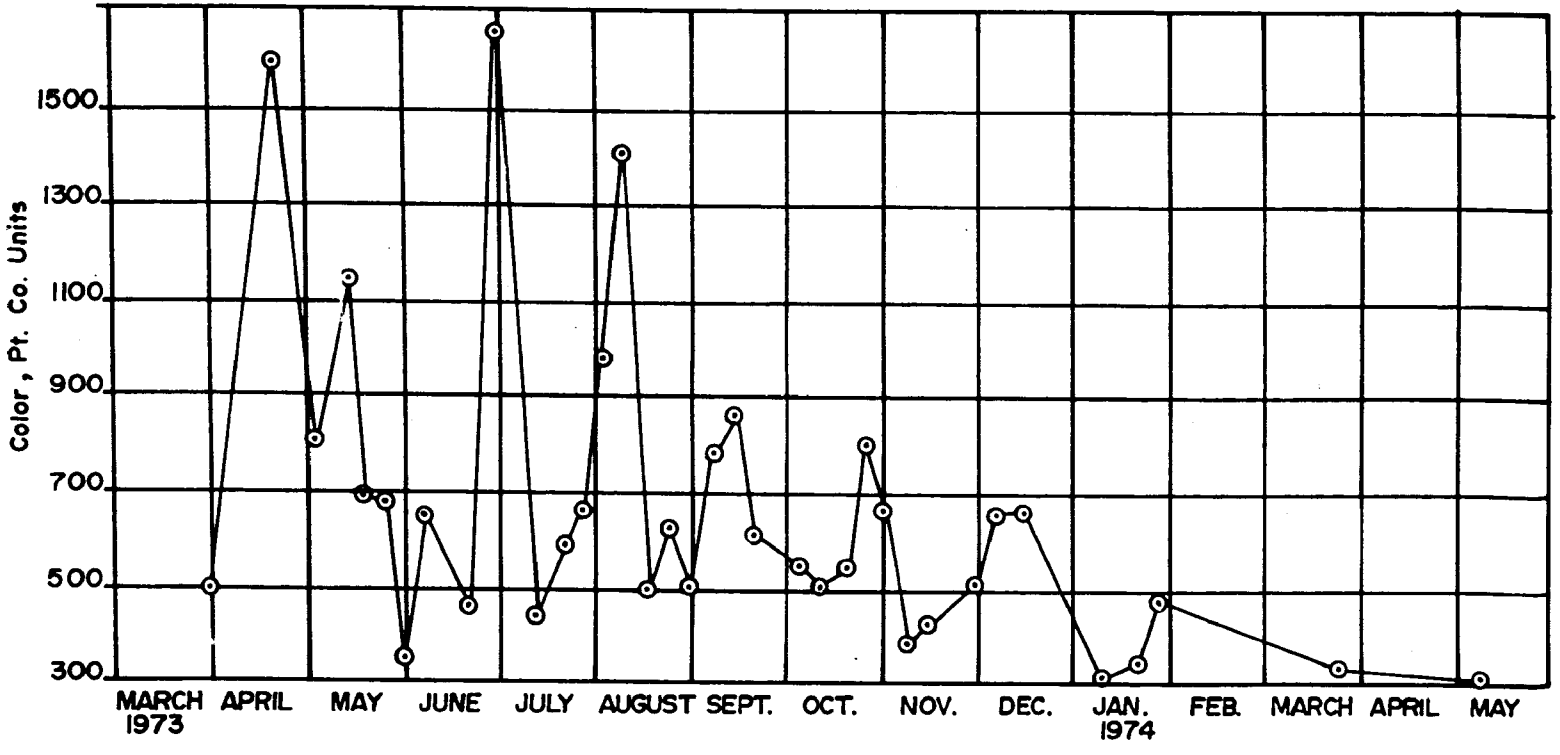

Figure 6. Color content of the composite wastewater.

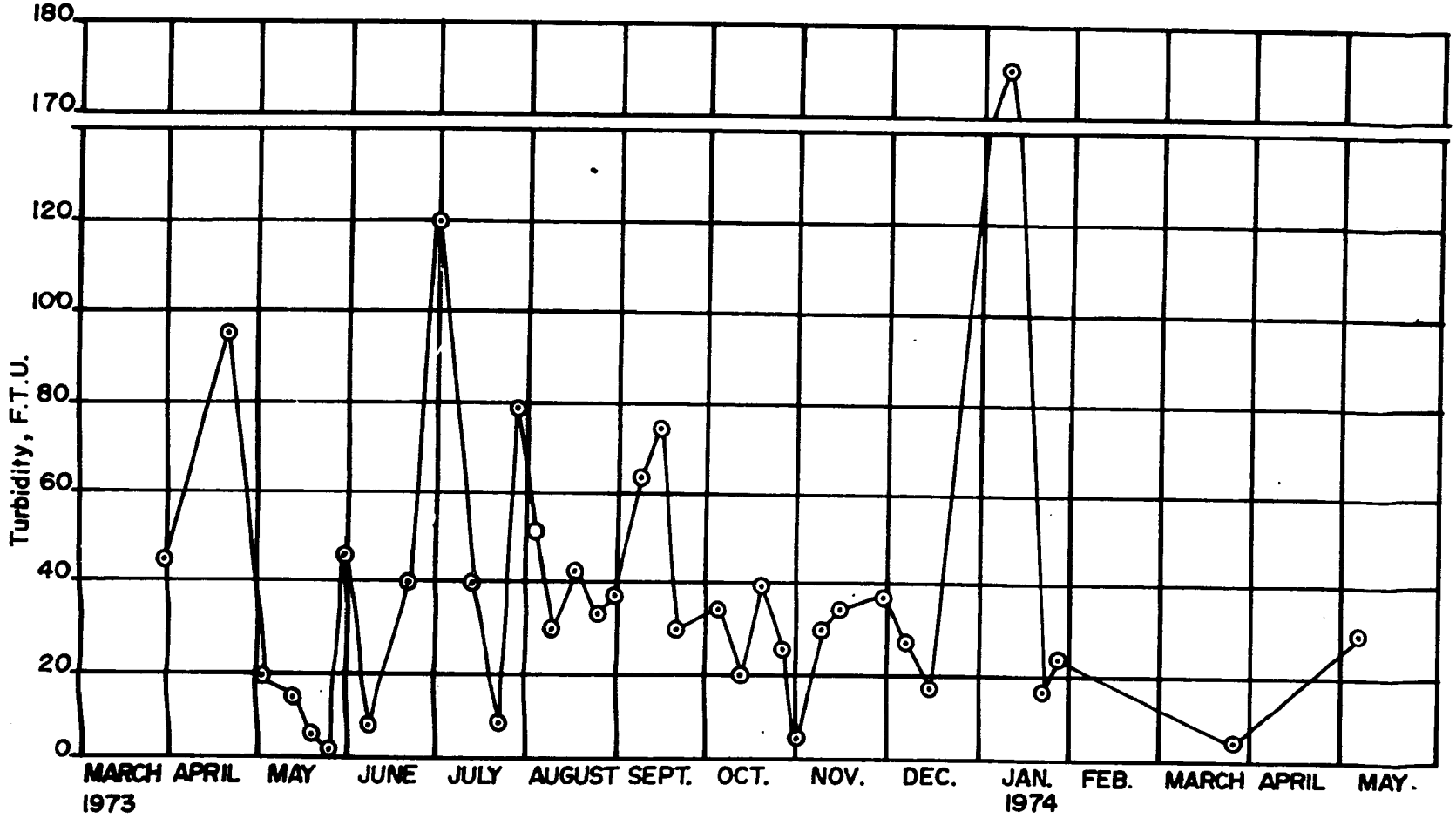

Figure 7. Turbidity of the composite wastewater.

Table 5. CHARACTERISTICS OF RAW COMPOSITE WASTEWATER DURING THE OPERATION OF THE PILOT PROJECT (March 1973 to May 1974)

	Minimum	Maximum	Average
COD, mg/ℓ	160	880	303
BOD, mg/ℓ	20	125	46
TOC, mg/ℓ	30	168	73
pH	6.0	7.6	6.75
Alkalinity, mg/ℓ	40	90	54
Hardness, mg/ℓ	20	80	36
Total Solids, mg/ℓ	640	1280	935
Volatile Solids, mg/ℓ	95	460	180
Dissolved Solids, mg/ℓ	640	1195	881
Suspended Solids, mg/ℓ	0	135	55
Color (Pt-Co units)	280	1660	757
Turbidity, F.T.U.	1.7	120	39.4
Conductivity (μmho/cm)	800	2160	1290
Metals			
Calcium, mg/ℓ	0.9	2.9	1.4
Zinc, mg/ℓ	2.0	6.0	3.8
Magnesium, mg/ℓ	0.51	4.0	2.9
Chromium, mg/ℓ	<0.1	0.3	<0.13
Copper, mg/ℓ	0.04	0.20	0.11
Iron, mg/ℓ	0.2	4.2	1.2
Mercury, μg/ℓ	0.46	1.08	0.76
Manganese, mg/ℓ	<0.1	<0.1	<0.1
Sodium, mg/ℓ	190	440	290

processing by the hyperfiltration equipment. The minimum, maximum, and average values of these parameters are presented in Table 5.

Because of the batch-type operation of the dye becks, there are periods when the waste stream is predominately wash water and other times when spent dye solutions cause the waste to be relatively highly concentrated. The sample selection for pilot plant use was random and somewhat biased toward higher levels of contaminants and color by the investigators' desire to avoid dilute wastewater. The treatment results are felt to be slightly conservative as wastewater characterization.

A final variable not measured directly, but of importance to all hyperfiltration except dynamic membranes, is fluid temperature. It was necessary to install a heat exchanger to maintain process temperature in the hyperfiltration unit in the safe operating range, less than 90 F (32 C) for the cellulose acetate and polyamide membranes (see Table 3).

Samples of process water were taken in the dyehouse at the time of the full scale reuse test dyeings. The chemical analyses were selected to permit a direct comparison with the recycled water. The results of the analyses of nine samples are summarized in Table 6.

Table 6. CHARACTERISTICS OF PROCESS (TAP WATER) WATER CURRENTLY USED IN THE LA FRANCE PLANT

	Minimum	Maximum	Average[a]
COD, mg/ℓ	<1	20	9
BOD, mg/ℓ	0.2	2	0.8
TOC, mg/ℓ	1	5	4
pH	5.8	7.4	6.7
Alkalinity, mg/ℓ	12	35	22
Hardness, mg/ℓ	9	30	16
Total Solids, mg/ℓ	45	85	61
Volatile Solids, mg/ℓ	10	55	26
Dissolved Solids, mg/ℓ	45	65	56
Color (Pt-Co units)	2	35	11
Turbidity, F.T.U.	0.15	4.1	1.1
Conductivity (μmho/cm)	60	100	75
Metals			
Calcium, mg/ℓ	1.0	2.0	1.32
Zinc, mg/ℓ	0.07	0.56	0.24
Magnesium, mg/ℓ	0.40	1.28	1.02
Chromium, mg/ℓ	<0.1	<0.1	<0.1
Copper, mg/ℓ	<0.04	0.04	<0.04
Iron, mg/ℓ	<0.15	1.2	0.90
Manganese, mg/ℓ	<0.05	0.11	–[b]
Sodium, mg/ℓ	5	10	8

[a] This is the average of 9 separate samples taken March 1973 to May 1974.

[b] There are too few data for manganese for a meaningful average.

SECTION VI

REUSE IN PRODUCTION DYEINGS

The reuse dyeings were carried out in a two-piece beck following standard plant procedures. Normally the dyeings were done at the beginning of the third week of each of the monthly test cycles. After the collection of 17 m^3 of purified product water and 1.5 m^3 to 3.8 m^3 of residual concentrate was completed, mixed samples of each were taken for analyses. These dyeings were conducted in the laboratory so that production scale formulations could be developed. The production dyeing formula was then given to the plant dyer who conducted the standard dyeing procedure.

Two types of plant dyeings were considered for each test cycle: (1) separate and independent dyeings employing only product water or only concentrate, and (2) one dyeing combining both the concentrate and product water. The concentrate was used as the initial dye bath with additional dyes added as prescribed in the formulation prepared in the laboratory. The product water was substituted for tap water in each step in the standard dyeing procedure.

Eighteen separate production dyeings were conducted with recycled product water and/or concentrate in the period March 1973 to July 1974. These are listed in Table 7 by cycle number which refers to operating periods, see Appendix B. The water recovery, i.e., the portion of the wastewater recovered as purified product water, is indicated for each test. Also, the performance of the membranes in terms of measured conductivity and color rejections is listed. The higher rejections are indicative of better quality product water and hence stronger concentrate. A higher water recovery generally means lower quality product water and stronger concentrate. Details of each production dyeing are given in Appendix B.

Table 7. PRODUCTION DYEINGS

Cycle number[a]	Membrane Type	Type of Water Used for Plant Dyeings[b]	Water Recovered	Conductivity Rejection	Color Rejections
			(%)	(%)	(%)
1	Polyamide	Product & Concentrate	75	90	98
2	Polyamide	Product & Concentrate	75	90	98
3	Polyamide	Combined	75	90	99
4	Polyamide	Combined	90	90	99
5	Polyamide	Combined	90	82	98
6	Polyamide	Product & Concentrate	90	75	86
7	Zr(IV)-PAA	Concentrate	75	85	99
8	Zr(IV)-PAA	Concentrate	75	65	98
9	Zr(IV)-PAA	Product & Concentrate	75	72	99
10	Cellulose Acetate	Product & Concentrate	75	92	99
12	Polyamide	Combined	75	95	99
14	Cellulose Acetate	Combined	75	95	99
16	Zr(IV)-PAA	Concentrate	75	88	99

[a] Cycles 11, 13, and 15 were equipment study cycles in which no water was saved for reuse dyeings.

[b] In some cycles, product and concentrate water were used separately in different dyeings and in some cycles they were combined for a single dyeing.

STANDARD DYEING PROCEDURE

The standard dyeing cycle involves the six-step procedure listed in Table 8.

Table 8. STANDARD DYEING CYCLE

Operation	Chemicals	Water Used (m^3)	Temperature (C)
Scouring	Detergent	1.9	50 - 82
Flush Bath		1.9	27
Dyeing	Dyes and Salt	1.5	50 - 93
Adjust Ahade	Dyes		93
Flush Bath		2.3	27
Dye Fixing Agent			27

REUSE OF CONCENTRATE WATER

Two types of tests were run classified by the procedure for selecting the shade to be dyed. Routinely the procedure was to select a shade in the immediate production schedule and add whatever dyes were needed to match the shade. Occasionally a shade was selected from the production catalog to be nearest that produced by the concentrate, therefore requiring minimal amounts of additional dyes. The first type of dyeing illustrates the technical feasibility of recycling the residue, even if only occasionally the production schedule may permit significant savings of dyes. The second type of dyeing indicates the optimum savings of dyes in recycled concentrate. Both types result in effective recycle of the concentrate, and thus avoid the cost of waste treatment. Successful production dyeings were achieved for both light and dark shades.

All the dyeings with concentrate are listed in Table 9. With a single exception, 100% cotton velour fabric was used in the concentrate

Table 9. REUSE DYEINGS OF COTTON VELOUR WITH CONCENTRATE WATER

Cycle number	Weight of Fabric (kg)	Shade	Number of Dyes		Amount of Dyes (% of Fabric Weight)	
			Reuse Test	Standard Test	Reuse Test	Standard Test
1	21.6	Tan	3	4	0.412	0.438
2	43.83	Blue-green	2	2	10.48	0.932
3[a,b]	36.9	Light Blue	1	3	0.055	0.189
4[b]	38.25	Rose	3	3	0.233	0.302
5[b]	36.9	Violet	2	2	0.130	0.130
6	88.65	Tan	3	4	0.305	0.438
7	68.85	Rose	3	3	0.310	0.189
8[c]	45.0	Blue-green	2	3	0.485	0.632
12[b]	23.4	Burnt-orange	3	3	1.450	1.940
14[b]	70.65	Gold	4	3	0.990	1.033
16[d]	16.2	Green	3	-	0.235	-

[a] Fabric composition this test: 65% Cotton - 35% Rayon

[b] Product and concentrate water were used together.

[c] Results from Cycle #9 and #10 are incomplete.

[d] This shade is not a standard item.

reuse dyeings. During Cycle #3, a 65% cotton - 35% rayon blend fabric was dyed. Nine different standard shades were dyed. The tan shade dyed in Cycle #1 was repeated in Cycle #6. This was done to (1) show that the shade for the reuse dyeing could be selected independently of the composition of the concentrate, and (2) provide a direct comparison of results achieved for 75% and 90% water recoveries. In each case the finished product was graded as first quality.

Dye formulations developed for the reuse tests generally were no more complex than the standards. The number of dyes employed are indicated in Table 9 for each reuse test. The amount of dye used in the reuse tests are listed with the standard for the shade. The comparison indicates a wide variation in the dye savings. In two cases, Cycle #2 and #7, more dye was required with the concentrate than in the standard formulae. The average of the 10 comparisons is, however, a 16 percent reduction in dye required to achieve standard shades.

A limitation of the reuse of reconcentrated dye residues is that they often yielded a dull grey color. Thus a darker shade had to be used so that the dullness would not affect the color of the finished fabric. In the 11 test cycles, successful production dyeings were achieved for both light and dark shades, however. The finished fabrics were generally the equivalent to standards in crocking and 40-hour Fade-O-Meter tests.

The analyses of the concentrated used in the reuse dyeings are given in Table 10.

Table 10. ANALYSES OF CONCENTRATED RESIDUES EMPLOYED IN REUSE DYEING

Constituent (mg/ℓ)	Cycle Number 1	2	3	4	5	6	7	8	12	14	16
COD	425	815	455	580	690	435	190	415	365	430	255
BOD	70	135	60	102	95	10	15	45	15	20	55
TOC	87	200	110	165	220	-	-	-	-	230	100
pH	6.7	6.5	7.0	7.2	7.2	7.4	8.0	7.5	6.8	6.7	9.0
Alkalinity	110	135	110	160	190	140	155	115	95	160	250
Hardness	90	120	80	90	135	130	50	55	245	190	130
Total Solids	2360	5570	2545	3020	4425	3425	1580	2510	4320	3025	3110
Volatile Solids	200	450	280	310	405	315	165	275	245	275	-
Dissolved Solids	2330	5540	2480	2985	4230	3435	1480	2450	4320	3025	3055
Color (Pt-Co units)	850	1250	1500	1000	1200	1250	1300	1680	920	1100	190
Turbidity, F.T.U.	39	31	2	40	30	80	8	15	4	35	18
Metals											
Calcium	3.0	-	-	6.5	9.0	6.0	1.0	8.1	34.0	7.5	15.5
Zinc	9.7	-	-	-	8.5	9.0	2.4	3.1	7.2	3.0	1.8
Magnesium	1.2	-	-	10.2	13.8	17.0	4.5	9.6	27.0	15.0	12.0
Chromium	-	<0.1	<0.1	-	0.1	-	-	-	-	0.6	-

REUSE OF PRODUCT WATER

The purified product water was used instead of tap water in each step of the standard dye procedure. Two types of tests were run classified by the use of product water in combination with the concentrate or with a standard dye formulation. The use of the product water in the production dyeing of a standard light shade, considered by the plant dyer to be the most difficult dye system in the plant, was expected to magnify any difficulties in the recycle of product water. This critical dyeing, done on a 54% nylon - 46% viscose automotive upholstery fabric, contained the formulation given in Table 11.

Table 11. CRITICAL TEST DYEING FORMULATION

Chemical	Dye Name
Acid Dye	Nylon Fast Yellow FLW
Acid Dye	Ciba Brown 2GL
Acid Dye	Ciba Yellow 2BRL
Acid Dye	Irgalan Black RBL
Direct Dye	Lumicrease Grey 3LBN
Direct Dye	Lumicrease Orange 3LG
Direct Dye	Lumicrease Bordeau 3LR

This critical test of the reuse of product water was carried out four times; Cycle #1, #6, #9, and #10. This test was thus used for each type of membrane and for each level of water recovery. In each case, this product water was used for all steps from scouring to final rinsing. The shade was obtained with no difficulty following routine procedures. The finished fabric passed 100-hour Weather-O-Meter test for color fastness.

In Cycle #2, product water was used to dye a yellow shade on a cotton ribbed velour fabric. The dyeing followed routine procedures with the

product water used in all steps. The appearance of the finished fabric was normal and crocking and light fastness were standard. After completing Cycle #2, it was apparent that the product water could be substituted freely for normal tap water in this plant's production dyeings.

The analyses of the product water used in all reuse dyeings is given in Table 12. The average of a number of analyses of tap water, collected at the time and at the place of the test dyeing is given for comparison. In general, the product water contains more solids than the tap water, but has lower concentrations of metals.

Table 12. ANALYSES OF PRODUCT WATER

Constituent (mg/ℓ)	Cycle Number 1	2	3	4	5	6	9	10	12	14	Tap Water
COD	25	20	20	15	15	25	30	200	10	25	<4
BOD	10	5	5	4	0.3	1	2.7	1.3	2	1	0.6
TOC	3	4	4	4	4	-	-	-	-	5	4
pH	6.1	6.0	6.4	6.5	7.1	7.2	6.2	6.2	6.4	5.9	6.7
Alkalinity	10	15	15	15	25	15	40	3	10	8	27
Hardness	30	15	20	5	5	10	4	6	3	0.5	19
Total Solids	100	270	130	280	440	285	630	215	230	45	67
Volatile Solids	30	N.D.	20	40	40	60	95	75	65	15	36
Dissolved Solids	100	270	130	280	440	285	630	205	230	50	59
Color (Pt-Co units)	30	20	13	6	30	60	30	60	20	40	13
Turbidity (F.T.U.)	2.4	0.5	1.3	0.8	3.4	6.3	1.5	6	2.0	2.5	1.11
Metals											
Calcium	0.5	-	-	0.24	0.10	0.5	0.17	0.88	1.00	0.08	1.45
Zinc	<0.04	-	-	-	0.08	0.7	0.06	0.82	0.50	0.04	0.07
Magnesium	<0.01	0.1	-	0.28	0.22	0.9	0.58	0.78	0.42	0.02	0.96
Chromium	-	<0.1	<0.1	-	0.1	-	-	-	-	0.10	<0.1
Copper	-	-	<0.4	-	-	0.8	-	-	-	0.04	<0.04
Iron	0.04	<0.13	<0.1	-	-	-	0.63	1.13	-	0.14	<0.68
Mercury (μg/ℓ)	0.3	N.D.	0.56	-	-	-	-	-	-	-	2.51
Manganese	-	<0.1	-	-	-	-	-	-	0.04	0.03	<0.05
Sodium	-	-	-	94	160	90	270	55	75	15	10

SECTION VII

EQUIPMENT PERFORMANCE

A major goal of the project was to demonstrate the practicality of hyperfiltration equipment in an actual plant-site evaluation. This goal was accomplished by evaluating four commercial membrane modules in a pilot plant. The layout and operation of the pilot plant are described prior to presentation of the performance data for each membrane module.

Specific pretreatment of the wastewater feeds to the membrane modules, e.g., fine filtration, pH adjustment, and temperature control, was utilized as required by manufacturer specifications. However, limited attention was given to the study of pretreatment, and certainly no optimization of pretreatment for textile wastes was attempted. Because of the strong influence of membrane flux on hyperfiltration treatment plant costs, the evaluation of means to minimize flux decline is important.

Three membranes were evaluated; polyamide, cellulose acetate, and Zr(IV)-polyacrylate. Cellulose acetate was evaluated in two configurations, thus four commercial module configurations were evaluated: (1) tubular, cellulose acetate membranes on the internal wall of 13 mm diameter channels[6], (2) hollow-fine polyamide fibers[5], (3) spiral-wound sheets of cellulose acetate[2], and (4) external coatings of Zr(IV)-PAA dynamically deposited[7] on ceramic, 21 mm diameter tubes. The original program plan was to evaluate only the polyamide and the Zr(IV)-polyacrylate membranes. The project was extended since the four configurations represented basically all the commercially available configurations.

The details operation performance of each membrane module evaluated is presented in this section. The separation efficiency (rejection percentage) for the important parameters of color and specific conductivity rejection and membrane flux are presented graphically for the entire evaluation periods. The detailed chemical analyses and percentage rejection for each measured species are presented in Appendix C.

PILOT PLANT

Figure 8 presents a schematic description of the pilot plant equipment. The raw wastewater feed was introduced into the pilot plant either from the total plant operation downstream of a 150 m^3 level-controlled mixing sump, or directly from a dyehouse drain. The dyehouse drain led from only five (of 32) of the larger dye becks and was subject to wide variations in composition ranging from that of the spent dye liquor to that of comparatively clean wash water.

The raw wastewater was introduced into 2.3 m^3 elevated reservoirs through 40-mesh screen to remove particulates, especially fibers. In effect, the raw feed to the pilot plant was collected and processed as 2.3 m^3 batches. Since the productivity and the capacity of the individual hyperfiltration modules was not constant, the number of batches processed per day varied.

The hyperfiltration membrane modules evaluated were of two basic types. The modules with pre-formed membranes (polyamide and cellulose acetate) were evaluated in a low pressure, up to 450 psi (3.1×10^6 Pa), system employing a variety of prefilters, and temperature control (below 38 C). As required for cellulose acetate membranes, pH control was effected by monitoring and adjusting each 2.3 m^3 batch. This system employed a 5.6 kW motor with a centrifugal pump (Gould BP3933).

The ceramic tube modules (dynamic Zr(IV)-PAA membranes) were evaluated in a high pressure loop, up to 1000 psi (6.9×10^6 Pa), employing a triplex positive displacement Gaso pump with a 22 kW motor. Since no pretreatment was required, it was possible to study the effect of prefiltration only by by-passing feed from the low pressure system downstream of its pretreatment section.

For evaluation of the pre-formed membranes, the wastewater collected in the 2.3 m^3 elevated reservoirs was transferred by gravity to a 0.2 m^3 pump suction reservoir. Before entering the membrane modules, the wastewater passed through a prefiltration unit, which contained 25 micron and 1 micron cartridge filters in series. When required, the wastewater could also be directed through a 2.2 m^2 diatomaceous earth filter.

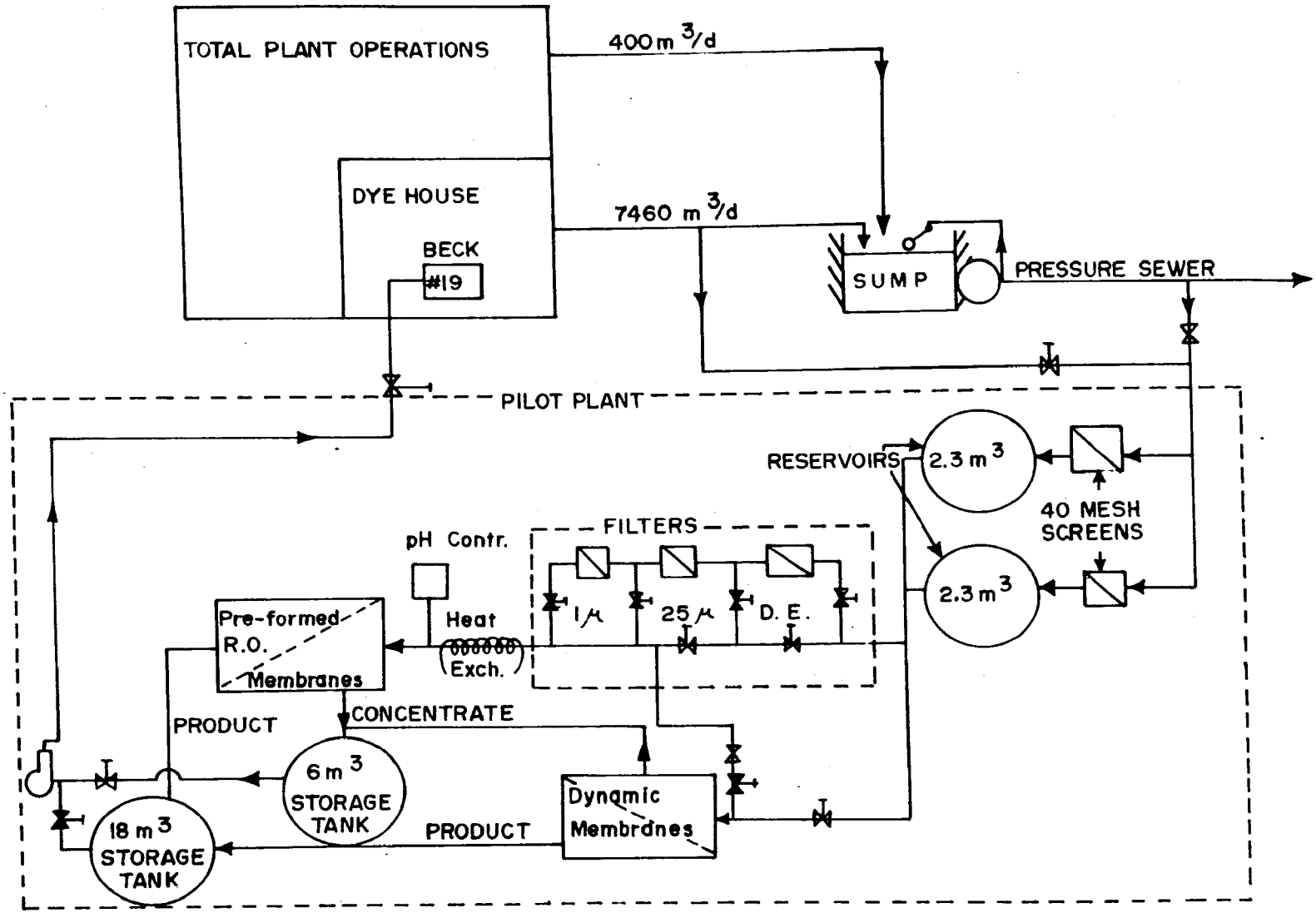

Figure 8. Schematic of pilot plant layout.

Instrumentation was included to permit monitoring of flow rates, pressure, and feed temperature. Sampling ports were provided to facilitate sample collection for monitoring module performance in terms of water quality and concentration factors.

The product and concentrate from the hyperfiltration modules were collected in stainless steel storage tanks. Generally it was necessary to collect from 1.5 to 3.8 m^3 of concentrate and from 9.5 to 17 m^3 of product water to carry out a full scale production dye cycle in the standard two-piece beck. The normal procedure was to do one reuse dyeing per month. On occasion, two reuse dyeings were accomplished by using the product and concentrate in separate full scale production dyeings.

TUBULAR CELLULOSE ACETATE (Westinghouse)

During the period from December 5, 1973, to February 1, 1974, a Westinghouse tubular, cellulose acetate membrane module (No. 4-291) was operated on total plant composite wastewater for 1059 hours. The unit was used to process a total of 10.7 m^3 of wastewater collected in four batches. To simulate the operating conditions for a full scale treatment plant, the module performance was monitored as the wastewater was concentrated to product water recoveries of 96%. The first two batches, a total of 6.1 m^3, were concentrated to an average recovery of 72%. The concentrate and product waters were collected and used in a full scale dyeing (Cycle #10). Independently, the last two batches, approximately 2.3 m^3, each were concentrated to 96% recovery.

The module evaluated was a tubular configuration having 0.86 m^2 of cellulose acetate membrane surface. The tubular flow passages consisted of eighteen, 13 mm diameter channels in a porous cylindrical block, a "sand log", enclosed in a 101 mm diameter by 1.22 m long stainless steel pressure vessel. The fluid flows through each of these eighteen channels in series.

Two operational modes were used. The first was the concentration mode. In this mode, the product water from the module was collected for reuse while the concentrate was directed back to the 0.2 m^3 polyethelene

tank at the pump suction. Raw feed was continuously added to this tank from the 2.3 m^3 elevated feed tanks so that the level in the pump suction tank was constant. The concentration of the feed in the test loop continuously increased as the product water was withdrawn. The variation of concentration with time simulated the variation of concentration with location in a full scale plant.

In the second mode, one 0.2 m^3 batch of wastewater was recirculated continuously through the module with both the product water and the concentrate directed back to the pump suction tank. Except for minor changes in the characteristics of the wastewater with time, this recirculation mode was a steady state condition. This steady state performance simulated the operating conditions of individual modules in a full scale treatment plant.

The main operating parameters which were varied during the course of the tests were the feed pressure upstream of the module, 300 - 450 psi (2.7×10^6 to 3.1×10^6 Pa), the supply temperature, 55 - 90 F (12.8 - 32.2 C), and the circulation velocity, 5 - 10 ft/sec (1.5 - 3 m/sec). The operation of the loop was conducted on a continuous basis except for maintenance downtime. When the loop was shut down, the module was flushed with tap water for about 10 minutes in both the normal and reverse flow directions.

Before any wastewater was supplied to the module, it was tested with a solution of 500 mg/ℓ NaCl in water. The results of 150 hours of operation using the NaCl solution are shown in Figure 9. After an initial decline, the product flux was constant at 8.3 GFD (0.023 cm/min) for a pressure of 300 psi (2.07×10^6 Pa), and temperature of 60 F (15.5 C). The conductivity rejection averaged 91% for this salt solution.

The operating performance of the Westinghouse module is presented in Figure 9, where the membrane flux, color, and conductivity rejections are plotted for the initial 36 days of operation. Following the introduction of wastewater to the module, on the ninth day, the flux dropped 15% as the concentration of the feed was more than doubled by recovering 66% as product water. Additional raw wastewater was mixed with this residual of Batch #1 on the sixteenth day. Operation continued to 73% water recovery;

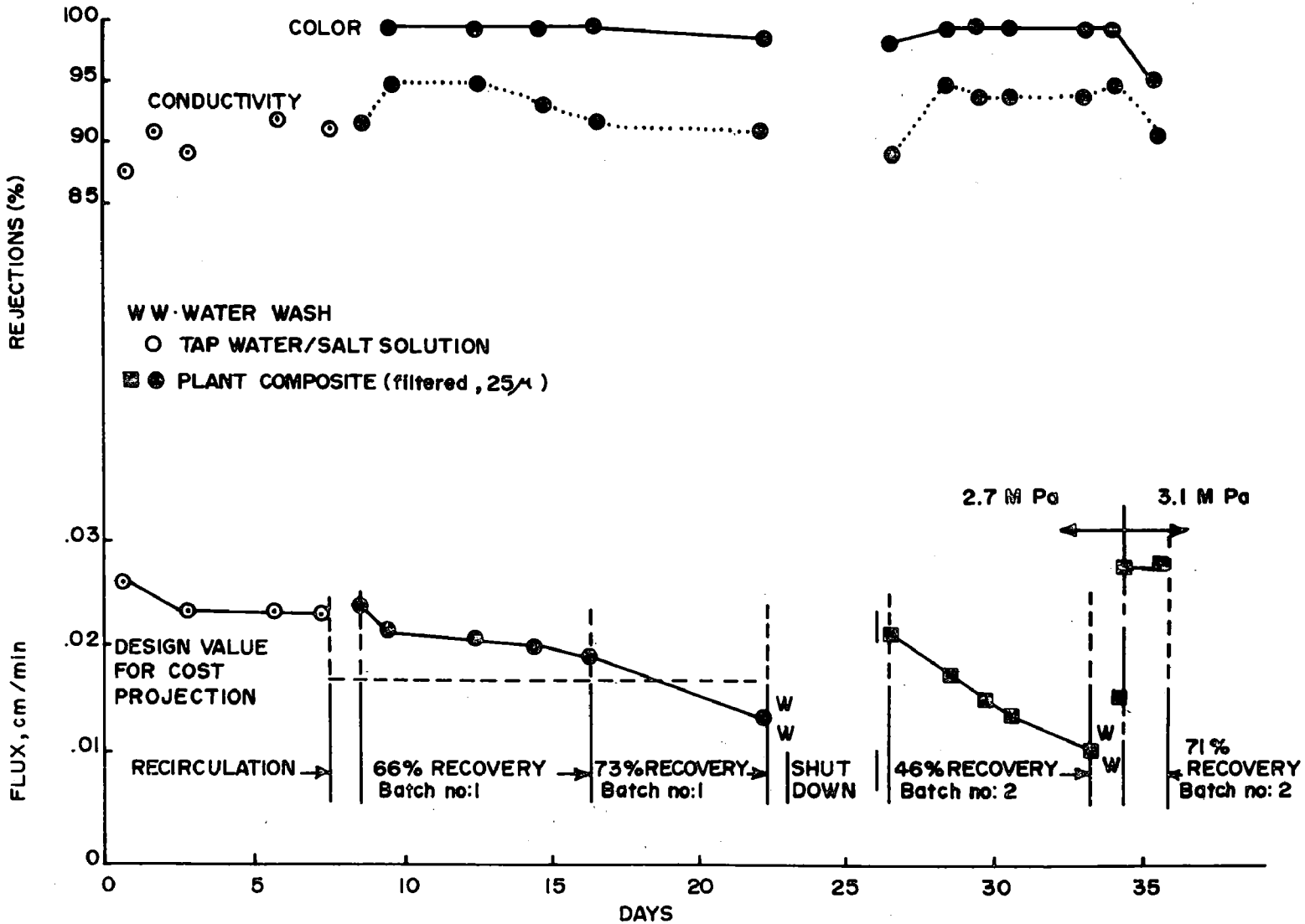

Figure 9. Operating performance of Westinghouse module at La France.

i.e., about 4-fold concentration of the feed to the module, was accomplished on the twenty-second day. During the processing of this combined batch of wastewater, the flux decline increased. The flux had declined nearly 40% as wastewater was processed to 73% recovery; from 0.023 to 0.014 cm/min. Both the conductivity rejection (95 - 91%) and color rejection (99+ - 98%), however, exhibited only slight decreases as the concentration of the feed supply to the module was increasing.

Following the transfer of Batch #1 concentrate to storage, the module was cleaned by flushing with tap (plant process) water for 15 minutes. Following shut down over the weekend, the flux was 0.02 cm/min during the initial operation with Batch #2 wastewater. This was a recovery to approximately 90% of the flux with the salt water solution.

Wastewater Batch #2 was processed to slightly more than 71% recovery during the period from the twenty-sixth day through the thirty-fifth day of operation. During the next seven days as the feed to the module was processed to about double its original concentration, the flux declined rapidly to 50% of the original value. A 20-minute flush with tap water only partially restored the flux. A second 20-minute tap water flush was followed immediately by an increase in the operating pressure from 2.07×10^6 to 3.1×10^6 Pa. The flux increased correspondingly to 0.027 cm/min. With this high flux, wastewater Batch #2 was then concentrated to 71% product water recovery rapidly. No flux decline was noted during the two-day operation at this elevated pressure. There was a significant drop in rejections, however, color (99 - 95%), and conductivity (95 - 90%).

These results are tabulated in Table 13. The pH was maintained in the range of 5.6 - 6.6. The total solids concentration of the two batches of wastewater were 1380 mg/ℓ and 2265 mg/ℓ. The total solids concentration in the final mixed concentrate from these two batches was 4000 mg/ℓ.

During the final 500 hours of operation of the Westinghouse module, the parameters of velocity, temperature, and pressure were varied while both the product water and concentrate were recirculated to maintain a constant feed to the module. The recirculation prior to any concentration of the raw wastewater feed simulated the inlet section of a treatment plant. Recirculation after an initial period of recovery of 96% of the

Table 13. OPERATING PERFORMANCE[a] OF TUBULAR CELLULOSE ACETATE WESTINGHOUSE MODULE WITH LA FRANCE COMPOSITE WASTEWATER

Operating time (hrs)	Flux (cm/min)	Rejections[b] (%)			Recovery Fraction (%)
		Total Solids	Color	Conductivity	
December 1973	(Pressure 2.07 x 10^6 Pa)				
1	0.023	-	-	92	0
23	0.020	97	99.7	95	-
95	0.018	96	99.9	95	-
143	0.016	96	99.3	93	-
185	0.016	-	99.0	92	66
337	0.014	-	98.7	91	73
January 1974					
435	0.014	97	99.9	94	27
502	0.011	96	99.9	94	46
	(Pressure 3.1 x 10^6 Pa)				
525	0.027[c]	-	99.9	95	46
530	0.028	92	93.2	88	-
545	0.028	92	93.2	88	71

[a] Operating conditions held constant. Flow = 11 dm^3/min; pH = 5.8 - 6.9; T = 11 - 15 C.
[b] Color 585 - 3960 Pt-Co units; total solids 1380 - 4155 mg/ℓ, conductivity 960 - 8500 μmho/cm.
[c] Tap water flush increased flux 0.11 to 0.18 cm/min.

product water (corresponding to about a 20-fold increase in concentration of the feed to the module) simulated the extreme outlet section of a treatment plant.

The results are tabulated in Table 14, and illustrated in Figure 10. The decline of flux and rejections with increasing concentration, as product water recovery increased, is evident for both 2.3 m^3 batches of wastewater processed. The effects of pressure and temperature are as expected. The sharp drop in flux that occurred at the end of the test period is not understood.

In summary, the performance of the Westinghouse tubular cellulose acetate module exhibited a 40% loss in flux for product water recoveries of 75 - 90%. This result is reflected in the selection of a design condition of 450 psi (3.1×10^6 Pa), which at a temperature of 90 F (32 C) yielded a flux of over 0.042 cm/min. The design value for these operating conditions was taken as 0.038 cm/min for the cost projection. No detergent cleaning was used in this study, however, this may prove practical periodically, particularly in modules exposed to the higher concentrations near the outlet of a treatment plant. The quality of product water at 75% recovery was satisfactory for reuse in all dyeing operations at La France.

HOLLOW POLYAMIDE FIBER (DuPont)

During the period from February 6, 1974, to March 27, 1974, a DuPont hollow-fine polyamide fiber module (No. 400600) was evaluated. During this period the module was operated for 187 hours with a continuous fresh supply of wastewater from five dye becks. The limited capacities of the specific prefiltration available in the pilot plant made it possible to operate the module only an average of about 4 hours per working day. However, the module was used to process over 79 m^3 of wastewater, the final portion of which was reused in Cycle #12.

During the first several months of operation of the pilot plant, two other DuPont modules were used to process total plant composite wastewater. Even though the earlier processed wastewater was reused in plant dyeings, Cycles #1 through #6, only the equipment performance evaluated during

Table 14. OPERATING PERFORMANCE[a] OF TUBULAR CELLULOSE ACETATE WESTINGHOUSE MODULE WITH LA FRANCE COMPOSITE WASTEWATER UNDER VARIABLE CONDITIONS

Operating time (hrs)	Temperature (C)	Flux cm/min	Rejections[b] (%) Color	Rejections[b] (%) Conductivity	Recovery Fraction (%)
	Pressure = 450 psi (3.1×10^6 Pa); Flow = 22.7 dm^3/min				
556	17	.030	99.3	92	0
648	18	.025	98.9	93	62
670	13	.025	99.5	95	73
674	32	.044	99.7	93	79
701	34	.043	94.7	85	97
	Flow = 11.3 dm^3/min				
720	26	.043	97.0	92	19
744	30	.045	97.1	91	45
	Pressure = 300 psi (2.07×10^6 Pa)				
750	17	.021	99.1	93	45
891	18	.012	99.3	90	96
901	19	.012	99.3	88	96
920	19	.012	98.8	80	96
	Pressure = 450 psi (3.1×10^6 Pa); Flow = 22.7 dm^3/min				
947	16	.024	96.9	93	0
1010	19	.023	99.2	94	0
1035	19	.018	98.4	93	0
1059	17	.010	96.7	92	0

[a] Operating conditions: pH = 6.0 - 8.0

[b] Color 60 - 2085 Pt-Co units, conductivity 650 - 11,200 μmho/cm

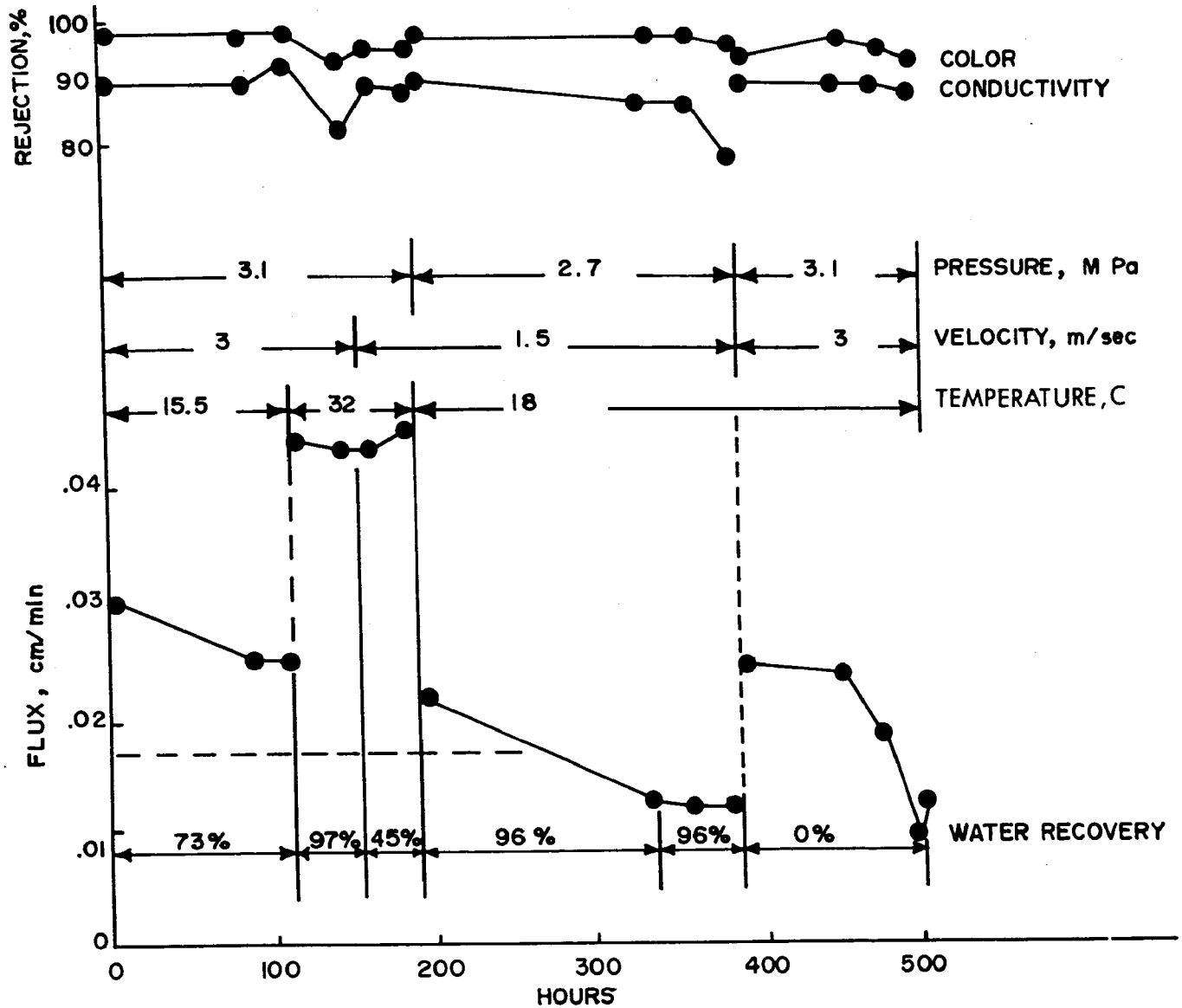

Figure 10. Operating evaluation of Westinghouse module during final 500 hours.

Cycle #12 is felt to be typical for the DuPont modules. The procedure followed during Cycle #12 is: (1) Only dyehouse wastewater (to minimize sanitary constituents) was treated, (2) only "fresh" feed entered the module; i.e., no recirculation of wastewater, (3) no stagnant conditions with wastewater in the modules were permitted, and (4) diatomaceous earth prefiltration (prior to 25 micron and 1 micron cartridge prefilters) was employed. These conditions limited the productivity of the pilot plant which had limited prefiltration capacity. As indicated in the cost projections for a full scale treatment plant, these procedures have little effect on cost of plant operation.

These four operating procedures were followed as the module was evaluated for a 20 dm^3/min supply rate which at 350 psi (2.4×10^6 Pa) and about 60 F (15.5 C) resulted in approximately a 50% recovery of water. Only during the last 15 hours of operation was recirculation of processed concentrate employed. At that time the initial concentrate was collected; e.g., 1.2 m^3 from each 2.3 m^3 of dyehouse wastewater, and reprocessed, also at 20 dm^3/min and 50% recovery for in-plant reuse evaluation.

The details of the operation of the DuPont module are presented in Table 15 and shown in Figure 11. The tabulated results indicate the wastewater pH range was 6.2 - 8.0. No pH adjustment was required as the polyamide fibers can operate in the range of pH 2 - 11. The temperature ranged from 11 C - 23 C.

Even though constant attention was required to maintain the proper prefiltration, the pressure drop across the module did not exceed the specified limit of 20 psi (0.14×10^6 Pa) until after approximately 166 hours of operation. Four hours of detergent washing reduced the pressure drop to its initial level. As shown in Figure 11, the product flow rate was reduced only slightly at the greater module pressure differential, and was not significantly improved by the detergent washing.

In Figure 11, a very sharp decline in product flow that occurred at 65 hours of operation is noted. The total solids concentration of the wastewater supplied to the module was 16,000 mg/ℓ. Other declines in product flow rate occurred at 30 hours and at 187 hours. At both of these times the total solids were higher than the average of about 2300 mg/ℓ;

Table 15. OPERATING PERFORMANCE[a] OF HOLLOW POLYAMIDE FIBER DUPONT MODULE WITH LA FRANCE DYEHOUSE WASTEWATER

Operating time (hrs)	Temperature (C)	Product Flow Rate dm^3/min	Rejections[b] (%)		Recovery Fraction (%)
			Color	Conductivity	
February 1974					
1	19	9.0	>99	96	53
10	14	8.0	98	97	49
16	11	7.9	93	94	47
23	20	8.3	>99	98	49
27	17	8.3	>99	97	49
32	9	6.4	>99	96	56
48	13	8.3	>99	97	49
64	14	3.8	>99	92	22
65	18	3	-	93	18
73	11	7.6	-	95	44
81	12	7.9	>99	97	47
106	19	8.0	>99	94	49
129	23	7.9	>99	93	47
144	18	7.9	>99	88	47
160	20	7.6	>99	94	44
166	16	6.8	>99	91	40
March 1974	(shut down for detergent wash)				
172	12	6.4	>99	89	50
176	16	6.8	98	82	50
180	18	7.6	>99	84	50
187	20	6.4	>99	86	50

[a] Operating conditions: $P = 2.4 \times 10^6$ Pa; flow = 17 dm^3/min; pH = 6.2 - 8.0.
[b] Color 30 - 1250 Pt-Co units; conductivity 610 - 22,000 μmho/cm.

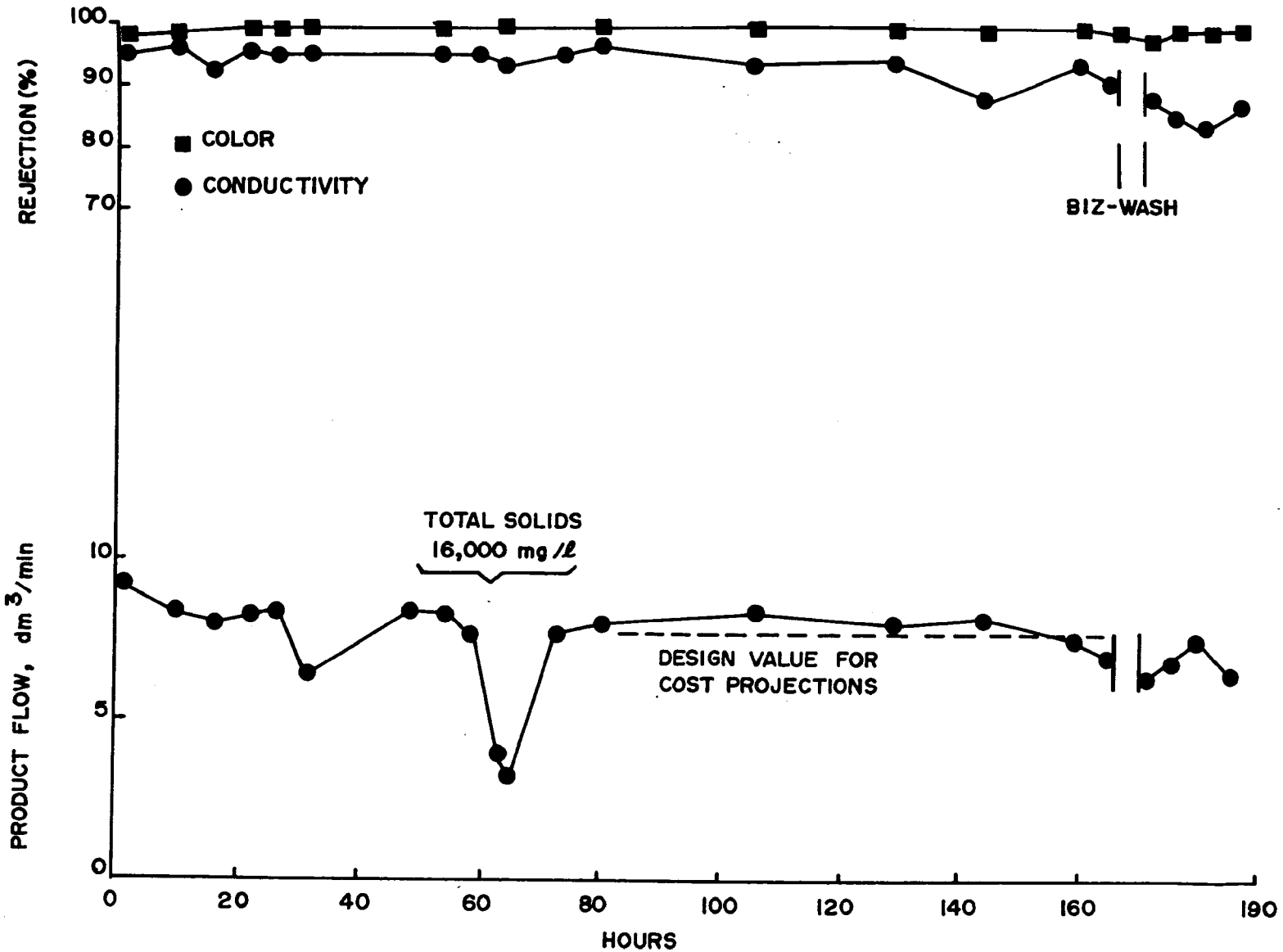

Figure 11. Operating performance of DuPont hollow polyamide fiber module at La France.

i.e., 4515 mg/ℓ at 30 hours and 3400 mg/ℓ at 187 hours. There is evidently a significant effect on product flow rate of high solids loading, even after extensive prefiltration. It does appear that the effect is easily reversed by returning to a lower solids concentration. The effect of total solids concentration upon the rejections is quite small.

Following the wash with Biz detergent at 166 hours, the wastewater was recirculated to achieve a constant 50% product water recovery. This recirculation was continued for only 15 hours, but seemed to influence both product flow rate and rejection. The conductivity rejection decreased from 90 to 85%, while the product flow rate increased by 17%. Following the Biz detergent wash, 1.2 m^3 of concentrate was collected while the module was operating at 50% product recovery. When this concentrate was returned to the module as feed, the product flow rate dropped by 10%, and the conductivity rejection increased slightly. (The data are shown as the last data points in Figure 11.)

There is no apparent explanation for these trends. It seems worthwhile to conclude, however, that while detergent washing was effective in reducing the pressure differential across the module, the washing had no significant effect on either product flow rate or rejections.

In summary, the performance of the DuPont hollow fiber module was evaluated for 187 hours. With filtered dyehouse wastewater fed continuously to the module, and with no recirculation of concentrate, the pressure differential across the module exceeded desired limits after 166 hours of operation. It is possible that the daily re-charging required for the small diatomaceous earth filter allowed particulates to enter the module which could account for the pressure differential build-up. ABCOR used the above data to prepare the cost projections for a full scale treatment plant. The cost analysis included prefiltration as recommended by DuPont.

The quality of the product water from the DuPont module was adequate for reuse in all dyeing operations at La France.

SPIRAL-WOUND CELLULOSE ACETATE (Gulf)

During the period from March 28, 1974, to May 7, 1974, a spiral-wound, cellulose acetate membrane module was evaluated. During this interval the module was operated for 632 hours on wastewater supplied from five dye becks and subsequently for 172 hours on composite wastewater from the total plant. The unit thus processed approximately 230 m^3 of wastewater. A portion of the approximately 45 m^3 of composite wastewater processed was stored for reuse in dye Cycle #14.

The module evaluated contained 3 standard spiral-wound units in a 101 mm diameter x 3.65 m long pressure vessel. The membrane surface area was 18 m^2.

During the evaluation, the module was supplied with 13 dm^3/min of 25 micron prefiltered wastewater and operated at 400 psi (2.76×10^6 Pa), in the temperature range of 14.4 - 25.5 C. The initial product water flow rate was 4.5 dm^3/min yielding 33% product recovery. After about 90 hours of operation a portion of the module effluent was recirculated directly to the pump suction to maintain a 75% recovery. The pH was controlled in the range of 5.8 - 7.0, except for brief exposures to pH 8. pH control was by chemical addition to each 2.3 m^3 batch of wastewater processed.

The operating performance of the Gulf module is shown in Figure 12, and Table 16. The product flow rate, color, and conductivity rejections are plotted for the entire period of the evaluation. The product flow rate decreased from an initial value of 6.7 dm^3/min exhibited during the treatment of a 1500 mg/ℓ NaCl solution to a stable value of 3 dm^3/min.

The variations in prefiltration, wastewater source, and mode of operation did not seem to materially influence the membrane performance. The performance over the last 170 hours of operation with 25 micron prefiltration, while processing composite wastewater to 75% product recovery, was used as the basis for the cost projections.

The color rejection was uniformly greater than 99%. The conductivity rejection averaged approximately 95%. The slight decrease in conductivity rejection, shown in Figure 12, is apparently related to higher total solids concentration in the wastewater.

Table 16. OPERATING PERFORMANCE[a] OF SPIRAL CELLULOSE ACETATE GULF MODULE WITH LA FRANCE WASTEWATER

Operating time (hrs)	Product Flow Rate dm^3/min	Rejections[b] (%)		Recovery Fraction (%)
		Color	Conductivity	
March 1974	(1500 mg/ℓ NaCl)			
1	6.4	-	95	37
20	6.4	-	96	37
	(dyehouse wastewater, 1 micron filter)			
1	4.5	97	97	33
20	4.2	97	98	32
91	3.8	98	98	29
April 1974				
95	4.5	99	97	75
120	4.5	99	97	75
146	4.5	99	97	75
	(dyehouse wastewater, 25 micron filter)			
165	4.5	99	96	75
193	4.5	99	96	75
259	4.5	99	93	75
	(closed circuit recycle started)			
272	3.0	99	95	75
440	3.0	99	95	75
630	3.0	99	93	75
	(end recycle - 1 hour tap water flush)			
	(composite wastewater - collection for dye Cycle #14)			
633	3.8	99	97	75
May 1974				
660	3.0	99	97	75
708	3.0	99	97	75
780	3.0	99	97	75

[a] Operating conditions: $P = 2.8 \times 10^6$ Pa; Flow = 19 dm^3/min; T = 14 - 26 C; pH = 5.8 - 7.0.
[b] Color 57 - 2800 Pt-Co units; conductivity 1450 - 5900 μmho/cm.

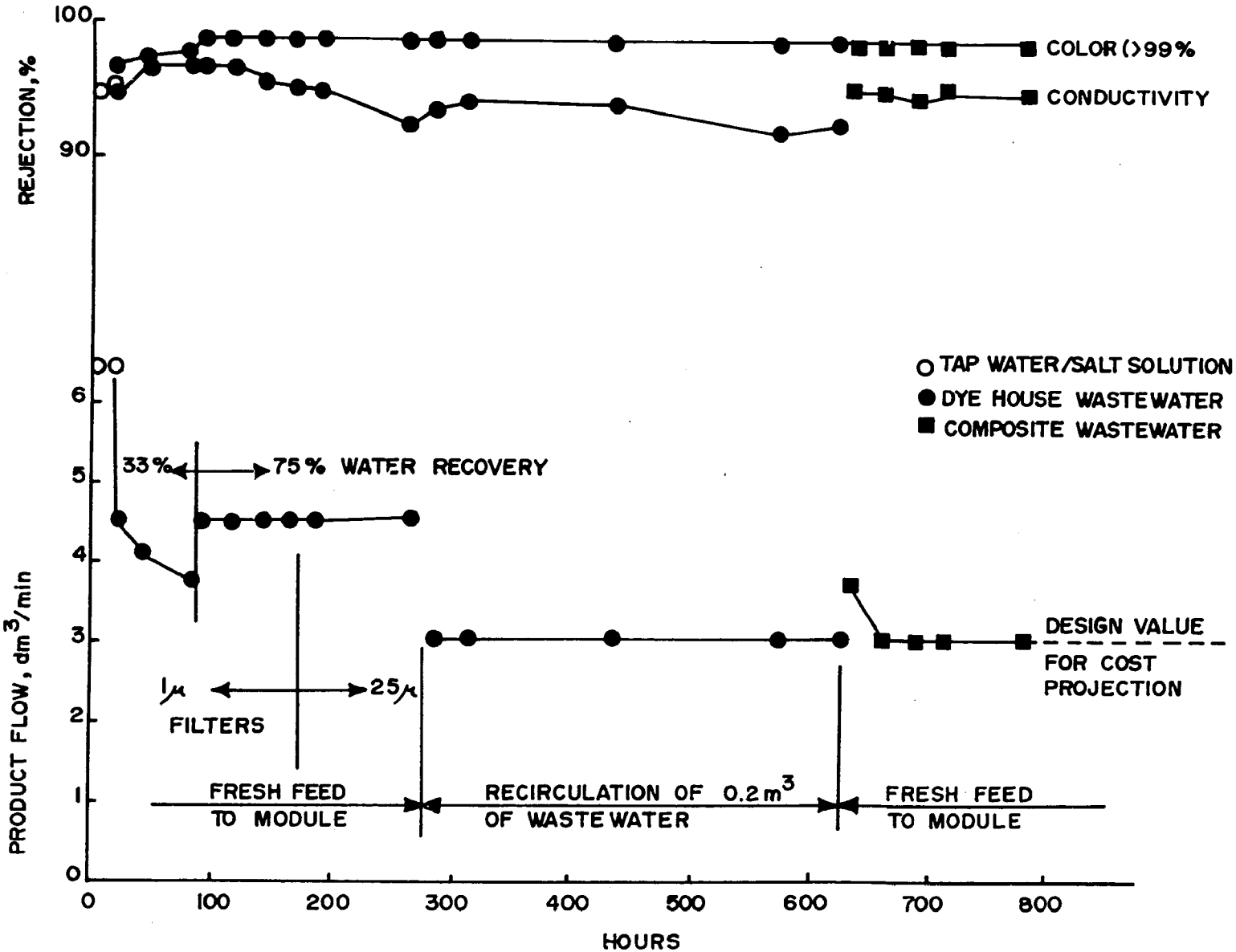

Figure 12. Operating performance of Gulf (U.O.P.) spiral cellulose acetate module at La France

In summary, the Gulf spiral-wound cellulose acetate module exhibited a flux decline of approximately 40% for treatment of composite wastewater to 75% recovery of product. The product flow rate was stable over an extended period of operation. The quality of product water was satisfactory for reuse in all dyeing operations at La France.

DYNAMIC Zr(IV)-POLYACRYLIC ACID (Selas)

During the period June 4, 1974, to July 2, 1974, a Selas ceramic tube, Zr(IV)-polyacrylic acid membrane was operated for 650 hours. The unit was evaluated first with wastewater from five dye becks and then with the composite wastewater from the total plant. In addition, the membranes were used in a separate evaluation of indigo wash water. The concentrate from the treatment of the dyehouse wastewater was reused in Cycle #16.

The module evaluated was a tubular configuration employing eight units in series. Each unit consisted of 19, 5.5 mm diameter porous ceramic tubes. The membranes were deposited on the external surface of the tubes. With a 0.16 m^3/min wastewater supply rate to the module, the ratio of product water or permeate flow to wastewater flow through the module was considerably less than 1%.

Two modes of operation were used. The first was the concentration mode. In this mode of operation product water from the module was collected while the concentrate was recirculated to a 0.3 m^3 stainless steel tank at the pump suction. Raw wastewater was continuously added from the 2.3 m^3 elevated reservoir to maintain a controlled level in the 0.3 m^3 tank. The concentration of the feed to the module continuously increased as the product water was withdrawn. In the second mode of operation, one 0.3 m^3 batch of wastewater was recirculated continuously through the module with both the product water and concentrate directed back to the pump suction tank.

The operating parameters varied during the course of the evaluation were: (1) type of wastewater, (2) degree of prefiltration, (3) pressure, 300 - 700 psi (2.07×10^6 to 4.8×10^6 Pa), (4) temperature, 80 - 190 F (26 - 88 C), and (5) circulation velocity, 2.3 - 4.6 m/sec. The

pH was not controlled, since dynamic membranes can operate in a range of pH 4 - 11, well within the range observed for the wastewater at La France.

Previously, dynamic membranes in laboratory test modules provided by the Oak Ridge National Laboratory were used to provide the renovated wastewater reused in Cycles #7, #8, and #9. Since these test modules were not commercially available, only the performance of the Selas module is considered appropriate for use in the cost projections.

Before any wastewater was supplied to the Selas module, it was tested with a 500 mg/ℓ NaCl solution. At 700 psi (4.8×10^6 Pa) and 50 C, the flux was 0.33 cm/min and the conductivity rejection was 91%. The operating performance of the Selas module is described in Figure 13, and Table 17, where the flux, color, and conductivity rejections are presented for 30 days of operation. To evaluate the effect of wastewater composition and prefiltration on the rate of flux decline, the module was evaluated under what was expected to be increasingly more difficult conditions. Because the characteristic of high temperature operation permits the possibility of energy recovery, the tests were carried out at elevated temperatures.

Initially, the module was supplied with wastewater from five dye becks. This wastewater was prefiltered through the 25 micron cartridge filters. The flux declined sharply from greater than 0.33 cm/min to 0.045 cm/min. Subsequently, a flush with tap water returned the flux to 0.1 cm/min. A repeated concentration of dyehouse wastewater to about 75% product recovery produced a similar decline in flux to about 0.055 cm/min. Another flush with tap water resulted in a flux of about 0.1 cm/min.

A series of tests with indigo rinse water was carried out from the fourteenth to the twenty-first day. During this time the flux recovered to over 0.22 cm/min. The sharp drop in conductivity rejection that occurred on the seventeenth day corresponds to a total solids concentration of 57,000 mg/ℓ.

Beginning on the twenty-first day, the module was then supplied with total plant composite wastewater through 25 micron prefilters. The flux decline was again rapid. After about 20 hours, the module supply was

Table 17. OPERATING PERFORMANCE[a] OF CERAMIC TUBE Zr(IV)-PAA SELAS MODULE WITH LA FRANCE WASTEWATER

Operating time (hrs)	Flux (cm/min)	Temperature (C)	Rejections[b] Color	Rejections[b] Conductivity
June 1974	(salt solution)			
22	.34	50	-	91
	(dyehouse wastewater, 25 micron filter)			
30	.23	43	>99	83
76	.05	46	>99	88
98	.04	48	88	87
	(salt solution)			
148	.10	36	-	92
	(dyehouse wastewater, 25 micron filter)			
167	.07	30	>99	89
190	.12	48	>99	88
238	.07	48	97	88
262	.06	48	95	86
	(tap water)			
330	.12	54	-	-
	(indigo)			
338	.13	58	-	91
356	.15	60	>99	88
375	.12	46	>99	88
402	.16	60	>99	61
497	.29	55	>99	87
	(composite wastewater, 25 micron filter)			
502	.23	55	97	80
518	.12	57	98	81
	(composite wastewater, 250 micron)			
535	.16	53	>99	80
571	.13	58	>99	75

[a] Operating conditions: $P = 4.8 \times 10^6$ Pa; Flow = 0.15 m^3/min.
[b] Color 715 - 19,575 Pt-Co units; conductivity 960 - 36,650 μmho/cm.

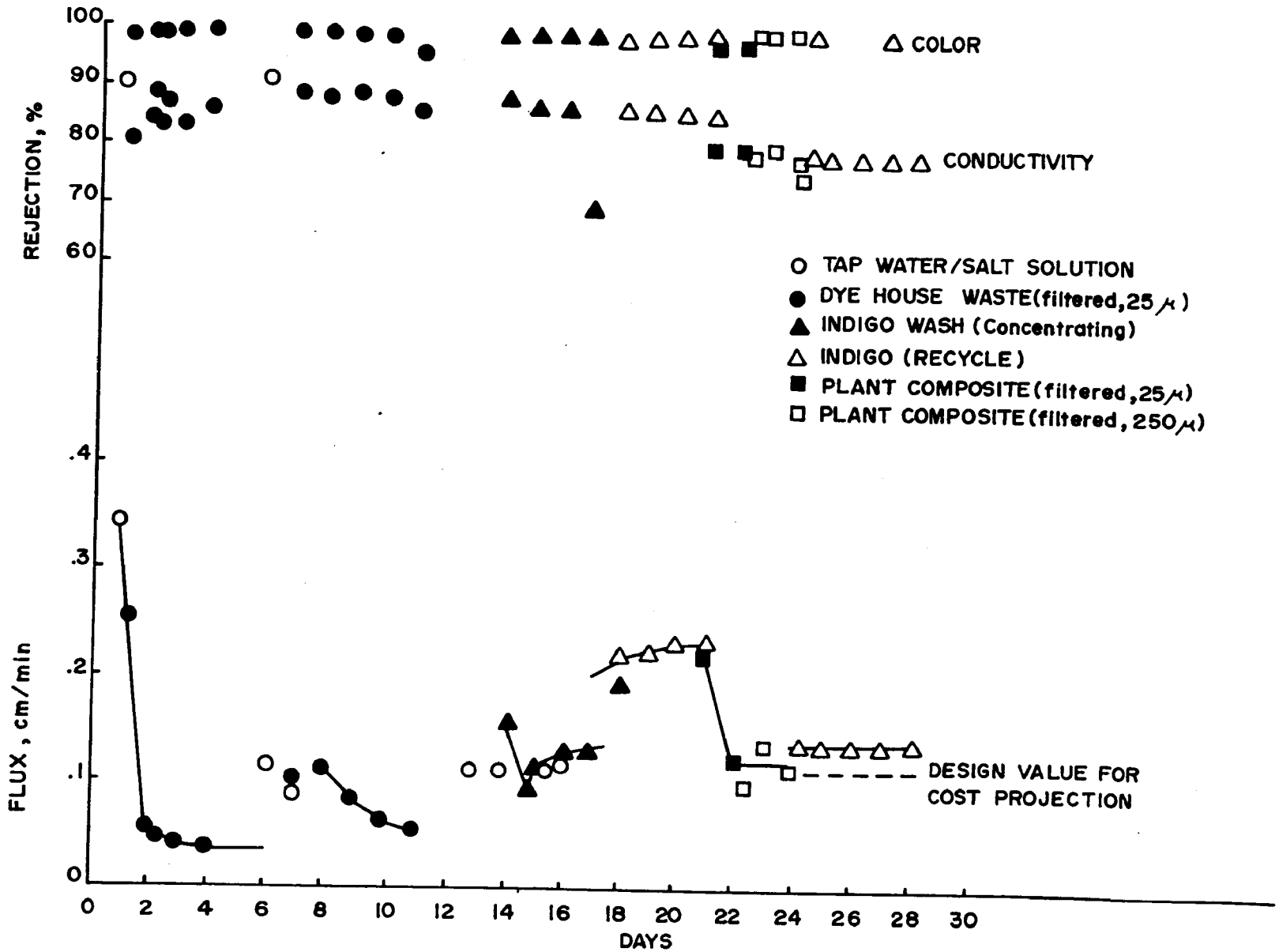

Figure 13. Operating performance of Selas dynamic membrane module at La France.

changed to total plant composite wastewater, through only 250 micron prefilter. For 55 hours the flux remained at about 0.11 cm/min. The evaluation was concluded with a period of 90 hours of operation with recirculation of indigo rinse water. The flux remained stable at 0.14 cm/min.

Throughout the period of evaluation, the color rejection remained near 99%. The conductivity rejection decreased gradually from about 90 to 80%. This membrane has subsequently been exposed to a variety of dye wastewaters and retains these percentage rejections after about 4000 hours of operation.

In summary, the dynamic membrane operating performance exhibited a characteristic of quick accommodation to particular feed conditions. The design value for the treatment plant cost projection was 0.14 cm/min based on 950 psi (6.5×10^6 Pa) operation, which corresponds to a value of 0.11 cm/min based on the performance data at 700 psi (4.8×10^6 Pa) and 50 C. The performances indicate best operation on unfiltered (except for 40-mesh screening) total plant composite wastewater. The quality of the product water was satisfactory for reuse in all dyeing operations at La France.

DESIGN VALUES FOR COST PROJECTIONS

The operating performance data obtained during the pilot plant program form the basis for the cost projections for a 7570 m^3/day treatment plant. The four membrane modules were evaluated within the manufacturers recommended operating limitations. The parameter of primary importance in the cost projections is the membrane flux, i.e., the product water flow rate per module. The long-time membrane flux, estimated from the test data, is listed in Table 18. In the case of the hollow fiber polyamide membrane, the estimate of long-term flux is 20% below the value observed during the relatively brief operating time during the pilot plant program (less than 200 hours).

The membrane flux is directly dependent upon the operating pressure and is strongly influenced by the operating temperature . Both the pilot

Table 18. MEMBRANE FLUX FOR COST PROJECTIONS

MEMBRANE	Polyamide	Cellulose Acetate	Cellulose Acetate	Dynamic Zr(IV)-PAA
MODULE CONFIGURATION	hollow fiber	spiral-wound	tubular	tubular
PILOT PLANT RESULTS				
Pressure, M Pa	2.4	2.8	2.1	4.8
Temperature, C	21	21	16	50
Flux, cm/min	0.004[a]	0.017	0.017	0.15
DESIGN VALUES				
Pressure, M Pa	2.4	2.8	2.8	5.2
Temperature[b], C	32	30	30	45[c]
Flux, cm/min	0.005	0.020	0.028	0.15

[a] 20% reduction from value measured at less than 200 hours operation
[b] Temperature effects based on manufacturers data.
[c] Thermodynamic mean temperature of plant effluents.

plant test values and the design values of pressure and temperature to be used in the cost projections are tabulated in Table 18. The design value of flux for each membrane module configuration, in Table 18, is thus the value measured in the pilot plant corrected to the design temperature and pressure.

SECTION VIII

TREATMENT PLANT COST PROJECTIONS

The equipment performance data determined in the pilot plant investigation are used in the following cost projections for a 2-million-gallons per day (7570 m^3/day) hyperfiltration treatment plant for the La France wastewater. The analyses includes pretreatment, i.e., pH control, temperature control, and suspended solids removal, as required for each of the four membrane configurations. However, no allowance is included for storage reservoirs, nor for the 10 - 20% make-up water, nor for treatment of any required blow down of concentrate.

There is a wide variation in both the capital cost and operating costs among the four module systems. The major operating cost for the polyamide and cellulose acetate membrane systems is for membrane replacement. The major operating cost for the dynamic membrane system is electrical power for pumping. The major capital cost for all the systems is for the membrane modules.

The polyamide and spiral-wound cellulose acetate membrane systems are of interest for water treatment applications because of their relatively low capital and operating costs. They generally require fine prefiltration, however. Tubular cellulose acetate membranes have a relatively high initial capital cost, but are somewhat easier to operate since they require only relatively coarse prefiltration. The tubular membranes are relatively easier to mechanically clean, a possibly significant advantage for some industrial applications. The dynamic Zr(IV)-PAA membranes have a relatively high initial cost, but require the least prefiltration. The advantage of high temperature operation (to 100 C) precludes pretreatment temperature control requirements and may, through recycle of hot water, permit significant energy conservation.

THE TREATMENT SYSTEM

A schematic material balance for the treatment of textile wastewater by hyperfiltration is shown in Figure 14. The composite textile wastewater

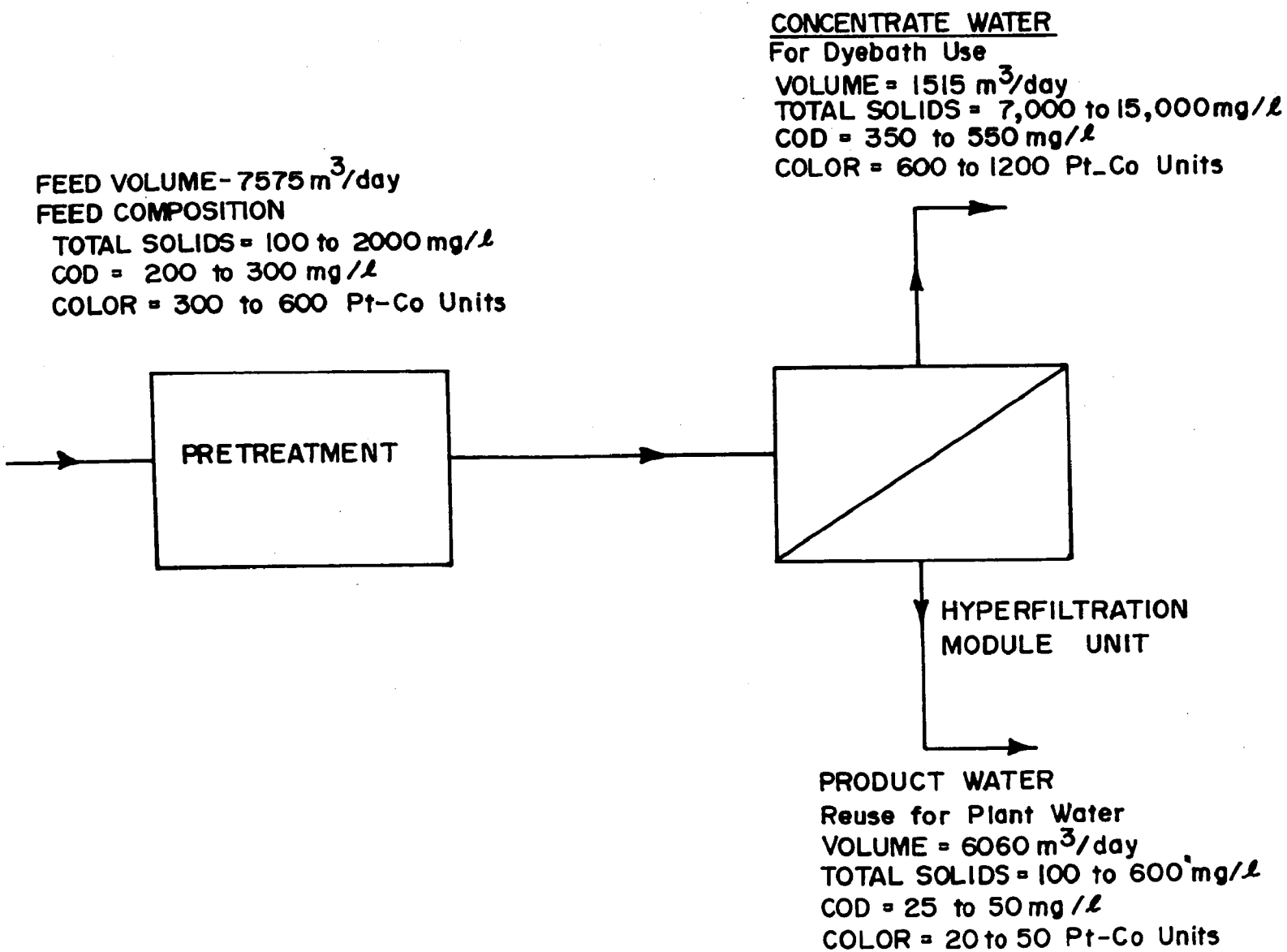

Figure 14. Simplified flow schematic of a textile dyewaste treatment system.

at a rate of 2-million-gallons per day (7570 m^3/day) is processed through a pretreatment section. The pretreatment section may consist of equipment for pH adjustment, coarse and/or fine filtration to remove suspended matter, and heat exchangers to cool the feed stream to about 32 C, the normal operating temperature for the pre-formed membranes.

As shown in Figure 14, 80% of the wastewater feed will be recovered as product (desalted and decolored) by the hyperfiltration unit, and recycled to the textile plant for use as process water. The concentrate will be recycled to the dyeing process for salt and/or dye reuse. The point of recycle must be determined by the chemical composition of the concentrate stream and the details of the dyeing process.

The complete and continued recycle of wastewater within the textile mill may cause a gradual build up of impurities in the process water. If the level of impurities reaches an undesirable level, there must be a blow down of some concentrate from the system. Selection of a treatment method for the concentrate must be determined for the particular wastewater. Wastewater or blow down disposal from the hyperfiltration plant has not been included in the plant design presented here.

EQUIPMENT DESCRIPTION AND CAPITAL COST PROJECTIONS

Four capital cost estimates for full scale hyperfiltration treatment plants are presented. Each deals with a particular membrane configuration. Case 1 involves the hollow fiber polyamide membranes (DuPont); Case 2 involves the spiral-wound cellulose acetate membranes (Gulf); Case 3 involves tubular cellulose acetate membranes (Westinghouse); and Case 4 involves dynamic membranes (Selas). Cost and characteristics for the four types of membrane modules are given in Table 19. Costs of pumps and filters are based on quotations from vendors and other equipment costs and estimated in 1975 prices.

The cost projections are developed for the hyperfiltration module unit and then for the pretreatment units separately. The cost projections for the total plant are obtained by combining the costs of these two major units with auxilliary equipment and engineering costs.

Table 19. MEMBRANE MODULE CAPITAL COST BASIS FOR PROJECTIONS

MEMBRANE	Polyamide	Cellulose Acetate	Cellulose Acetate	Dynamic Zr(IV)-PAA
CONFIGURATION	hollow fiber	spiral-wound	tubular	ceramic tubes
MODULE DIMENSIONS, Diameter x Length, m	0.2 x 1.2	0.2 x 1.0	.15 x 1.8	0.07 x 0.9
MEMBRANE AREA, m^2	603	28	2.6	0.8
DESIGN PRODUCT FLOW, dm^3/min	32	5.8	0.7	1.2
OPERATING PRESSURE, M Pa	2.4 - 2.8	2.4 - 2.8	2.4 - 2.8	6.5
FEED RATE, dm^3/min	49	189	340	227
PRESSURE DROP, M Pa	0.14	0.27	0.14	.10
BARE MEMBRANE COST	$2500	$665	$271	<1
HOUSING AND ASSEMBLY	$1000	$1200	$230	$585

Hyperfiltration Module Unit Cost Projections

The cost projection for the hyperfiltration module unit are tabulated in Table 20. The specific characteristics of the design for each membrane module configuration are individually discussed as Cases 1 through 4.

Case 1 - The membrane module product flow rate depends on membrane life and cleanliness. Although new polyamide membrane modules will yield about 37 dm^3/min of product per module, the plant has been sized for 32 dm^3/min per module. If the product flow rate is too high initially, it can be controlled by decreasing the operating pressure of the system. Three-and-one-half percent extra membrane area has been provided for operation during membrane cleaning for emergency situations.

The hollow fiber module requires periodic back-flushing and cleaning. It is assumed that enough product will be available to back-flush and forward-flush every module for at least two hours per week. This will require about 163 m^3/day of product water. The plant size is augmented to 7774 m^3/day. Thus the number of modules required is given by the ratio of the plant size to the product flow rate multiplied by the percent product recovery, i.e., 134 modules. Ten extra modules are included, bringing the total to 144.

The 144 polyamide membrane modules are incorporated into 16 parallel banks consisting of two stages per bank, as shown in Figure 15. Each bank consists of nine modules. The first stage of each bank includes six modules in parallel. The second stage has three modules in parallel. Fifteen of the 16 banks must operate at all times while one may be idle for maintenance or cleaning.

Each module requires 49 dm^3/min of wastewater feed. The total flow of 331 dm^3/min through each module bank, once through both stages one and two, will yield 80% product water recovery. The concentrate and product effluents from each bank will be monitored by flow indicators. They are designed to be 66 dm^3/min and 265 dm^3/min, respectively.

For equal distribution of wastewater flow through the parallel, a

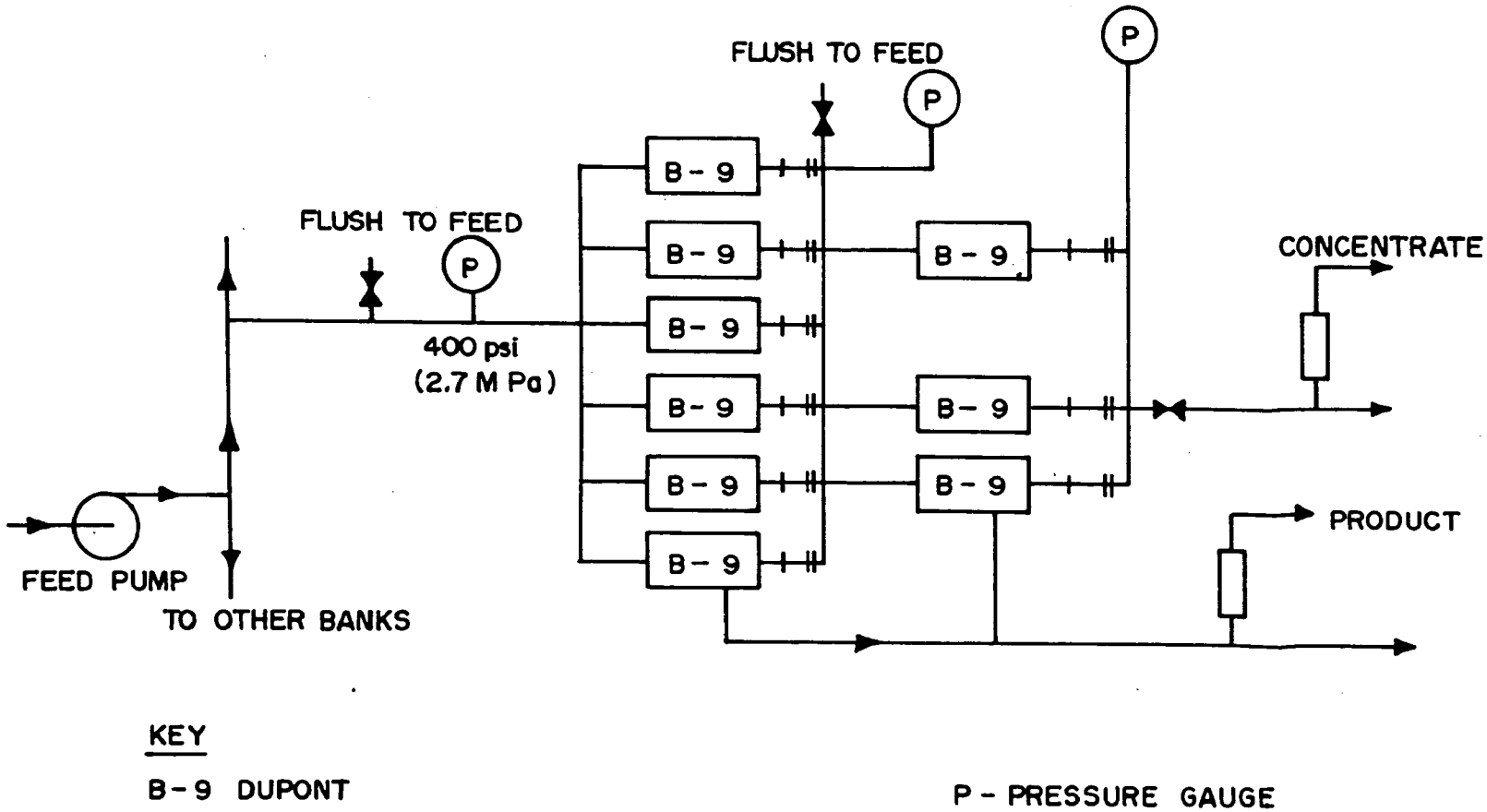

Figure 15. Case 1 - Details of a membrane bank design.

flow balancing resistance equivalent to 0.137×10^6 Pa pressure differential is incorporated at the discharge of each module. Whenever the pressure drop across any stage becomes high and/or the product flow rate of any bank drops below a set limit, the membrane bank in question is isolated and cleaned.

High flow at low pressure are necessary for efficient module cleaning. A separate cleaning pump in a quick-disconnecting piping system are provided for cleaning. The details of the pumping requirements for the modules are included in Table 20, with the summary of characteristics and costs of the hyperfiltration module unit. Cost projections for the pumping station required to flush, or clean, the module are also included. The cost projections for piping and installation, electrical services, and instrumentation required for the hyperfiltration membrane unit are the same for each membrane type. These are also tabulated in Table 20.

Case 2 - The design product flow rate per module is based on the pilot plant results. At the pilot plant test conditions, the membrane flux in the spiral-wound module was measured as 0.017 cm/min. This flux corresponds to a product flow rate of 5.8 dm^3/min per module under the design pressure of 2.7 M Pa and temperature of 30 C. Therefore, 750 modules in 125 pressure vessels yields 82.7% product water recovery. This provides for 204 m^3/day for module flushing.

These 125 pressure vessels are incorporated into three stages. The first stage will contain 504 modules, the second 162 modules, and the third 84 modules. A tapered arrangement of modules, similar to that shown in Figure 15, is employed. Six modules, and one pressure vessel assembly may be idle for maintenance or cleaning. A separate cleaning pump is provided for cleaning.

The details of the pumping requirements for the modules are included in Table 20, with the summary of characteristics and costs of the hyperfiltration module unit. Cost projections for the pumping station required to flush, or clean, the module are also included. The cost projections

Table 20. DETAILS OF CAPITAL COST PROJECTIONS FOR HYPERFILTRATION MODULE UNIT

(7570 m^3/day & 80% Product Recovery)

CASE NUMBER	1	2	3	4
MEMBRANE MODULES				
Configuration	hollow fiber	spiral-wound	tubular	ceramic tube
Number	144	750	5932	3600
Cost, $	504,000	648,750	2,971,932	2,109,600
Membrane Cost Included	360,000	498,750	1,230,000	3,600
PUMPS				
Flow, m^3/min	5.3	5.3	5.3	5.3
Head, M Pa	2.4	2.7	2.7	6.5
Power, kW	410	410	745	2600
Cost, $	75,000	75,000	75,000	337,124
CLEANING STATION, $	17,400	17,400	17,400	17,400
PIPING COST, $	150,000	150,000	150,000	150,000
ELECTRICAL AND INSTRUMENTS	100,000	100,000	100,000	100,000
TOTAL COST, $	846,400	991,150	3,314,332	2,714,124

for piping and installation, electrical services, and instrumentation required for the hyperfiltration membrane unit are the same for each membrane type. These are also tabulated in Table 20.

Case 3 - The design product flow rate per module is based on the pilot plant results. For the pilot plant test conditions, the cellulose acetate membrane flux for the tubular configuration was measured as 0.017 cm/min. This flux corresponds to a product flow rate of 0.7 dm^3/min per module under the design pressure of 2.7 M Pa and temperature of 30 C. Therefore, 5933 modules are required to provide 82.1% product water recovery. This provides 159 m^3/day for module flushing. A tapered arrangement of modules, similar to that shown in Figure 15, is employed. Additional horsepower is required for recirculation of feed to provide the required flow rates per module.

The details of the pumping requirements for the modules are included in Table 20, with the summary of characteristics and costs of the hyperfiltration module unit. Cost projections for the pumping station required to flush, or clean, the module are also included. The cost projections for piping and installation, electrical services, and instrumentation required for the hyperfiltration membrane unit are the same for each membrane type. These are also tabulated in Table 20.

Case 4 - The design product flow rate per module is based on the pilot plant results. For the pilot plant test conditions, the dynamic Zr-polyacrylate membrane flux was measured as 0.15 cm/min. This flux corresponds to a product flow rate of 1.2 dm^3/min per module under the design pressure of 5.2 M Pa and temperature of 45 C. Therefore, 3600 modules are required to provide 82.1% project water recovery. This provides 159 m^3/day for module flushing.

A tapered arrangement of modules, similar to that shown in Figure 15, is employed. Additional horsepower is required (1) to pressurize the feed to 950 psi (6.5 M Pa), and (2) to recirculate feed to provide the required flow rate per module.

The details of the pumping requirements for the modules are included in Table 20, with the summary of characteristics and costs of the hyperfiltration module unit. Cost projections for the pumping station required to flush, or clean, the module are also included. The cost projections for piping and installation, electrical services, and instrumentation required for the hyperfiltration membrane unit are the same for each membrane type. These are also tabulated in Table 20.

Pretreatment Unit Cost Projections

The cost projections for the pretreatment unit are tabulated in Table 21. The specific characteristics for each membrane module configuration are individually discussed as Cases 1 through 4.

In general, pretreatment costs are not a large part of the total costs for the complete hyperfiltration system. The improved performance of the membrane modules often effects savings to offset pretreatment expenditures. The design case for each module configuration includes the pretreatment recommendations from the general experience of the manufacturers and the pilot plant results for operation with La France's textile wastewater. It was beyond the scope of this project to optimize the pretreatment.

Case 1 - Based on the pilot plant experience with both total plant composite and segregated dyehouse wastewater, the hollow polyamide fiber membrane modules require very fine prefiltration, and wastewater cooling to 32 C. Even though not required in the pilot plant tests, pH control is included in the cost projections.

Based on the pilot experience, the hollow polyamide fiber module is very sensitive to wastewater feeds containing collodial solids below 1 micron in diameter. Depth-type cartridge filters, 1 micron size, were found to be insufficient in preventing hollow fiber module plugging during prolonged operation with the total plant composite wastewater. Segregated wastewater from the dyehouse, after filtration through a pre-coat system, could be processed for about 200 hours without substantial module plugging (i.e., substantial increase in module pressure loss), or deterioration in

Table 21. DETAILS OF CAPITAL COST PROJECTIONS FOR PRETREATMENT UNIT

(7570 m^3/day & 80% Product Recovery)

CASE NUMBER	1	2	3	4
MEMBRANE	Polyamide	Cellulose Acetate	Cellulose Acetate	Dynamic Zr-PAA
CONFIGURATION	hollow fiber	spiral-wound	tubular	external tubular
PREFILTER				
Type	pre-coat	rotary screen	rotary screen	screen
Removal	(<1 micron)	(>25 micron)	(>25 micron)	(>250 micron)
Cost, $	123,950	35,000	35,000	25,000
COOLING TOWER				
Utilized Power, kW	75	85	85	a
Range, C	13	15	15	
Cost, $	220,000	240,000	240,000	
pH CONTROL				
Cost, $	8,000[b]	8,000	8,000	8,000[b]
TOTAL PRETREATMENT, $	351,950	283,000	283,000	33,000

[a] Dynamic membranes require no temperature control.
[b] Polyamide and dynamic Zr-PAA membranes have pH ranges of 2 - 10 and 4 - 10, respectively.

membrane flux or rejection. Consequently, a pre-coat (leaf) filter is included in this Case 1 design.

Diatomaceous earth pre-coat was used in the pilot plant. Other similar filter-aid material is expected to be equally effective. The use of wood flour is assumed in this design.[8] The cost projection includes all the necessary equipment to handle 453 kg as body feed to 50 mg/ℓ. The cost projection is $123,950 for this prefiltration.

A cooling tower is designed to reduce the wastewater feed temperature to 32 C. The maximum operating temperature of the hollow fiber module is 35 C. The cooling tower basin also serves as a feed surge tank and a mixing zone for pH adjustment and any required water treatment chemicals. Since the mixed temperature of the hot and cold dyehouse effluents is 45 C in the summer, the cooling tower must provide a cooling range of 13 C. The cooling tower and auxiliary equipment cost projection is $220,000.

Case 2 - Based on the pilot plant experience with total plant composite wastewater, the spiral cellulose acetate membrane modules require (1) 25 micron prefiltration, (2) wastewater cooling to 30 C, and (3) pH control to pH 3 - 6.

During the pilot plant evaluation, depth-type cartridge filters, 25 micron size, were sufficient in preventing performance deterioration of the spiral-wound module. A rotary screen filter is included in the cost projection.

The cooling requirements for cellulose acetate membranes are similar to those for the polyamide fibers. The recommended temperature is 30 C for cellulose acetate, so the cooling range on the cooling tower is 15 C. The cooling tower and auxiliary equipment cost projection increased $20,000 from the Case 1 estimate because of the higher cooling load.

The acceptable range for operation of cellulose acetate at the temperature of 30 C is pH 3 - 6. pH control is required for the La France textile wastewater that averages nearly pH 7, but has peaks up to pH 10 or more.

Case 3 - Based on the pilot plant experience with total composite wastewater, the tubular cellulose acetate membrane modules require (1) 25 micron prefiltration, (2) wastewater cooling to 30 C, and (3) pH control to pH 3 - 6.

These are the same requirements listed for the spiral module. However, since previous experience suggested finer prefiltration, these cost projections include a 25 micron rotary screen filter.

The cooling requirements and pH control are exactly the same as for Case 2.

Case 4 - Based on the pilot plant experience with both total plant composite and segregated dyehouse wastewater, the dynamic Zr-PAA modules require only coarse (>250 micron prefiltration). In fact, performance with only this coarse prefilter was actually superior to that observed with depth-type cartridge filters, 25 micron size.

No wastewater cooling nor pH control was needed in the pilot plant. Since this membrane can operate at elevated temperatures, it is desirable to take advantage of increased flux. The cost of pH control is included since there was some indication of optimal performance at pH 8.5 - 9.5 that might make pH adjustments desirable.

Capital Cost Projections Summary

The total capital cost projections include auxiliary equipment and services common to systems, independent of the type of membrane module. The two main items are (1) a building to house equipment and controls, and (2) the engineering services (including design, equipment procurement, construction, supervision, and start-up).

The capital cost projections are summarized for each of the four cases in Table 22. The principal differences among the four cases are, of course, in the cost of the membrane modules. There are also major differences among the costs of required pretreatment. The cost of the auxiliaries are the same except for Case 3 (Westinghouse). In Case 3 the engineering costs are considered part of the module cost.

Table 22. CAPITAL COST PROJECTION SUMMARY FOR HYPERFILTRATION TREATMENT OF LA FRANCE WASTEWATER (7570 m^3/day & 80% Recovery)

CASE NUMBER	1	2	3	4
PRETREATMENT UNIT, $	351,950	283,000	293,000	33,000
MEMBRANE MODULE UNIT, $	846,400	991,150	3,314,332	2,714,124
AUZILIARY EQUIPMENT, $	117,500	117,500	117,500	117,500
ENGINEERING, $	300,000	300,000	a	300,000
TOTAL, $	1,615,850	1,691,650	3,714,832	3,164,624
CONTINGENCY (10%), $	161,585	169,165	371,483	316,462
TOTAL CAPITAL, $	1,777,435	1,860,815	4,086,315	3,481,086
MEMBRANE COSTS INCLUDED IN CAPITAL, $	360,000	498,750	1,230,000	3,600
UTILIZED HORSEPOWER	585	595	932	2,600

[a] Included in cost of membrane module unit.

OPERATING COST PROJECTIONS

The operating cost projections tabulated in Table 23 are based on 365 operating days per year. The costs are incremental for treating wastewater at an existing textile plant. The operating costs are items in three principal categories: (1) labor, (2) electric power, and (3) membrane replacement. The costs are based on the wages and prices typical for the Southeast in the fall of 1975. The operating cost projections in Table 23 do not include the value of recycleable water, chemicals, or heat (energy). The recycle potential for textile wastewater renovated by hyperfiltration is estimated separately in Table 24.

The estimates of labor requirements by the four membrane manufacturers were different. However, the same labor cost is used in the projection for each membrane system for consistency in comparison. Even though the pilot plant experience supports the existence of some variation in labor requirements, this variation should not be a major consideration in the comparisons among the four membrane systems.

The membrane life, i.e., the replacement interval, for the polyamide fiber membrane and both configurations of the cellulose acetate is taken as three years. The replacement costs are depreciated linearly over this time period. The dynamic Zr-PAA membrane replacement interval is taken to be one year. Of course, determination of membrane life for textile wastewater treatment is beyond the scope of this pilot plant program. The maximum evaluation period in the pilot plant study was about 1000 hours. The experiences of the manufacturers in other applications were the basis for the selection of the replacement period for the polyamide and cellulose acetate membrane systems. For the prototype dynamic Zr-PAA membrane system, the membrane replacement is a minor item. Thus, the accuracy of the replacement interval is not significant in the total operating cost projections. Data with textile wastewater do support the estimated one-year replacement period, however.

The cost projections do not include amortization of capital. Because of effects of legislation on capital investment for environmental protection and the fluctuations in the prime interest rate, inclusion of the amortization

Table 23. OPERATING COST PROJECTIONS SUMMARY FOR HYPERFILTRATION TREATMENT OF LA FRANCE WASTEWATER ($/day)

CASE NUMBER	1	2	3	4
PRETREATMENT UNIT				
Filter Aid (@6.6¢/kg)	30.00	-	-	-
Chemicals (detergent & acid)	20.00	45.00	45.00	5.00
LABOR				
Operating (6 man-yrs)	202.20	202.20	202.20	202.20
Maintenance (0.5 man-yrs)	27.40	27.40	27.40	27.40
Supervision	22.96	22.96	22.96	22.96
MAINTENANCE MATERIAL	72.35	58.63	174.14	205.45
ELECTRIC POWER (@ 1.5¢/kW hr)	210.60	214.20	335.52	936.00
MEMBRANE REPLACEMENT	328.77	455.48	1123.30	16.43
TOTAL[a]	914.28	1025.87	1930.52	1415.44
UNIT OPERATING COSTS (¢/m^3)	12.1	13.6	25.5	18.7
UNIT OPERATING COSTS (¢/kgal)	45.7	51.3	96.5	70.8

[a] Does not include amortization

would add no significant information to the capital cost projections already presented.

The operating costs for pretreatment are not a major item for any membrane system. The labor, electric power, and membrane replacement costs are about equal for the polyamide membrane system. The membrane replacement costs become progressively more important for the spiral-wound and tubular cellulose acetate, being the major factor for the tubular configuration. The major operating cost for dynamic Zr-PAA membranes is the electric power costs. In-situ membrane replacement is a particularly small cost for the dynamic membranes.

The daily operating cost ranges from 12.1¢/m^3 (45.7¢/kgal) for polyamide membranes to 25.5¢/m^3 (96.5¢/kgal) for tubular cellulose acetate. Neither figure includes the amortization of capital investment. No credits for the value of recycle water, chemicals, or energy (heat) are included.

In Table 24 the credit for the value of recycled water, salt, and energy (heat) are tabulated. The credit for recycled water is based on 80% product water recovery at 50¢/kgal (13.2¢/m^3), the current cost of water preparation and waste treatment at La France. The credit for recycled chemicals is based solely on the value of salt at 2¢ per pound (4.4¢/kg). The value of recycled dyes may eventually increase the credit for recycled chemicals significantly. The credit for energy conservation is based on a fuel oil cost of $2.06 per million BTU (1.9¢/10^7 J). The energy conservation is calculated on the basis of reduced heating required during the dye cycle. About 25% of the 7570 m^3/day of water is heated from 60 F (15 C) to 210 F (99 C). The product water recycled from the hyperfiltration membrane module unit, when used directly, requires additional heating only from its relatively elevated temperature (e.g., 32 C), thus effecting an energy conservation. Since the design temperature for the polyamide and cellulose acetate membrane units are 32 C and 30 C respectively, the energy conservation is somewhat less than for the dynamic Zr-PAA membrane unit operating at the mean mixed effluent temperature of 45 C.

Table 24. NET OPERATING COST PROJECTIONS SUMMARY INCLUDING POTENTIAL RECYCLE CREDITS ($¢/m^3$)

CASE NUMBER	1	2	3	4
RECYCLE POTENTIAL, $¢/m^3$				
1. Water (@ $13¢/m^3$)	10.6	10.6	10.6	10.6
2. Salt (@ 4.4¢/kg)	1.5	1.5	1.5	1.5
3. Energy (@ $1.9¢/10^7$ J)	3.4	2.8	2.8	6.2
TOTAL RECYCLE CREDITS	15.5	14.9	14.9	18.3
UNIT OPERATING COSTS[a]	12.1	13.6	25.5	18.7
NET OPERATING COSTS, $¢/m^3$	(3.4)[b]	(1.3)[b]	10.6	0.4
NET OPERATING COSTS, ¢/kgal	(12.9)[b]	(4.9)[b]	40.1	1.5

[a] From Table 23
[b] Indicates net savings

The net operating costs, Table 24, includes credit for recycle. A small net savings is projected for the polyamide membrane and the spiral cellulose acetate membrane systems.

COST PROJECTIONS FOR A COMBINED MEMBRANE SYSTEM

Because of the relatively low capital and operating costs of both the polyamide and cellulose acetate (spiral) membrane systems and the high temperature capability of the dynamic Zr-PAA membrane system, a hyperfiltration treatment facility combining two types of membranes has advantages over any single membrane system.

The dye procedure employed at La France, Table 8, involves the dilution of the 210 F (99 C) spent scouring and dyeing baths. The dilution is accomplished with clean, cold rinse water introduced to the dyeing machine. This procedure results in a slow quenching of the cloth to 165 F (74 C). Approximately 25% of the water used in dyeing cycle is exhausted to the drain at an average temperature of 165 F (71 C). The final rinsing of the cloth results in a mixed effluent of about 90 F (32 C).

A dynamic Zr-PAA membrane unit can process the relatively hot portion (25%) of the wastewater and effect energy recovery since with procedural modifications the 165 F (71 C) water could be directly recycled in many dyeing operations. Either spiral or hollow-fiber membranes can process the remaining portion (75%) of the wastewater without requiring a cooling tower. The following approximations of capital and operating costs illustrate the cost advantages of such a combined system. A detailed economic analysis of a combined system was not carried out, however.

Because of the increased membrane flux with temperature, each dynamic Zr-PAA membrane module has a product flow rate of 2.06 dm^3/min at 71 C. Therefore, to process 25% of the 7570 m^3/day wastewater to 82.1% product recovery requires 524 modules. This is 14% the size of the membrane unit used in the cost projections summarized in Table 22. As a first approximation then, the capital costs of this smaller unit is 14% of $3,481,086 or $487,352.

The capital cost of the polyamide, or spiral cellulose acetate, portion of the combined unit would be simply 75% of the value given in Table 22 with the exception that the entire cost of the cooling tower may be eliminated since the mixed effluent temperature is 32 C. The capital cost for the unit to process the relatively cool rinse water is then $1,151,576 for a polyamide membrane unit, or $1,197,611 for a spiral cellulose acetate membrane unit.

The approximate total capital cost for a combined membrane treatment is $1,650,000. A comparison with Table 22 indicates this is less than the capital cost of any single membrane system.

The operating costs for the combined membrane system are also approximated from the details developed for the individual membrane systems. The operating costs, excluding labor, are proportional to system size. That is, the operating cost for the dynamic Zr-PAA membranes is 14% of $1162.88 (Table 23), or $162.80. The operating cost of the polyamide membrane unit is 75% of $661.72 (Table 23), or $496.29. The labor costs are not reduced, but are taken to be the same for the combined system as for any other membrane unit, i.e., $252.56. The approximate operating costs for the combined system is the sum of $162.80, $496.29, and $252.56, or $911.65. The unit operating cost is 12¢/m^3 (45.6¢/1000 gallons) of wastewater processed. Comparison of this result with Table 23 shows that the operating cost of the combined system is less than for any single membrane system.

The credit for recycled water and salt is the same for all membrane systems (Table 24), 10.6¢/m^3 and 1.5¢/m^3, respectively. The credit for energy conservation that may be realized by direct recycle of the hot (71 C) product water from the dynamic membrane unit is 11.3¢/m^3. Thus, the total recycle credit for the combined membrane system is 23.4¢/m^3.

The net daily operating cost for the combined system is the difference between the 12¢/m^3 daily operating costs and the 23.4¢/m^3 recycle credit, or 11.4/m^3 (43¢/1000 gallons). This does not include amortization of the capital, however.

As noted above, this analysis of a combined system for the La France dyeing operation is only approximate. It does clearly make the point

that a combined system to take advantage of the relatively low costs of some membranes and the energy conservation potential, by direct recycle of hot water, of other membranes, should be considered for each application characterized by the utilization of hot dye baths and relatively cooler, higher volumes of rinse water. Further, procedural alterations to permit direct recycle of dye baths renovated at full process temperature could possibly yield even further energy conservation.

REFERENCES

1. Kraus, K. A., A. J. Shor, and J. S. Johnson, Jr. Desalination. 2:243. 1967.

2. Larson, T. J. Desalination. 7:187. 1970.

3. Brandon, C. A., J. S. Johnson, Jr., R. E. Minturn, and J. J. Porter. Journal of Textile Chemists and Colorists. 5(7):134. 1973.

4. Environmental Protection Agency, Demonstration Project #S800929; Thomas N. Sargent, Project Officer, Southeast Water Laboratory, Athens, Georgia.

5. Anonymous. Chemical Engineering. 78(27):53. 1971.

6. Coit, R. L. Proceedings of Third International Symposium on Fresh Water from the Sea. 2:351. 1970.

7. Johnson, J. S., Jr. "Polyelectrolytes in Aqueous Solutions." Reverse Osmosis Membrane Research. 379-403. 1972.

8. Fremont, H. A., D. C. Tate, and R. L. Goldsmith. "Color Removal from Kraft Mill Effluents by Ultrafiltration." Final Report, Project #S800261, Environmental Protection Agency. 1973.

SECTION X

APPENDIX A

APPENDIX A

WATER SAMPLING SCHEDULE, PROCEDURE, AND CHEMICAL ANALYSES

SAMPLING SCHEDULE

During this project, the detailed chemical analyses of a number of samples were required for the following reasons: (1) to characterize the La France composite wastewater, (2) to characterize the product water and concentrate employed in direct reuse dyeing operations, and (3) to evaluate the performance of the pilot plant hyperfiltration units. In order to achieve these goals, a sampling schedule and chemical analysis routine was established and maintained by pilot plant operators. This Appendix describes the sampling schedule, sampling procedures, and the chemical tests performed on the collected water samples.

In order to characterize the composite wastewater from the La France plant, several 0.1 dm^3 samples of raw wastewater were collected during work hours and the samples were mixed at the end of the week to yield a composite sample of wastewater.

The sample described as composite product water and composite concentrate were drawn from the 5.6 m^3 storage tanks at the end of each collection period. The composite raw waste sample which was used as feed for the pilot plant was prepared by collecting a sample of raw waste from each 2.3 m^3 raw feed batch to be processed and mixed at the end of the collection period. A sample of tap water was analyzed for comparison with the composite product water for each reuse dyeing.

COLLECTION AND STORAGE OF SAMPLES

To insure that representative samples were obtained, the following guidelines were established for sample storage during the project. Samples were analyzed within a two week period after collection and stored before analyses at a temperature of less than 5 C. No additives or preservatives were added to any of the samples because they often affect the results of many of the analyses.

ANALYTICAL PROCEDURES

The chemical analyses were performed by Texidyne, Inc. Those chemical parameters subject to rapid change after sample collection (pH, color, turbidity, conductivity) were determined on-site by the pilot plant operator, while the other analyses were performed at the Texidyne laboratory. The following is a brief description of the chemical parameters routinely analyzed. A complete discussion of these techniques is contained in Standard Methods for the Analysis of Water and Wastewater, Thirteenth Edition, A.P.H.A., 1971.

Chemical Oxygen Demand (COD)

The COD test indicates the total amount of organic matter in a sample. COD is determined by the dichromate oxidation method. A measured aliquot of the waste sample is refluxed in 50% sulfuric acid solution with a known amount of standard potassium dichromate solution, the essential reaction being the oxidation of organic matter in the sample and the reduction of the dichromate. At the end of reaction, excess dichromate is determined by back-titration with a ferrous salt. A standard solution of an organic compound, potassium acid phthalate, having a known theoretical COD is used to check the accuracy and precision of the analytical technique.

Biochemical Oxygen Demand (BOD)

The BOD test gives an indication of the amount of organic matter in a sample which can be degraded by normal microorganism growth and respiration, i.e., the amount of biodegradable organic matter. BOD was performed by the standard seed and dilution technique. A waste sample is suitably diluted and "seeded" with microorganism culture and the depletion of dissolved oxygen in the sample with time is then studied. All results given in this report are BOD_5 , the parts per million oxygen depletion in five days at 20 C. A standard biodegradable organic solution of 150 mg/ℓ each of glucose and glutamic acid in water is used routinely to check the precision and accuracy of the analytical technique.

Total Organic Carbon (TOC)

TOC is evaluated by difference. Total carbon is first determined by passing a sample aliquot into a 950 C furnace and conversion of all carbon present to carbon dioxide. Inorganic carbon is found by passing a second aliquot into a 150 C oven where only the inorganic carbon is converted to carbon dioxide. The carbon dioxide from both channels is determined by an infrared detection system. Standard solutions of sodium carbonate and biocarbonate, and potassium acid phthalate are used to calibrate the carbon channels. Total organic carbon is then evaluated as the difference between total carbon and inorganic carbon.

pH

Determination of pH is made with a potentiometric pH meter calibrated with buffers of known pH value.

Alkalinity

Alkalinity is determined by titrating a known volume for the sample to a pH of 4.5 with a standard acid solution. The results are expressed as mg/ℓ calcium carbonate.

Hardness

Hardness is determined by complexing the calcium and magnesium ions present in an aliquot of the sample with EDTA solution to a titrimetric end point indicated by Eriochrome Black T. The results are expressed as mg/ℓ calcium carbonate.

Total Solids

Total solids is taken as the weight of solid residue after an aliquot of the homogeneous sample is dried at 105 C for 24 hours. The results are expressed as mg/ℓ solids.

Volatile Solids

Volatile solids is taken to be the weight of solid material which volatilizes when the residue of the total solids determination is heated to 650 C for 15 minutes. The result is expressed as mg/ℓ.

Dissolved Solids

Dissolved solids is the weight of solid matter remaining after a sample is filtered at room temperature through Whatman #42 filter paper or equivalent, and a measured aliquot of the filtrate is dried at 105 C for 24 hours. The result is expressed as mg/ℓ.

Color

The determination of color is made by comparing the absorbance of the sample at 410 nm with those of standard platinum-cobalt color solutions, also at 410 nm. The results are expressed as platinum-cobalt color units.

Turbidity

Turbidity is measured using a nephelometer type turbidimeter. Light scattered by the sample is incident upon a photo-tube, which is connected to a meter movement. Calibration is made against standards of known turbidity. The results are expressed in Formazin Turbidity Units (FTU).

Conductivity

A conductance bridge and cell of known cell constant calibrated against standard potassium chloride solutions is used for determining conductivity. The result is expressed in micromhos per centimeter (μmho/cm).

Metals

Metals are determined by atomic absorption spectrophotometry with comparison made to standards formulated for the various metals according

to guidelines presented in Perkin-Elmer Analytical Methods for Atomic Absorption Spectrophotometry.

All metals except mercury were determined with an air acetylene flame. Mercury was determined by the flameless technique. It should be noted that, because of this special technique, mercury can be reported in the μg/ℓ range, while other metals are limited to the mg/ℓ range.

Rejection

The observed rejection is defined by the relationship

$$R_{obs} = 1 - \frac{\text{concentration of product}}{\text{concentration of feed}}$$

SECTION XI

APPENDIX B

APPENDIX B

PRODUCTION SCALE REUSE DYEINGS

The production scale reuse dyeings demonstrated the technical feasibility of direct recycle of both the product water and concentrate from hyperfiltration of composite wastewater. After collection of sufficient water for reuse, 1.9 - 5.7 m^3 of concentrate and 11.4 - 17 m^3 of product water, mixed samples were used in the laboratory, at the plant, to develop production scale dye formulations for use in a two-piece beck, Machine No. 19.

The product water was found to be reuseable with no adjustment of standard dye formulations. Even the most critical shade, a light covert shade on a 54% nylon - 46% viscose blend fabric, was repeatedly achieved with no difficulties. The concentrate required special formulations to produce standard commercial shades.

For each test dyeing, standard production procedures were followed in the dyehouse. The standard dyeing procedure, given in Table 8 in the text, involves scouring and rinsing steps in addition to the dyeing and shade adjustment.

Two types of plant dyeings were carried out: (1) separate dyeings with the product water and with the concentrate, and (2) one dyeing combining both the concentrate and the product water. When used separately, the product water was used in all of the six scouring, rinsing, and dyeing steps in the standard procedure. When used in combination, the product water was used in all steps except the dyeing; the dyebath was the concentrate. When used separately, the normal process water was used for scouring and rinsing with the concentrate as the dyebath.

In this Appendix are given the details of the water analyses of the product water and concentrate, the standard and special dye formulations, and the evaluation of each test cycle. Cycle #11, #13, and #15 are omitted because no dyeings were done during these periods which were devoted solely to equipment performance evaluations.

CYCLE #1

The analyses of the average feed to the DuPont module, the product water, and the concentrate are tabulated in Table B-1.

Table B-1. WATER ANALYSES FOR CYCLE #1 (March 22, 1973)

	Feed[a] Water Analyses	Product Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	160	25	425
BOD, mg/ℓ	45	10	70
TOC, mg/ℓ	36	3	87
pH	6.5	6.1	6.7
Alkalinity, mg/ℓ	50	10	110
Hardness, mg/ℓ	40	30	90
Total Solids, mg/ℓ	1030	100	2360
Volatile Solids, mg/ℓ	140	30	200
Dissolved Solids, mg/ℓ	980	100	2330
Color (Pt-Co units)	500	30	850
Turbidity, F.T.U.	44.0	2.4	39.0
Conductivity (μmho/cm)	1150	180	2200
Metals			
Calcium, mg/ℓ	1.0	0.5	3.0
Zinc, mg/ℓ	4.8	<0.04	9.7
Magnesium, mg/ℓ	0.51	<0.01	1.18
Chromium, mg/ℓ	-	-	-
Copper, mg/ℓ	0.04	0.04	0.18
Iron, mg/ℓ	0.3	0.3	3.0
Mercury, μg/ℓ	-	-	-
Manganese, mg/ℓ	-	-	-
Sodium, mg/ℓ	-	-	-

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #1 for the DuPont module.

Product Water

The first plant dyeing using product water was conducted on a 54% nylon - 46% viscose blended fabric using a dye formulation containing 7 different dyes, Table B-2. Laboratory dyeings were conducted to establish the suitability of the product water with the shade chosen before the plant dyeing was performed. This particular fabric and dye formulation were chosen because, in the opinion of the plant dyer and chemist, this was one of the most difficult dye systems in use in the plant.

Table B-2. CYCLE #1 PRODUCT WATER REUSE DYEING[a]

Chemical	Dye Name	Weight Used Based On % Fabric Wt.
Acid Dye	Nylon Fast Yellow FLW	0.018
Acid Dye	Ciba Brown 2GL	0.039
Acid Dye	Ciba Yellow 2BRL	0.017
Acid Dye	Irgalan Black RBL	0.016
Direct Dye	Lumicrease Grey 3LBN	0.027
Direct Dye	Lumicrease Orange 3LG	0.030
Direct Dye	Lumicrease Bordeau 3LR	0.006
Salt		10.

[a] 43 kg of fabric in a dyebath of 1.5 m^3 at pH = 6 - 7.

The color obtained from the above dye formulation was a gold shade (light covert). While the causes for the production difficulties with this shade are not documented, it is known to give more problems than most of the dye/fabric systems used. The problems have been attributed to the quality of the plant water, improper cleaning of the dyeing equipment, improper temperature control during the dyeing operation, and inaccurate

measure of dyes and chemicals used for dyeing. It was assumed that this dye/fabric system constituted a critical test for the reuse of product water in the plant.

A light shade of gold was produced with the product water. The dyeing operation proceeded normally with no visible problems occurring. The product water was used in all steps in the dyeing operation. This particular fabric passed a 100-hour Weather-O-Meter Test, a severe test of light fastness.

Concentrate Water

Before a dye/fabric system was selected to be used with the concentrate water, the plant laboratory conducted trial dyeings using the concentrate water as the dyebath. This was done to select a system to best use the dyes present in the concentrate. This could be successful only when the current production shades were similar to the shade of the concentrate water. At other times a production shade had to be chosen that obscured the dyes present in the concentrate water.

The concentrate produced by the hyperfiltration module for the first cycle was a grey-green color. Laboratory dyeings gave grey-green shades on standard test fabrics. Since no green dye shades were scheduled for the plant production this particular week, a tan shade (Color No. 133) on a 100% cotton velour fabric was chosen for use with the concentrate for this test, Table B-3.

The tan shade was produced on the velour fabric with no difficulty being encountered during the dyeing operation. The results of the light fastness test and crock test were the same as that obtained with normal dyeing procedures. The fabric was graded as first quality and sold.

Table B-3. CYCLE #1 CONCENTRATE WATER REUSE DYEING[a]

Chemical[b]	Dye Name	Dye Used Based on % Fabric Wt. Test Dyeing	Normal Dyeing
Direct Dye	Bellchem Yellow EFC	0.349	0.341
Direct Dye	Calco Red 6BLL	0.044	0.025
Direct Dye	Diphenyl F Blue 4GL	0.019	
Direct Dye	Sol Brown GRL		0.043
Direct Dye	Sup F Blue 8GLN		0.029
Salt		20.	

[a] 21.8 kg of fabric in a dyebath of 0.87 m^3 at pH = 7.

[b] The fabric was finished with a Scotchgard.

CYCLE #2

The analyses of the average feed to the DuPont module, the product water, and the concentrate are tabulated in Table B-4.

Table B-4. WATER ANALYSES FOR CYCLE #2 (April 24, 1973)

	Feed[a] Water Analyses	Product Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	315	20	815
BOD, mg/ℓ	35	5	135
TOC, mg/ℓ	65	5	200
pH	6.0	6.0	6.5
Alkalinity, mg/ℓ	55	15	135
Hardness, mg/ℓ	40	15	120
Total Solids, mg/ℓ	1155	270	5570
Volatile Solids, mg/ℓ	175	N.D.	450
Dissolved Solids, mg/ℓ	1095	270	5540
Color (Pt-Co units)	810	20	1250
Turbidity, F.T.U.	19.0	0.5	31.0
Conductivity (μmho/cm)	1900	580	1030
Metals			
Calcium, mg/ℓ	-	-	-
Zinc, mg/ℓ	-	-	-
Magnesium, mg/ℓ	3.30	0.1	10.4
Chromium, mg/ℓ	<0.1	<0.1	<0.1
Copper, mg/ℓ	-	-	-
Iron, mg/ℓ	0.25	<0.13	2.0
Mercury, μg/ℓ	0.75	N.D.	7.2
Manganese, mg/ℓ	<0.1	<0.1	<0.1
Sodium, mg/ℓ	-	-	-

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #2 for the DuPont module.

Product Water

The product water was used to dye a yellow shade (Color No. 114) on a ribbed, 100% cotton velour fabric, Table B-5. The dyeing operation was conducted by normal plant procedures with no problems being encountered.

Table B-5. CYCLE #2 PRODUCT WATER REUSE DYEING[a]

Chemical	Dye Name	Weight Used Based On % Fabric Wt.
Direct Dye	Bellchem Yellow EFC	0.046
Direct Dye	Intralite F Yellow 2GLL	0.600
Salt		20.

[a] 64.8 kg of fabric in a dyebath of 1.5 m^3 at pH = 6 - 7.

Concentrate Water

The concentrate water was used to dye a medium dark blue-green shade (Color No. 676) on a 100% cotton velour fabric, Table B-6.

The concentrate in the laboratory produced a dull grey shade on a test fabric. Since the plant had no production color to match this dull grey color, a darker color had to be used so that the dullness would not affect the color of the final dyed fabric. This is a limitation that arises when the concentrate contains many different dyes and chemicals.

The dyeing operation proceeded normally with no apparent problems. The desired blue-green shade was obtained on the 100% cotton velour fabric. The crocking test was good and comparable to results obtained with fabric dyed in the normal manner. The fabric in that test did show significant fading after 40-hours exposure in the Fade-O-Meter. This was not considered unusual for this particular shade and therefore was not

attributed to the use of the concentrate water. The fabric was graded as first quality and sold.

Table B-6. CYCLE #2 CONCENTRATE WATER REUSE DYEING[a]

Chemical	Dye Name	Dye Used Based on % Fabric Wt.	
		Test Dyeing	Normal Dyeing
Direct Dye	Solo Green 5BL	1.03	0.900
Direct Dye	Intralite F Yellow 2GLL	0.018	0.032
Salt			15.

[a] 44.1 kg of fabric in a dyebath of 1.5 m^3 at pH = 7.

CYCLE #3

The analyses of the average feed to the DuPont module, the product water, and the concentrate are tabulated in Table B-7.

Table B-7. WATER ANALYSES FOR CYCLE #3 (May 21, 1974)

	Feed[a] Water Analyses	Product Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	220	20	455
BOD, mg/ℓ	40	5	60
TOC, mg/ℓ	70	5	110
pH	6.75	6.4	7.0
Alkalinity, mg/ℓ	45	15	110
Hardness, mg/ℓ	40	20	80
Total Solids, mg/ℓ	855	130	2545
Volatile Solids, mg/ℓ	140	20	280
Dissolved Solids, mg/ℓ	825	130	2480
Color (Pt-Co units)	680	13	1500
Turbidity, F.T.U.	1.7	1.3	1.6
Conductivity (μmho/cm)	1300	200	3800
Metals			
Calcium, mg/ℓ	-	-	-
Zinc, mg/ℓ	-	-	-
Magnesium, mg/ℓ	2.06	-	-
Chromium, mg/ℓ	<0.1	<0.1	<0.1
Copper, mg/ℓ	-	<0.4	0.84
Iron, mg/ℓ	0.2	<0.1	0.3
Mercury, μg/ℓ	1.08	0.56	1.24
Manganese, mg/ℓ	-	-	-
Sodium, mg/ℓ	-	-	-

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #3 for the DuPont module.

Product Water and Concentrate

To establish the compatibility of the product water and concentrate, it was decided to use them together in a plant production dyeing. The product water was used for all water needs in the dyeing procedure except the actual dyeing operation, when the concentrate was used as the dyebath.

A light blue shade (Color No. 662) was dyed on a 65% cotton - 35% rayon velour, Table B-8. The shade was selected to achieve good utilization of the dyes in the concentrate. A 71% reduction of dyes, compared to that required in standard formulation, was achieved.

The light fastness and crocking fastness of the dyed fabric was normal. Even though the shade was not in the production schedule, it is a catalog shade and demonstrates that savings can be achieved from dye recycling.

This cloth was graded first quality but sold as second because the small yardage of fabric dyed was not part of the scheduled production.

Table B-8. CYCLE #3 COMBINED PRODUCT WATER AND CONCENTRATE REUSE DYEING[a]

Chemical	Dye Name	Dye Used Based On % Fabric Wt.	
		Test Dyeing	Normal Dyeing
Direct Dye	Sup F Blue 8GLN		0.146
Direct Dye	Bellchem Yellow EFC		0.028
Direct Dye	Direct Fast Red 8BLN		0.015
Direct Dye	Pyrazol F Blue 2GLN	0.055	
Salt		15.	15.

[a] 37 kg of fabric in a dyebath of 1.5 m^3 at pH = 7.

CYCLE #4

The analyses of the average feed to the DuPont module, the product water, and the concentrate are tabulated in Table B-9.

Table B-9. WATER ANALYSES FOR CYCLE #4 (June 12, 1973)

	Feed[a] Water Analyses	Product Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	245	15	580
BOD, mg/ℓ	49	4	102
TOC, mg/ℓ	70	5	165
pH	6.8	6.5	7.2
Alkalinity, mg/ℓ	55	15	160
Hardness, mg/ℓ	30	5	90
Total Solids, mg/ℓ	970	280	3020
Volatile Solids, mg/ℓ	95	40	310
Dissolved Solids, mg/ℓ	945	280	2985
Color (Pt-Co units)	470	6	1000
Turbidity, F.T.U.	40	0.8	40
Conductivity (μmho/cm)	1600	540	4800
Metals			
Calcium, mg/ℓ	2.3	0.24	6.5
Zinc, mg/ℓ	-	-	-
Magnesium, mg/ℓ	2.9	0.28	10.2
Chromium, mg/ℓ	-	-	-
Copper, mg/ℓ	-	-	-
Iron, mg/ℓ	-	-	-
Mercury, μg/ℓ	-	-	-
Manganese, mg/ℓ	-	-	-
Sodium, mg/ℓ	240	94	980

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #4 for the DuPont module.

Product Water and Concentrate

The procedure of combining the product water and concentrate in a single reuse test dyeing (as in Cycle #3) was repeated. The concentrate yielded a grey shade on the laboratory test fabric. A rose shade (Color No. 405) was selected to get maximum use of the dyes in the concentrate. A 100% cotton velour fabric was dyed in the full scale reuse test, Table B-10.

The light fastness of the fabric dyed with the concentrate was equal to the standard material. The plant scale dyeing proceeded normally. The fabric was sold as first quality.

Table B-10. CYCLE #4 COMBINED PRODUCT WATER AND CONCENTRATE REUSE DYEING[a]

Chemical	Dye Name	Dye Used Based On % Fabric Wt.	
		Test Dyeing	Normal Dyeing
Direct Dye	Direct Fast Red 8BLN	0.094	
Direct Dye	Bellchem Yellow EFC	0.092	0.167
Direct Dye	Superlite Blue 8GLN	0.047	0.047
Direct Dye	Calco Red G BLL		0.088
Salt		10.	10.

[a] 38.5 kg of fabric in a dyebath of 1.5 m^3 at pH = 7.

CYCLE #5

The analyses of the average feed to the DuPont module, the product water, and the concentrate are tabulated in Table B-11.

Table B-11. WATER ANALYSES FOR CYCLE #5 (July 7, 1973)

	Feed[a] Water Analyses	Product Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	230	15	690
BOD, mg/ℓ	45	0.3	95
TOC, mg/ℓ	50	5	220
pH	6.4	6.5	7.2
Alkalinity, mg/ℓ	45	25	190
Hardness, mg/ℓ	25	5	135
Total Solids, mg/ℓ	990	440	4425
Volatile Solids, mg/ℓ	135	40	405
Dissolved Solids, mg/ℓ	930	440	4230
Color (Pt-Co units)	510	30	1200
Turbidity, F.T.U.	45.0	3.4	30.0
Conductivity (μmho/cm)	2000	1000	9500
Metals			
Calcium, mg/ℓ	1.10	0.10	9.0
Zinc, mg/ℓ	4.40	0.08	8.50
Magnesium, mg/ℓ	3.10	0.22	13.8
Chromium, mg/ℓ	0.1	0.1	0.1
Copper, mg/ℓ	-	-	-
Iron, mg/ℓ	-	-	-
Mercury, μg/ℓ	-	-	-
Manganese, mg/ℓ	-	-	-
Sodium, mg/ℓ	300	160	1400

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #5 for the DuPont module.

Product Water and Concentrate

The procedure of combining the product water and concentrate in a single reuse test dyeing (as in Cycle #3) was repeated. The concentrate yielded a grey shade on the laboratory test fabric. A violet shade (helio) was selected to get maximum use of the dyes in the concentrate. A 100% cotton velour fabric was dyed in the full scale reuse test, Table B-12.

The light fastness of the fabric dyed with the concentrate was equal to the standard material. The plant scale dyeing proceeded normally. The fabric was sold as first quality.

Table B-12. CYCLE #5 COMBINED PRODUCT WATER AND CONCENTRATE REUSE DYEING[a]

Chemical	Dye Name	Dye Used Based On % Fabric Wt.	
		Test Dyeing	Normal Dyeing
Direct Dye	Direct Fast Red 8BLN	0.01	0.01
Direct Dye	Pyrazol Fast Violet 4BL	0.12	0.12
Salt		25.	25.

[a] 37 kg of fabric in a dyebath of 1.5 m^3 at pH = 7.

CYCLE #6

The analyses of the average feed to the DuPont module, the product water, and the concentrate are tabulated in Table B-13.

Table B-13. WATER ANALYSES FOR CYCLE #6 (September 20, 1973)

	Feed[a] Water Analyses	Product Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	170	25	435
BOD, mg/ℓ	15	1	10
TOC, mg/ℓ	-	-	-
pH	6.6	7.1	7.4
Alkalinity, mg/ℓ	45	15	140
Hardness, mg/ℓ	45	10	130
Total Solids, mg/ℓ	780	285	3425
Volatile Solids, mg/ℓ	130	60	315
Dissolved Solids, mg/ℓ	755	285	3435
Color (Pt-Co units)	595	60	1250
Turbidity, F.T.U.	55	6.3	80
Conductivity (μmho/cm)	850	520	6200
Metals			
Calcium, mg/ℓ	1.0	0.5	6.0
Zinc, mg/ℓ	4.0	0.7	9.0
Magnesium, mg/ℓ	4.0	0.9	17
Chromium, mg/ℓ	-	-	-
Copper, mg/ℓ	0.08	0.08	2.0
Iron, mg/ℓ	-	-	-
Mercury, μg/ℓ	-	-	-
Manganese, mg/ℓ	-	-	-
Sodium, mg/ℓ	250	90	1120

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #6 for the DuPont module.

Product Water

The product water was used with the same dye/fabric system as Cycle #1, i.e. a gold shade (light covert) on a 54% nylon - 46% viscose blend. During Cycle #6, 90% of the wastewater was recovered as product water. Therefore, the product water contained more impurities than in the previous reuse tests. Thus it was decided to again check separately its suitability for plant use, see Table B-2. In Cycle #6, 45.4 kg of fabric were dyed in a 1.5 m^3 dyebath at a pH of 6 - 7.

The light fastness and wash fastness of the dyed fabric was good and comparable to that obtained with normal plant dyeings. No adverse results were observed from the use of the product water in the plant dyeing.

Concentrate Water

The concentrate water was used with the same tan shade (Color No. 133) on 100% cotton velour fabric, dyed in Cycle #1. This shade was repeated so that a comparison could be made of the results obtained with the dyeing in Cycle #1, Table B-14. This comparison was desired because at 90% water recovery, the concentrate contains more dyes and impurities.

The dyeing operation proceeded normally with no apparent problems. The same shade was produced on the cotton velour fabric as was used for the concentrate in Cycle #1. The light fastness of the dyed fabric was comparable to that obtained with regular production dyeings. The material was graded as first quality and sold.

Table B-14. CYCLE #6 CONCENTRATE WATER REUSE DYEING[a]

Chemical	Dye Name	Dye Used Based On % Fabric Wt. Test Dyeing	Dye Used Based On % Fabric Wt. Normal Dyeing
Direct Dye	Bellchem Yellow EFC	0.280	0.341
Direct Dye	Calco Red 6BLL	0.015	0.025
Direct Dye	Diphenyl F Blue 4GL	0.010	
Direct Dye	Sol Brown GRL		0.043
Direct Dye	Sup F Blue 86LN		0.029
Salt		20.	20.

[a] 89.4 kg of fabric in a dyebath of 1.5 m^3 at pH = 7.

CYCLE #7

The analyses of the average feed to the ORNL module, and the concentrate are tabulated in Table B-15.

Table B-15. WATER ANALYSES FOR CYCLE #7 (November 6, 1973)

	Feed[a] Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	150	190
BOD, mg/ℓ	10	15
TOC, mg/ℓ	25	-
pH	8.1	8.0
Alkalinity, mg/ℓ	75	155
Hardness, mg/ℓ	15	50
Total Solids, mg/ℓ	860	1580
Volatile Solids, mg/ℓ	120	165
Dissolved Solids, mg/ℓ	820	1480
Color (Pt-Co units)	510	1300
Turbidity, F.T.U.	35	8.5
Conductivity (μmho/cm)	1400	1700
Metals		
Calcium, mg/ℓ	0.53	0.96
Zinc, mg/ℓ	1.70	2.4
Magnesium, mg/ℓ	1.87	4.5
Chromium, mg/ℓ	-	-
Copper, mg/ℓ	-	-
Iron, mg/ℓ	4.0	18
Mercury, μg/ℓ	-	-
Manganese, mg/ℓ	-	-
Sodium, mg/ℓ	250	470

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #7 for the ORNL module.

Concentrate Water

For Cycle #7, the concentrate water was used for the dyebath formulation and regular process water was used for all other phases of the dyeing operation. The product water had been used interchangeably with process water in previous dyeings and its suitability for plant use had been demonstrated. In Cycle #7, the primary interest was in the use of the concentrate to further demonstrate dye recovery.

The concentrate water produced a dyeing with a light pink shade on cotton test fabric. Because of this, a rose shade (Color No. 405) was chosen for the plant dyeing of a 100% cotton velour fabric, Table B-16. The plant dyeing proceeded normally with no problems being observed with the use of the concentrate water.

The light fastness was the same as that normally obtained with fabric dyed this shade. The fabric was sold as first quality.

Table B-16. CYCLE # 7 CONCENTRATE WATER REUSE DYEING[a]

Chemical	Dye Name	Dye Used Based On % Fabric Wt.	
		Test Dyeing	Normal Dyeing
Direct Dye	Sup F Blue 8GLN	0.060	0.146
Direct Dye	Bellchem Yellow EFC	0.125	0.028
Direct Dye	Direct Fast Red 8BLN	20.	15.

[a] 69.4 kg of fabric in a dyebath of 1.5 m^3 at pH = 7.

CYCLE #8

The analyses of the average feed to the ORNL module, and the concentrate are tabulated in Table B-17.

Table B-17. WATER ANALYSES FOR CYCLE #8 (November 26, 1973)

	Feed[a] Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	220	415
BOD, mg/ℓ	35	45
TOC, mg/ℓ	-	-
pH	6.8	7.5
Alkalinity, mg/ℓ	35	115
Hardness, mg/ℓ	20	55
Total Solids, mg/ℓ	1010	2510
Volatile Solids, mg/ℓ	155	275
Dissolved Solids, mg/ℓ	970	2450
Color (Pt-Co units)	450	1680
Turbidity, F.T.U.	2.8	15.0
Conductivity (μmho/cm)	1100	1850
Metals		
Calcium, mg/ℓ	1.48	8.1
Zinc, mg/ℓ	1.90	3.14
Magnesium, mg/ℓ	2.63	9.6
Chromium, mg/ℓ	-	-
Copper, mg/ℓ	-	-
Iron, mg/ℓ	0.3	40.0
Mercury, μg/ℓ	-	-
Manganese, mg/ℓ	-	-
Sodium, mg/ℓ	325	780

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #8 for the ORNL module.

Concentrate Water

As in Cycle #7, the concentrate water was used with the regular process water and the product water was not used in the plant.

The concentrate water produced a dyeing with a light blue-grey shade on cotton test fabric. Because of this a blue-green shade (Color No. 616) was chosen for the plant dyeing on a 100% cotton velour, Table B-18.

The light fastness of the dyed fabric was the same as that obtained with fabric dyed by normal procedures. The dyed fabric did show some slight side-to-center shading. This was probably the result of a twist in the fabric rope during dyeing. This problem was not associated with the concentrate water. The fabric was sold as first quality.

Table B-18. CYCLE #8 CONCENTRATE WATER REUSE DYEING[a]

Chemical	Dye Name	Dye Used Based On % Fabric Wt. Test Dyeing	Normal Dyeing
Direct Dye	Sup F Blue 8GLN	0.420	
Direct Dye	Sup Yellow EFC	0.065	0.099
Direct Dye	Direct Fast Red 8BLN		0.016
Direct Dye	Pyrazol Blue 2GLN		0.517
Salt		25.	15.

[a] 45.4 kg of fabric in a dyebath of 1.5 m^3 at pH = 7.

CYCLE #9

The analyses of the average feed to the ORNL module, the product water, and the concentrate are tabulated in Table B-19.

Table B-19. WATER ANALYSES FOR CYCLE #9 (January 23, 1974)

	Feed[a] Water Analyses	Product Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	230	30	265
BOD, mg/ℓ	35	2.7	30
TOC, mg/ℓ	-	-	-
pH	6.6	7.2	7.1
Alkalinity, mg/ℓ	45	40	105
Hardness, mg/ℓ	25	4	95
Total Solids, mg/ℓ	1085	630	1515
Volatile Solids, mg/ℓ	170	95	285
Dissolved Solids, mg/ℓ	1050	630	1445
Color (Pt-Co units)	180	30	470
Turbidity, F.T.U.	20	1.5	30
Conductivity (μmho/cm)	1050	715	1200
Metals			
Calcium, mg/ℓ	0.88	0.17	6.40
Zinc, mg/ℓ	5.20	0.06	7.04
Magnesium, mg/ℓ	2.76	0.58	5.76
Chromium, mg/ℓ	-	-	-
Copper, mg/ℓ	-	-	-
Iron, mg/ℓ	2.38	0.63	18.1
Mercury, μg/ℓ	-	-	-
Manganese, mg/ℓ	-	-	-
Sodium, mg/ℓ	350	270	505

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #9 for the ORNL module.

Product Water

The product water was used to dye the same shade (light covert) and fabric (54% nylon - 46% viscose) used with the product water in Cycle #1. This was done so a comparison could be made between the product water from the DuPont hollow fiber polyamide membrane module and the product water from a dynamic membrane module. This light shade provided a critical test for the reuse of the product water, see Table B-2. In Cycle #9, 48 kg of fabric were dyed in a dyebath of 1.5 m^3 at pH of 6 - 7.

The desired shade was obtained with no problems being encountered. The dyed fabric passed all of the tests for light fastness and crocking.

Concentrate Water

The concentrate water was used to dye a light tan shade (oyster) on 100% cotton velour, Table B-20.No dyes were added to the concentrate water and the shade produced was due solely to the dyes in the concentrate.

The dyeing operation proceeded normally with no apparent problems. The fabric exhibited satisfactory light fastness and was sold commercially.

Table B-20. CYCLE #9 CONCENTRATE WATER REUSE DYEING[a]

Chemical[b]	Dye Name	Dye Used Based On % Fabric Wt. Test Dyeing	Normal Dyeing
Salt	-	10.	-[b]

[a] 21.8 kg of fabric in a dyebath of 1.5 m^3 at pH = 7.

[b] No dyes were added to the dyebath.

CYCLE #10

The analyses of the average feed to the Westinghouse module, the product water, and the concentrate are tabulated in Table B-21.

Table B-21. WATER ANALYSES FOR CYCLE #10 (January 22, 1974)

	Feed[a] Water Analyses	Product Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	150	200	385
BOD, mg/ℓ	15	1.3	25
TOC, mg/ℓ	-	-	-
pH	6.6	6.2	7.1
Alkalinity, mg/ℓ	25	3	90
Hardness, mg/ℓ	30	6	105
Total Solids, mg/ℓ	655	215	1765
Volatile Solids, mg/ℓ	120	75	240
Dissolved Solids, mg/ℓ	645	205	1740
Color (Pt-Co units)	490	60	960
Turbidity, F.T.U.	25	6	125
Conductivity (μmho/cm)	950	340	2250
Metals			
Calcium, mg/ℓ	1.43	0.88	2.57
Zinc, mg/ℓ	6.00	0.82	16.0
Magnesium, mg/ℓ	5.84	0.78	8.00
Chromium, mg/ℓ	-	-	-
Copper, mg/ℓ	-	-	-
Iron, mg/ℓ	2.38	1.13	3.00
Mercury, μg/ℓ	-	-	-
Manganese, mg/ℓ	-	-	-
Sodium, mg/ℓ	190	55	600

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #10 for the Westinghouse module.

Product Water

The product water was used to dye the same shade (light covert) and fabric (54% nylon - 46% viscose) used with the product water in Cycle #1. This was done so a comparison could be made between the product water from the DuPont hollow fiber polyamide membrane module and product water from the Westinghouse cellulose acetate membrane module. This shade provided a critical test for the reuse of the product water, see Table B-2. In Cycle #10, 46.2 kg of fabric were dyed in a dyebath of 1.5 m^3 at pH of 6 - 7.

The desired shade was obtained with no problems being encountered. The dyed fabric passed all of the tests for light fastness and crocking.

Concentrate Water

The concentrate water was used to dye a burnt-orange shade (Color No. 214), on 100% cotton velour fabric, Table B-22. The concentrate water gave a light grey shade by itself so little dye was present in the concentrate.

The dyeing operation proceeded normally with no apparent problems. A burnt-orange shade was produced on a cotton velour fabric. The light fastness of the dyed fabric was comparable to that obtained with regular production dyeings and the fabric was sold as first quality.

Table B-22. CYCLE #10 CONCENTRATE WATER REUSE DYEING[a]

Chemical	Dye Name	Dye Used Based On % Fabric Wt.	
		Test Dyeing	Normal Dyeing
Direct Dye	Fastusol Orange LTG	1.500	1.500
Direct Dye	Supra Light Fast Blue 8GLN	0.020	0.040
Direct Dye	Fast Red 8 BLN	0.065	0.080
Salt		20.	20.

[a] 44 kg of fabric in a dyebath of 1.5 m^3 at pH = 7.

CYCLE #12

The analyses of the average feed to the DuPont module, the product water, and the concentrate are tabulated in Table B-23.

Table B-23. WATER ANALYSES FOR CYCLE #12 (March 4, 1974)

	Feed[a] Water Analyses	Product Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	110	10	365
BOD, mg/ℓ	15	2	15
TOC, mg/ℓ	-	-	-
pH	6.5	6.4	6.8
Alkalinity, mg/ℓ	30	10	95
Hardness, mg/ℓ	50	3	245
Total Solids, mg/ℓ	1160	230	4320
Volatile Solids, mg/ℓ	155	65	245
Dissolved Solids, mg/ℓ	1150	230	4320
Color (Pt-Co units)	320	20	920
Turbidity, F.T.U.	5.5	2.0	3400
Conductivity (μmho/cm)	1400	400	3400
Metals			
Calcium, mg/ℓ	7.20	1.00	34.0
Zinc, mg/ℓ	3.60	0.50	7.20
Magnesium, mg/ℓ	9.00	0.42	27.0
Chromium, mg/ℓ	-	-	-
Copper, mg/ℓ	-	-	-
Iron, mg/ℓ	-	-	-
Mercury, μg/ℓ	-	-	-
Manganese, mg/ℓ	0.07	0.04	0.45
Sodium, mg/ℓ	395	75	1470

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #12 for the DuPont module.

Product Water and Concentrate

The product water and concentrate were used together in this dye cycle. The concentrate gave a light tan shade on a cotton velour test fabric. After checking several production shades for which the concentrate could be used, a burnt-orange shade (Color No. 212) was selected, Table B-24.

A burnt-orange shade was produced on a 100% cotton velour fabric. No problems were encountered during the dyeing operation and the fabric was graded as first quality.

Table B-24. CYCLE #12 COMBINED PRODUCT WATER AND CONCENTRATE REUSE DYEING[a]

Chemical	Dye Name	Dye Used Based On % Fabric Wt.	
		Test Dyeing	Normal Dyeing
Direct Dye	Diaz-Orange 5JA	1.350	1.780
Direct Dye	Lum-DR-Brown 3LB	0.020	-
Direct Dye	Dir. F-Red 8BLN	0.080	0.090
Direct Dye	Sol Brown GRLN		0.070
Salt		25.	15.

[a] 23.6 kg of fabric in a dyebath of 1.5 m^3 at pH 6 - 7.

CYCLE #14

The analyses of the average feed to the Gulf module, the product water, and the concentrate are tabulated in Table B-25.

Table B-25. WATER ANALYSES FOR CYCLE #14 (May 7, 1974)

	Feed[a] Water Analyses	Product Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	160	25	430
BOD, mg/ℓ	10	1	20
TOC, mg/ℓ	35	5	230
pH	6.2	5.9	6.7
Alkalinity, mg/ℓ	50	8	160
Hardness, mg/ℓ	75	0.5	190
Total Solids, mg/ℓ	670	45	3025
Volatile Solids, mg/ℓ	145	15	275
Dissolved Solids, mg/ℓ	655	50	3025
Color (Pt-Co units)	280	40	1100
Turbidity, F.T.U.	30	2.5	35
Conductivity (μmho/cm)	580	80	2000
Metals			
Calcium, mg/ℓ	1.80	0.08	7.50
Zinc, mg/ℓ	0.96	0.04	3.04
Magnesium, mg/ℓ	3.10	0.02	15.0
Chromium, mg/ℓ	0.30	0.10	0.60
Copper, mg/ℓ	0.12	0.04	2.50
Iron, mg/ℓ	0.14	0.14	0.14
Mercury, μg/ℓ	-	-	-
Manganese, mg/ℓ	0.14	0.03	0.60
Sodium, mg/ℓ	225	15	1090

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #14 for the Gulf module.

Product Water and Concentrate

The product water and concentrate were used together in this dye cycle, also. The concentrate gave a grey-green shade on a cotton test fabric. After checking several production shades for which the concentrate could be used, it was decided to select a gold shade (Color No. 175) which had not previously been used in the pilot study, Table B-26.

The gold shade was produced on a 100% cotton velour fabric. No problems were encountered during the dyeing operation and the fabric was graded as first quality.

Table B-26. CYCLE #14 COMBINED PRODUCT WATER AND CONCENTRATE REUSE DYEING[a]

Chemical	Dye Name	Dye Used Based On % Fabric Wt.	
		Test Dyeing	Normal Dyeing
Direct Dye	Diaz-Orange 5JA	0.900	0.950
Direct Dye	Intralite Green BLL	0.040	0.061
Direct Dye	Intralite Red 6BLL	0.020	0.022
Direct Dye	Bellchem Yellow EFL	0.030	-
Salt		20.	15.

[a] 71.2 kg of fabric in a dyebath of 1.5 m^3 at pH = 6 - 7.

CYCLE #16

The analyses of the average feed to the Selas module, the product water, and the concentrate are tabulated in Table B-27.

Table B-27. WATER ANALYSES FOR CYCLE #16 (July 9, 1974)

	Feed[a] Water Analyses	Product Water Analyses	Concentrate Water Analyses
COD, mg/ℓ	160	15	255
BOD, mg/ℓ	-	-	55
TOC, mg/ℓ	30	5	100
pH	7.1	9.2	9.0
Alkalinity, mg/ℓ	40	20	250
Hardness, mg/ℓ	55	20	130
Total Solids, mg/ℓ	805	195	3110
Volatile Solids, mg/ℓ	-	-	-
Dissolved Solids, mg/ℓ	780	190	3055
Color (Pt-Co units)	295	30	190
Turbidity, F.T.U.	6.3	0.45	18
Conductivity (μmho/cm)	1250	450	4200
Metals			
Calcium, mg/ℓ	5.20	0.20	15.5
Zinc, mg/ℓ	0.94	0.02	1.80
Magnesium, mg/ℓ	4.40	0.26	12.0
Chromium, mg/ℓ	-	-	-
Copper, mg/ℓ	-	-	-
Iron, mg/ℓ	-	-	-
Mercury, μg/ℓ	-	-	-
Manganese, mg/ℓ	-	-	-
Sodium, mg/ℓ	-	-	-

[a] This is the analyses of a composite sample taken from the feeds that were used during Cycle #16 for the Selas module.

Concentrate Used with Regular Plant Water

The product water was not used in a plant scale dyeing because of the results of several earlier recycle dyeings which established that water of this quality could be used interchangeably with process water. The concentrate gave a grey-green shade on a cotton velour test fabric. After checking several production shades for which the concentrate could be used, a green shade (special) was selected, Table B-28.

A medium green shade was produced on a 100% cotton velour fabric. No problems were encountered during the dyeing operation and the fabric was graded was first quality.

Table B-28. CYCLE #16 CONCENTRATE WATER REUSE DYEING[a]

Chemical	Dye Name	Dye Used Based On % Fabric Wt.	
		Test Dyeing	Normal Dyeing
Direct Dye	Int. Green BLL	0.050	-[b]
Direct Dye	Sup Yellow EFC	0.170	-
Direct Dye	Dir. Red 5BLN	0.015	-
Salt		20.	-

[a] 16.3 kg of fabric in a dyebath of 1.5 m^3 at pH = 6 - 7.

[b] No dyes were added to the dyebath.

SECTION XII

APPENDIX C

Table C-1. PERFORMANCE OF HYPERFILTRATION MODULES IN THE LA FRANCE PILOT PLANT

Rejection and Absolute Values of COD, BOD, TOC, and pH[a]

(mg/ℓ)[b]

Sample number	Operating time (hrs)	COD				BOD				TOC				pH		
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C
	Cycle No. 1 - DuPont Permeator #7753N															
4	7	730	20	1370	97.3	-	-	-	-	140	5	245	96.4	7.0	8.0	7.2
7	16	400	20	590	95.0	-	-	-	-	45	5	135	88.9	7.8	8.0	7.2
	DuPont Permeator #7725N															
12	13	160	10	350	93.8	-	-	-	-	30	2	100	93.3	6.1	5.6	6.4
16	27	200	20	430	90.0	-	-	-	-	35	3	75	91.4	6.4	5.7	6.8
22	37	195	20	405	89.7	35	<1	125	>97.1	25	15	70	40.0	6.8	6.1	6.9
23	49	130	10	300	92.3	-	-	-	-	30	3	55	90.0	6.3	5.8	6.6
24	55	295	10	505	96.6	20	2	40	90.0	75	4	160	94.7	6.8	6.3	7.2
25	61	300	10	415	96.7	-	-	-	-	70	2	115	90.7	6.6	6.2	6.9
26	70	205	15	280	92.7	-	-	-	-	65	7	90	89.2	6.8	6.4	6.8
27	76	190	15	270	92.1	-	-	-	-	45	3	80	93.3	6.8	6.2	7.0
28	84	170	35	380	79.4	50	20	130	60.0	35	7	75	80.0	6.6	6.2	7.3
29	88	215	60	315	72.1	-	-	-	-	45	-	65	-	6.6	6.4	6.8
31	92	175	15	250	91.4	-	-	-	-	45	4	80	91.1	6.8	6.4	6.5
	Cycle No. 2 - DuPont Permeator #7725N															
33	94	700	20	870	97.1	90	15	125	83.3	130	10	185	92.3	6.7	5.9	6.9
35	102	415	1	615	99.8	-	-	-	-	110	10	190	90.9	6.3	6.0	6.8
36	106	540	1	790	99.8	-	-	-	-	130	5	235	96.2	6.2	6.1	6.7
37	108	940	30	1235	96.8	-	-	-	-	260	15	445	94.2	6.4	6.0	6.4
39	119	330	15	445	95.5	-	-	-	-	70	10	125	85.7	6.3	6.0	6.5
42	131	375	30	525	92.0	-	-	-	-	100	5	140	95.0	6.4	6.2	6.6
44	145	445	70	620	84.3	65	15	105	76.9	115	15	175	87.0	6.4	5.9	6.5
46	150	650	85	995	86.9	-	-	-	-	190	20	385	89.5	6.6	6.2	7.0
48	155	795	100	1260	87.4	-	-	-	-	335	25	605	92.5	6.8	5.9	7.3
50	161	1040	195	1590	81.3	220	60	295	72.7	310	50	655	83.9	6.7	6.3	7.0
52	170	970	180	1515	81.4	-	-	-	-	380	10	495	97.4	6.9	6.2	7.1
53	179	1155	195	1795	83.1	-	-	-	-	315	60	590	81.0	7.1	6.3	7.2

Table C-1. (continued)

Sample number	Operating time (hrs)	COD S	COD P	COD C	COD R%	BOD S	BOD P	BOD C	BOD R%	TOC S	TOC P	TOC C	TOC R%	pH S	pH P	pH C
	Cycle No. 3 - DuPont Permeator #7725N															
55	188	500	55	760	89.0	-	-	-	-	140	15	235	89.3	7.7	6.7	8.1
60	209	645	45	850	93.0	-	-	-	-	200	10	245	95.0	7.0	6.5	7.2
61	217	235	35	330	85.1	-	-	-	-	40	5	55	87.5	7.0	6.2	7.1
65	231	245	40	455	83.7	25	5	45	80.0	65	10	140	84.6	7.1	6.6	7.5
67	284	45	15	85	66.7	-	-	-	-	10	2	25	80.0	7.2	6.6	7.2
69	326	45	15	60	66.7	-	-	-	-	10	3	15	70.0	7.2	6.5	7.5
71	400	280	40	380	85.7	55	5	60	90.9	40	10	70	75.0	7.0	6.7	7.2
73	423	130	30	165	76.9	-	-	-	-	30	5	45	83.3	6.9	6.4	7.0
75	427	85	35	165	58.8	-	-	-	-	25	10	45	60.0	7.0	6.6	7.1
	Cycle No. 4 - DuPont Permeator #7753N															
77	24	590	30	850	94.9	-	-	-	-	150	5	245	96.7	6.9	5.9	7.0
79	28	440	25	615	94.3	-	-	-	-	115	5	165	95.7	6.7	6.2	6.8
81	37	390	35	485	91.0	-	-	-	-	95	5	125	94.7	6.6	6.2	6.7
82	41	350	30	495	91.4	-	-	-	-	105	5	160	95.2	7.0	6.1	7.0
84	49	290	20	495	93.1	-	-	-	-	90	6	140	93.3	6.6	6.0	6.9
86	62	280	55	380	80.4	36	7	60	80.6	100	20	145	80.0	7.0	6.3	7.1
88	148	440	25	560	94.3	75	15	85	80.0	115	7	155	93.9	7.1	6.8	7.4
89	170	450	15	575	96.7	-	-	-	-	115	5	165	95.7	6.9	6.4	7.1
91	218	150	10	190	93.3	-	-	-	-	-	-	-	-	7.1	6.2	7.2
	Cycle No. 5 - DuPont Permeator #7753N															
94	236	540	5	735	99.1	-	-	-	-	145	10	245	93.1	7.2	6.7	7.4
96	251	690	40	790	94.2	-	-	-	-	220	10	255	95.5	7.0	6.5	7.4
99	275	440	40	495	90.9	-	-	-	-	125	5	145	96.0	7.1	6.2	7.2
101	284	260	30	290	88.5	55	10	60	81.8	55	10	65	81.8	7.2	6.2	7.2
104	305	840	35	1025	95.8	-	-	-	-	265	10	475	96.2	7.6	6.4	7.7
108	337	420	20	460	95.2	-	-	-	-	100	5	115	95.0	7.4	6.6	7.4
	Cycle No. 6 - DuPont Permeator #7725N															
116	437	150	35	160	76.7	-	-	-	-	20	15	25	25.0	6.8	6.4	6.8
117	439	175	35	275	80.0	-	-	-	-	30	6	35	80.0	6.8	6.6	7.0
118	442	205	40	250	80.5	-	-	-	-	30	15	40	50.0	7.0	6.5	7.1
120	445	425	50	500	88.2	-	-	-	-	25	15	45	40.0	6.8	6.8	6.8

Table C-1. (continued)

Sample number	Operating time (hrs)	COD				BOD				TOC				pH		
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C
121	452	780	130	975	83.3	-	-	-	-	90	15	120	83.3	7.0	6.7	7.0
124	463	90	15	125	83.3	-	-	-	-	15	2	40	86.7	7.2	6.6	7.1
126	471	150	25	195	83.3	15	5	15	66.7	20	7	25	65.0	7.3	7.0	7.4
128	503	105	15	110	85.7	-	-	-	-	7	2	8	71.4	7.9	7.2	7.7
129	506	130	25	155	80.8	-	-	-	-	10	4	15	60.0	7.4	6.9	7.4
	Cycle No. 7 - ORNL Module															
139	-	150	15	-	90.0	-	-	-	-	25	10	-	60.0	8.7	8.7	-
141	-	225	5	-	97.8	-	-	-	-	30	1	-	96.7	7.6	7.0	-
142	-	135	15	-	88.9	-	-	-	-	15	4	-	73.3	6.8	8.6	-
143	-	160	15	-	90.6	-	-	-	-	30	10	-	66.7	8.9	9.8	-
144	-	150	15	-	90.0	-	-	-	-	20	5	-	75.0	7.9	9.6	-
	Cycle No. 8 - ORNL Module															
149	-	225	40	-	82.2	7	2	-	71.4	55	15	-	72.7	8.1	8.2	-
150	-	290	45	-	84.5	-	-	-	-	30	8	-	73.3	6.6	6.4	-
151	-	195	30	-	84.6	-	-	-	-	35	6	-	82.9	7.1	6.8	-
153	-	265	35	-	86.8	25	7	-	72.0	50	10	-	80.0	6.2	7.0	-
154	-	320	50	-	84.4	-	-	-	-	65	7	-	89.2	6.6	6.9	-
155	-	335	50	-	85.1	-	-	-	-	65	4	-	93.8	6.6	6.9	-
	Cycle No. 9 - ORNL Module															
158	-	110	5	-	95.5	-	-	-	-	35	-	-	-	7.4	6.9	-
159	-	190	10	-	94.7	-	-	-	-	65	-	-	-	7.8	8.6	-
160	-	370	20	-	94.6	-	-	-	-	95	10	-	89.5	8.4	9.0	-
162	-	445	10	-	97.8	-	-	-	-	85	4	-	95.3	7.8	8.4	-
163	-	1105	20	-	98.2	-	-	-	-	105	8	-	92.4	8.2	8.8	-
164	-	1260	30	-	97.6	-	-	-	-	295	15	-	94.9	10.0	10.3	-
167	-	1630	55	-	96.6	-	-	-	-	315	4	-	98.7	7.4	7.6	-
169	-	270	65	-	75.9	-	-	-	-	80	15	-	81.3	10.2	10.1	-
172	-	690	65	-	90.6	-	-	-	-	185	10	-	94.6	8.4	8.8	-
179	-	210	35	-	83.3	-	-	-	-	65	4	-	93.8	7.0	7.6	-
183	-	505	40	-	92.1	-	-	-	-	145	15	-	89.7	7.4	7.8	-
188	-	835	70	-	91.6	-	-	-	-	200	15	-	92.5	7.6	7.2	-
194	-	970	55	-	94.3	-	-	-	-	190	15	-	92.1	7.8	8.1	-

Table C-1. (continued)

Sample number	Operating time (hrs)	COD				BOD				TOC				pH		
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C
	Cycle No. 10 - Westinghouse Module #4-291															
165	23	265	75	260	71.7	-	-	-	-	50	8	60	84.0	7.0	6.2	7.1
168	95	520	10	-	98.1	-	-	-	-	110	7	-	93.6	7.5	6.0	-
173	143	625	10	-	98.4	-	-	-	-	55	10	-	81.8	7.3	6.0	-
174	387	825	20	-	97.6	-	-	-	-	150	5	-	96.7	6.9	5.9	-
176	435	1230	25	-	97.8	-	-	-	-	210	6	-	97.1	7.0	6.1	-
177	502	1630	25	-	98.5	-	-	-	-	135	10	-	92.6	7.2	6.1	-
178	530	890	30	-	96.6	-	-	-	-	155	8	-	94.8	7.0	6.2	-
180	545	1140	90	-	92.1	-	-	-	-	240	20	-	91.7	7.0	6.4	-
	Cycle No. 11 - Westinghouse Module #4-291															
182	556	130	6	-	95.4	-	-	-	-	45	6	-	86.7	6.8	5.6	-
192	701	685	15	-	97.8	-	-	-	-	140	5	-	96.4	7.6	6.7	-
195	744	145	35	-	75.9	-	-	-	-	115	10	-	91.3	6.9	6.4	-
	Cycle No. 12 - DuPont Permeator #400600															
203	1	470	15	1135	96.8	-	-	-	-	80	9	150	88.8	6.6	6.2	6.5
204	10	75	10	110	86.7	-	-	-	-	15	10	70	33.3	6.3	6.0	6.4
208	22	635	10	1215	98.4	-	-	-	-	105	10	215	90.5	6.8	8.6	7.2
209	26	425	20	910	95.3	-	-	-	-	105	10	170	90.5	6.5	6.2	6.7
210	31	290	10	430	96.6	-	-	-	-	45	-	65	-	6.5	5.6	6.6
212	48	190	2	270	98.9	-	-	-	-	20	-	30	-	6.5	5.3	6.6
218	63	360	25	760	93.1	-	-	-	-	15	2	15	86.7	6.4	6.1	6.4
220	80	145	35	210	75.9	-	-	-	-	30	1	35	96.7	6.3	5.9	6.4
223	105	120	10	225	91.7	-	-	-	-	30	6	60	80.0	8.0	9.6	7.4
225	128	145	210	255	-	-	-	-	-	25	7	40	72.0	6.6	6.0	6.4
230	160	320	20	575	93.8	-	-	-	-	75	2	75	97.3	6.4	6.2	6.5
232	165	155	30	230	80.6	-	-	-	-	50	11	50	78.0	6.4	6.0	6.5
235	176	55	20	70	63.6	-	-	-	-	15	1	15	93.3	6.7	6.2	6.7
236	178	160	30	225	81.3	-	-	-	-	20	5	45	75.0	6.3	6.2	6.4
	Cycle No. 13 - ORNL Module															
205	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
207	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cycle No. 14 - Gulf Module															

Table C-1. (continued)

Sample number	Operating time (hrs)	COD				BOD				TOC				pH		
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C
239	93	255	9	330	96.5	-	-	-	-	60	7	90	88.3	6.7	5.7	6.8
246	165	280	20	350	92.9	-	-	-	-	65	3	75	95.4	5.8	6.6	6.0
250	193	180	15	290	91.7	20	2	25	90.0	30	2	45	93.3	6.8	6.2	6.8
252	252	315	85	400	73.0	175	60	205	65.7	-	-	-	-	6.4	5.2	6.4
254	272	795	15	1175	98.1	205	6	260	97.1	155	4	225	97.4	6.7	6.9	7.0
256	316	655	35	675	94.7	-	-	-	-	160	8	165	95.0	6.6	5.9	6.6
257	434	720	25	795	96.5	-	-	-	-	110	8	165	92.7	6.8	6.2	6.9
258	583	660	30	790	95.5	-	-	-	-	170	15	170	91.2	7.1	6.4	7.0
259	631	630	35	740	94.4	-	-	-	-	145	8	220	94.5	7.2	5.9	7.2
260	633	345	15	480	95.7	-	-	-	-	90	5	105	94.4	6.9	6.2	6.8
262	684	390	20	480	94.9	-	-	-	-	80	10	95	87.5	6.4	6.1	6.6
263	708	440	15	570	96.6	-	-	-	-	110	6	120	94.5	6.7	5.9	6.6
264	779	380	20	460	94.7	15	3	20	80.0	135	7	195	94.8	7.0	6.1	7.0
	Cycle No. 16 - Selas Module															
272	-	240	20	-	91.7	20	2	-	90.0	55	7	-	87.3	7.4	6.6	-
273	-	-	20	-	-	-	-	-	-	-	7	-	-	-	6.3	-
274	-	-	20	-	-	-	-	-	-	-	7	-	-	-	6.3	-
277	-	360	-	-	-	-	-	-	-	80	-	-	-	7.6	-	-
278	-	-	30	-	-	-	-	-	-	-	10	-	-	-	9.3	-
281	-	380	10	-	97.4	-	-	-	-	145	6	-	95.9	8.2	9.4	-
282	-	390	-	-	-	-	-	-	-	145	9	-	93.8	7.5	7.3	-
287	-	160	15	-	90.6	-	-	-	-	30	5	-	83.3	7.1	7.7	-
289	-	210	10	-	95.2	-	-	-	-	55	2	-	96.4	8.2	8.9	-
290	-	250	15	-	94.0	-	-	-	-	70	5	-	92.9	8.3	9.2	-

[a] S = supply to module; P = permeate (or product); C = concentrate (or residue); R ≡ 1 - (P/S) = rejection

[b] All results are in mg/ℓ except for pH (unitless).

Table C-2. PERFORMANCE OF HYPERFILTRATION MODULES IN THE LA FRANCE PILOT PLANT

Rejection and Absolute Values of Alkalinity, Hardness, Total Solids, and Volatile Solids[a] (mg/ℓ)[b]

Sample number	Operating time (hrs)	Alkalinity				Hardness				Total Solids				Volatile Solids			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
	Cycle No. 1 - DuPont Permeator #7753N																
4	7	-	-	-	-	-	-	-	-	5390	230	8930	95.7	420	60	550	85.7
7	16	110	10	250	90.0	40	30	140	25.0	1250	40	3600	96.8	-	-	-	-
	DuPont Permeator #7725N																
12	13	30	5	100	83.3	35	20	70	42.9	840	60	2460	92.9	-	-	-	-
16	27	30	10	85	66.7	40	25	100	37.5	1490	135	4070	90.0	-	-	-	-
22	37	45	10	120	77.8	45	15	110	66.7	830	80	2360	90.4	155	40	320	74.2
23	49	60	10	135	83.3	40	15	95	62.5	850	75	2150	91.2	-	-	-	-
24	55	90	10	190	88.9	35	15	70	57.1	1095	85	2420	92.2	195	35	325	82.1
25	61	130	10	195	92.3	45	10	60	77.8	1560	85	2380	94.6	-	-	-	-
26	70	125	10	160	92.0	45	10	60	77.8	1550	95	2090	93.9	-	-	-	-
27	76	120	10	185	91.7	45	15	65	66.7	1490	100	2370	93.3	-	-	-	-
28	84	70	10	170	85.7	50	10	90	80.0	1315	170	3445	87.1	155	65	295	58.1
29	88	110	20	160	81.8	60	10	90	83.3	2105	180	3270	91.4	195	70	260	64.1
31	92	105	15	140	85.7	60	10	90	83.3	1660	155	2570	90.7	175	75	240	57.1
	Cycle No. 2 - DuPont Permeator #7725N																
33	94	115	20	150	82.6	70	15	80	78.6	10650	1200	15920	88.7	275	95	3935	88.7
35	102	150	10	195	93.3	50	15	65	70.0	3350	240	4965	92.8	215	85	330	60.5
36	106	105	15	150	85.7	45	15	80	66.7	2380	130	3720	94.5	190	60	365	68.4
37	108	105	15	115	85.7	110	10	135	90.9	4175	390	5505	90.7	545	95	645	82.6
39	119	110	15	155	86.4	60	15	70	75.0	1420	85	2095	94.0	200	55	280	72.5
42	131	90	25	110	72.2	120	15	165	87.5	3020	380	4245	90.7	225	85	325	62.2
44	145	130	15	190	88.5	40	15	50	62.5	910	80	1370	91.2	215	25	295	88.4
46	150	245	20	380	91.8	70	10	110	85.7	1730	135	2760	92.2	355	40	525	88.7
48	155	385	30	615	92.2	120	15	185	87.5	2765	220	4610	92.0	485	55	925	88.7
50	161	195	25	285	87.2	90	10	110	88.9	1575	150	2365	90.5	355	65	510	81.7
52	170	230	25	355	89.1	110	10	165	90.9	1940	185	2945	90.5	380	70	575	81.6
53	179	320	30	480	90.6	165	15	235	90.9	2660	235	4135	91.2	-	-	-	-

Table C-2. (continued)

Sample number	Operating time (hrs)	Alkalinity				Hardness				Total Solids				Volatile Solids			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
	Cycle No. 3 - DuPont Permeator #7725N																
55	188	120	10	185	91.7	50	10	60	80.0	2020	150	3105	92.6	295	55	400	81.4
60	209	110	25	140	77.3	295	20	390	93.2	3385	315	4410	90.7	380	75	505	80.3
61	217	50	10	65	80.0	85	10	100	88.2	1185	115	1525	90.3	245	60	285	75.5
65	231	110	30	200	72.7	30	5	40	83.3	8000	240	1610	97.0	100	85	365	15.0
67	284	60	25	110	58.3	10	2	20	80.0	530	160	885	69.8	115	105	220	8.7
69	326	65	25	110	61.5	5	1	12	80.0	520	160	880	69.2	150	55	245	63.3
71	400	70	25	110	64.3	40	10	50	75.0	1160	310	1825	73.3	175	70	215	60.0
73	423	70	30	105	57.1	25	5	45	80.0	1040	385	1630	63.0	115	60	160	47.8
75	427	65	30	100	53.8	20	5	30	75.0	965	475	1600	50.8	100	60	145	40.0
	Cycle No. 4 - DuPont Permeator #7753N																
77	24	80	15	130	81.3	55	5	105	90.9	2525	270	4400	89.3	400	110	495	72.5
79	28	85	15	110	82.4	75	5	105	93.3	2535	325	3575	87.2	265	80	360	69.8
81	37	75	25	105	66.7	55	5	75	90.9	1730	410	2295	76.3	290	85	350	70.7
82	41	100	15	135	85.0	70	5	100	92.9	2990	290	4290	90.3	205	30	270	85.4
84	49	65	15	105	76.9	50	5	90	90.0	1440	145	2415	89.9	170	85	260	50.0
86	62	105	20	145	81.0	40	4	80	87.5	1200	200	1760	83.3	155	50	230	67.7
88	148	120	25	150	79.2	65	5	65	92.3	2130	285	2855	86.6	265	90	355	66.0
89	170	85	15	105	82.4	50	5	70	90.0	2020	225	2650	88.9	290	90	365	69.0
91	218	80	15	100	81.3	55	5	65	90.9	1925	155	2370	91.9	165	25	210	84.8
	Cycle No. 5 - DuPont Permeator #7753N																
94	236	115	20	145	82.6	80	5	110	93.8	3835	560	5055	85.4	370	50	490	86.5
96	251	170	30	210	82.4	150	5	190	96.7	5245	650	6305	87.6	360	85	470	76.4
99	275	155	25	175	83.9	115	5	135	95.7	3945	360	4050	90.9	275	50	295	81.8
101	284	210	35	245	82.3	75	5	90	93.3	1980	355	2315	82.1	320	80	320	75.0
104	305	205	35	250	82.9	225	5	270	97.8	5400	690	6675	87.2	715	60	620	91.6
108	337	160	25	180	84.4	90	5	105	94.4	3785	455	4420	88.0	345	55	315	84.1
	Cycle No. 6 - DuPont Permeator #7725N																
116	437	65	25	80	61.5	90	15	125	83.3	1150	330	1500	71.3	200	65	220	67.5
117	439	55	20	70	63.6	15	5	20	66.7	790	175	1030	77.8	135	80	135	40.7
118	442	70	25	85	64.3	20	5	35	75.0	1020	260	1360	74.5	145	45	175	69.0
120	445	40	10	50	75.0	30	5	30	83.3	680	165	865	75.7	230	65	270	71.7

Table C-2. (continued)

Sample number	Operating time (hrs)	Alkalinity				Hardness				Total Solids				Volatile Solids			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
121	452	90	25	120	72.2	85	10	110	88.2	1810	385	2330	78.7	425	150	535	64.7
124	463	40	10	50	75.0	15	5	20	66.7	520	125	650	76.0	185	55	170	70.3
126	471	105	40	130	61.9	45	5	60	88.9	1555	350	2010	77.5	140	45	160	67.9
128	503	50	10	60	80.0	30	5	40	83.3	515	105	630	79.6	85	25	95	70.6
129	506	75	20	90	73.3	55	10	70	81.8	920	225	1100	75.5	120	40	140	66.7
	Cycle No. 7 - ORNL Module																
139	-	55	20	-	63.6	15	2	-	86.7	890	190	-	78.7	-	-	-	-
141	-	120	25	-	79.2	80	1	-	98.8	1730	235	-	86.4	-	-	-	-
142	-	75	30	-	60.0	10	0.5	-	95.0	1170	220	-	81.2	105	50	-	52.4
143	-	95	40	-	57.9	20	0.5	-	97.5	525	70	-	86.7	140	40	-	71.4
144	-	140	40	-	71.4	15	0.5	-	96.7	705	80	-	88.7	155	30	-	80.6
	Cycle No. 8 - ORNL Module																
149	-	150	60	-	60.0	55	10	-	81.8	2480	980	-	60.5	180	55	-	69.4
150	-	45	20	-	55.6	30	3	-	90.0	470	160	-	66.0	355	45	-	87.3
151	-	35	15	-	57.1	40	3	-	92.5	695	175	-	74.8	135	50	-	63.0
153	-	25	15	-	40.0	120	10	-	91.7	1190	360	-	69.7	265	50	-	81.1
154	-	60	25	-	58.3	60	4	-	93.3	1365	445	-	67.4	175	45	-	74.3
155	-	75	30	-	60.0	90	2	-	97.8	1460	490	-	66.4	160	50	-	68.8
	Cycle No. 9 - ORNL Module																
158	-	45	15	-	66.7	30	<0.5	-	98.3	865	155	-	82.1	220	70	-	68.2
159	-	60	25	-	58.3	25	1	-	96.0	1290	240	-	81.4	150	25	-	83.3
160	-	85	35	-	58.8	45	2	-	95.6	2400	440	-	81.7	300	85	-	71.7
162	-	90	30	-	66.7	40	1	-	97.5	1905	295	-	84.5	315	95	-	69.8
163	-	105	35	-	66.7	80	2	-	97.5	3230	500	-	84.5	650	80	-	87.7
164	-	235	95	-	59.6	30	0.5	-	98.3	3905	560	-	85.7	765	90	-	88.2
167	-	180	50	-	72.2	75	2	-	97.3	4670	780	-	83.3	845	60	-	92.9
169	-	175	65	-	62.9	20	0.4	-	98.0	1360	210	-	84.6	215	85	-	60.5
172	-	175	55	-	68.6	65	3	-	98.4	3555	800	-	77.5	410	110	-	73.2
179	-	55	25	-	54.5	100	3	-	97.0	1385	445	-	67.9	155	45	-	71.0
183	-	105	30	-	71.4	100	4	-	96.0	2545	725	-	71.5	375	110	-	70.7
188	-	115	20	-	82.6	170	6	-	96.5	3515	930	-	73.5	555	105	-	81.1
194	-	35	20	-	42.9	190	9	-	95.3	3950	1080	-	72.7	685	80	-	88.3

Table C-2. (continued)

Sample number	Operating time (hrs)	Alkalinity S	Alkalinity P	Alkalinity C	Alkalinity R%	Hardness S	Hardness P	Hardness C	Hardness R%	Total Solids S	Total Solids P	Total Solids C	Total Solids R%	Volatile Solids S	Volatile Solids P	Volatile Solids C	Volatile Solids R%
	Cycle No. 10 - Westinghouse Module #4-291																
165	23	75	5	75	93.3	60	0.5	60	99.2	1380	40	1380	97.1	150	10	150	93.3
168	95	150	5	-	96.7	150	1	-	99.3	3190	130	-	95.9	370	50	-	86.5
173	143	180	10	-	94.4	190	2	-	98.9	3915	155	-	96.0	405	50	-	87.7
174	387	170	6	-	96.5	124	1	-	99.2	2265	80	-	96.5	430	25	-	94.2
176	435	245	7	-	97.1	605	30	-	95.0	3210	110	-	96.6	660	45	-	93.2
177	502	325	9	-	97.2	370	2	-	99.5	4155	170	-	95.9	815	20	-	97.5
178	530	190	10	-	94.7	150	5	-	96.7	2365	115	-	95.1	470	35	-	92.6
180	545	225	20	-	92.2	200	15	-	92.5	3115	255	-	91.8	590	40	-	93.2
	Cycle No. 11 - Westinghouse Module #4-291																
182	556	40	2	-	95.0	30	2	-	93.3	505	15	-	97.0	115	7	-	93.9
192	701	380	10	-	97.4	100	6	-	94.0	4955	225	-	95.5	515	30	-	94.2
195	744	135	8	-	94.1	225	3	-	98.7	4190	220	-	93.6	370	45	-	87.8
	Cycle No. 12 - DuPont Permeator #400600																
203	1	150	15	265	90.0	40	1	150	97.5	5475	215	11380	96.1	940	105	2055	88.8
204	10	30	7	50	76.7	11	5	20	54.5	1260	25	2345	98.0	100	15	130	85.0
208	22	95	10	180	89.5	35	1	60	97.1	4925	90	14755	98.2	840	40	7090	95.2
209	26	100	6	170	94.0	30	0.05	65	99.8	2715	50	5515	98.2	245	45	845	81.6
210	31	80	7	120	91.3	30	1	50	96.7	4515	110	6820	97.6	490	1	1175	99.8
212	48	30	2	55	93.3	40	1	70	97.5	1615	35	9255	97.8	55	1	170	98.2
218	63	25	6	30	76.0	70	10	30	85.7	16035	1040	19490	93.5	335	60	540	82.1
220	80	45	5	75	88.9	30	1.5	70	95.0	700	20	1170	97.1	90	15	180	83.3
223	105	80	15	140	81.3	70	10	340	85.7	865	25	1505	97.1	170	15	245	91.2
225	128	60	7	80	88.3	35	6	40	82.9	3020	175	5190	94.2	140	115	240	17.9
230	160	100	20	125	80.0	75	2	75	97.3	1905	100	3140	94.8	210	35	365	83.3
232	165	60	7	85	88.3	150	2	215	98.7	1735	140	2570	91.9	205	25	275	87.8
235	176	30	8	40	73.3	80	4	120	95.0	770	85	1265	89.0	105	40	165	61.9
236	178	45	10	45	77.8	60	6	105	90.0	1085	135	1760	87.6	135	45	180	66.7
	Cycle No. 13 - ORNL Module																
205	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
207	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cycle No. 14 - Gulf Module																

Table C-2. (continued)

Sample number	Operating time (hrs)	Alkalinity				Hardness				Total Solids				Volatile Solids			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
239	93	110	10	150	90.9	60	2	85	96.7	1240	15	1685	98.8	220	1	280	99.5
246	165	45	8	55	82.2	70	9	70	87.1	1995	45	2520	97.7	155	6	225	96.1
250	193	50	5	60	90.0	40	2	45	95.0	1290	25	1680	98.1	95	5	130	94.7
252	252	60	10	70	83.3	30	3	60	90.0	1210	70	1520	94.2	175	40	180	77.1
254	272	300	15	365	95.0	105	1	310	99.0	5135	175	6340	96.6	460	9	555	98.0
256	316	150	15	210	90.0	145	1	210	99.3	5720	195	6850	96.6	654	20	690	96.9
257	434	225	20	265	91.1	230	1	230	99.6	5495	195	6645	96.5	595	75	620	87.4
258	583	315	25	370	92.1	100	0.5	280	99.5	5335	210	6535	96.1	585	45	635	92.3
259	631	290	25	345	91.4	75	0.5	175	99.3	4990	185	6070	96.3	430	30	550	93.0
260	633	195	10	240	94.9	100	0.5	110	99.5	1465	40	1855	97.3	315	25	365	92.1
262	684	110	9	135	91.8	95	0.5	135	99.5	3340	95	4385	97.2	295	15	760	94.9
263	708	135	20	165	85.2	155	0.5	305	99.7	4215	115	4855	97.3	480	75	440	84.4
264	779	150	10	180	93.3	95	0.5	210	99.5	2175	60	2665	97.2	280	30	215	89.3
	Cycle No. 16 - Selas Module																
272	-	35	15	-	57.1	50	15	-	70.0	1065	125	-	88.3	-	-	-	-
273	-	-	15	-	-	-	20	-	-	-	210	-	-	-	-	-	-
274	-	-	15	-	-	-	15	-	-	-	215	-	-	-	-	-	-
277	-	45	-	-	-	70	-	-	-	1330	-	-	-	-	-	-	-
278	-	-	10	-	-	-	15	-	-	-	120	-	-	-	-	-	-
281	-	55	10	-	81.8	65	10	-	84.6	1705	140	-	91.8	-	-	-	-
282	-	80	30	-	62.5	200	15	-	92.5	2080	180	-	91.3	-	-	-	-
287	-	40	10	-	75.0	55	15	-	72.7	805	70	-	91.3	-	-	-	-
289	-	70	15	-	78.6	100	15	-	85.0	1415	125	-	91.2	-	-	-	-
290	-	90	20	-	77.8	130	20	-	84.6	2005	195	-	90.3	-	-	-	-

[a] S = supply to module; P = permeate (or product); C = concentrate (or residue); R ≡ 1 - (P/S) = rejection

[b] All results are in mg/ℓ.

Table C-3. PERFORMANCE OF HYPERFILTRATION MODULES IN THE LA FRANCE PILOT PLANT

Rejection and Absolute Values of Dissolved Solids, Color, Turbidity, and Conductivity[a] (mg/ℓ)[b]

Sample number	Operating time (hrs)	Dissolved Solids				Color				Turbidity				Conductivity			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
	Cycle No. 1 - DuPont Permeator #7753N																
4	7	5235	230	8880	95.6	1450	5	2400	99.7	0.7	0.1	0.1	85.7	5000	400	8000	92.0
7	16	-	-	-	-	850	5	990	99.4	54	0.33	1.7	99.4	1450	65	2500	95.5
	DuPont Permeator #7725N																
12	13	-	-	-	-	485	5	1390	99.0	1.7	0.21	0.3	87.6	1100	130	2600	88.2
16	27	-	-	-	-	395	15	990	96.2	15	0.52	26	96.5	1650	250	2900	84.8
22	37	810	80	2275	90.1	250	10	600	96.0	7.0	0.4	2.8	94.3	1000	140	2500	86.0
23	49	-	-	-	-	180	15	650	91.7	2.0	0.35	3.1	82.5	1100	145	2000	86.8
24	55	1085	90	2350	91.7	1300	10	2300	99.2	2.0	0.24	0.25	88.0	1350	180	2700	86.7
25	61	-	-	-	-	1300	10	1900	99.2	0.61	0.25	0.24	59.0	1750	175	2400	90.0
26	70	-	-	-	-	900	10	1150	98.9	0.69	0.25	0.35	63.8	1800	200	2300	88.9
27	76	-	-	-	-	800	10	1200	98.8	0.84	0.1	0.31	88.1	1750	205	2500	88.3
28	84	1265	170	3445	86.6	305	5	650	98.4	5.8	0.43	2.4	92.6	1900	300	5000	84.2
29	88	-	-	-	-	400	5	550	98.8	4.5	0.36	3.0	92.0	2900	320	3750	89.0
31	92	-	-	-	-	550	10	700	98.2	3.7	0.31	2.4	91.6	2250	290	2900	87.1
	Cycle No. 2 - DuPont Permeator #7725N																
33	94	10650	1200	14090	88.7	590	30	800	94.9	25	0.84	22	96.6	25600	2760	38000	89.2
35	102	-	-	-	-	1000	15	1750	98.5	31	0.33	30	98.9	6400	610	9500	90.5
36	106	-	-	-	-	1150	15	1400	98.7	10	0.22	0.70	97.8	4100	255	6400	93.8
37	108	-	-	-	-	1800	20	1650	98.9	25	0.54	23	97.8	7200	860	10300	88.1
39	119	-	-	-	-	1350	10	1800	99.3	45	0.24	41	99.5	2600	175	3750	93.3
42	131	-	-	-	-	1300	10	1750	99.2	14.0	0.46	0.61	96.7	6000	850	7200	85.8
44	145	910	80	1370	91.2	650	20	950	96.9	6.0	1.0	11.0	83.3	1320	112	2400	91.5
46	150	-	-	-	-	950	30	1400	96.8	3.0	0.35	1.70	88.3	2820	245	4330	91.3
48	155	-	-	-	-	1000	35	1450	96.5	2.8	0.3	1.9	89.3	4840	420	7150	91.3
50	161	1565	135	2340	91.4	1350	50	1910	96.3	3.0	0.36	2.0	88.0	2600	230	3600	91.2
52	170	-	-	-	-	790	50	1140	93.7	1.9	0.34	1.5	82.1	3050	260	5000	91.5

Table C-3 (continued)

Sample number	Operating time (hrs)	Dissolved Solids S	Dissolved Solids P	Dissolved Solids C	Dissolved Solids R%	Color S	Color P	Color C	Color R%	Turbidity S	Turbidity P	Turbidity C	Turbidity R%	Conductivity S	Conductivity P	Conductivity C	Conductivity R%
53	179	-	-	-	-	750	55	1130	92.7	0.93	0.25	0.71	73.1	5000	465	7900	90.7
	Cycle No. 3 - DuPont Permeator #7725N																
55	188	-	-	-	-	780	20	1000	97.4	0.51	0.25	0.36	51.0	4100	360	6200	91.2
60	209	-	-	-	-	4100	35	4400	99.1	5.3	1.2	3.9	77.4	5200	470	6300	91.0
61	217	-	-	-	-	25	10	55	60.0	2.4	0.45	2.8	81.3	1750	90	2150	94.9
65	231	790	210	1565	73.4	545	45	830	91.7	45	6.2	50	86.2	1260	270	2600	78.6
67	284	-	-	-	-	50	10	90	80.0	2.3	0.56	3.0	75.6	740	230	1500	68.9
69	326	-	-	-	-	35	10	60	71.4	0.7	0.4	0.9	42.9	925	275	1500	70.3
71	400	1150	305	1790	73.5	625	60	800	90.4	23	2.9	16	87.4	1960	540	3200	72.4
73	423	-	-	-	-	205	40	325	80.5	2.5	0.56	1.95	77.6	1890	550	2950	70.9
75	427	-	-	-	-	160	35	245	78.1	2.0	0.45	1.9	77.5	1730	850	2700	50.9
	Cycle No. 4 - DuPont Permeator #7753N																
77	24	-	-	-	-	710	8	1120	98.9	2.5	0.12	1.0	95.2	4050	370	7000	90.9
79	28	-	-	-	-	1250	8	1600	99.4	1.5	0.25	0.8	83.3	4200	610	5900	85.5
81	37	-	-	-	-	520	6	600	98.8	40	0.18	40	99.6	2750	780	3650	97.5
82	41	-	-	-	-	410	6	590	98.5	16.0	0.16	17	99.0	5100	550	7200	89.2
84	49	-	-	-	-	460	4	675	99.1	20	0.18	6.9	99.1	2300	240	3700	89.6
86	62	1180	200	1730	83.1	440	4	605	99.1	4.5	0.43	2.7	90.4	2000	300	2950	85.0
88	148	2090	260	2835	87.6	1000	8	1500	99.2	55	0.52	55	99.1	3300	480	4300	85.5
89	170	-	-	-	-	1600	8	2200	99.5	210	0.42	160	99.8	3200	340	4000	89.4
91	218	-	-	-	-	450	8	550	98.2	2.6	0.43	2.4	83.5	3250	265	4100	91.8
	Cycle No. 5 - DuPont Permeator #7753N																
94	236	-	-	-	-	320	4	450	98.8	2.2	0.5	1.7	77.3	6700	1100	8000	83.6
96	251	-	-	-	-	1100	4	1400	99.6	3.8	0.5	2.1	86.8	8100	1350	9800	83.3
99	275	-	-	-	-	800	8	920	99.0	13.0	0.2	11.0	98.5	6100	560	6900	90.8
101	284	1980	345	2315	82.6	2200	6	250	97.3	16.0	0.28	17.0	98.3	3800	650	4600	82.9
104	305	-	-	-	-	1600	25	2000	98.4	12.0	0.4	10.0	96.7	8600	1600	10000	81.4
108	337	-	-	-	-	1100	10	1210	99.1	32.0	0.3	27.0	99.1	7600	870	8900	88.6
	Cycle No. 6 - DuPont Permeator #7725N																
116	437	-	-	-	-	65	10	75	84.6	8.0	3.0	8.0	62.5	2100	600	2700	71.4
117	439	-	-	-	-	330	40	360	87.9	20.0	3.1	20.0	84.5	1500	310	1900	79.3

Table C-3. (continued)

Sample number	Operating time (hrs	Dissolved Solids				Color				Turbidity				Conductivity			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
118	442	-	-	-	-	335	45	425	86.6	15.0	3.3	15.0	78.0	2000	485	2600	75.8
120	445	-	-	-	-	1670	215	2230	87.1	230	40	240	82.6	930	255	1300	72.6
121	452	-	-	-	-	3080	465	3830	84.9	200	80	180	60.0	3000	625	3800	79.2
124	463	-	-	-	-	240	25	295	89.6	25.0	3.5	30.0	86.0	940	250	1300	73.4
126	471	1540	340	1985	77.9	390	60	490	84.6	20	5.0	25.0	75.0	3100	650	4000	79.0
128	503	-	-	-	-	120	20	155	83.3	10.0	1.4	11	86.0	820	175	1000	78.7
129	506	-	-	-	-	175	25	200	85.7	9.0	1.5	9.0	83.3	1650	405	2100	75.5
	Cycle No. 7 - ORNL Module																
139	-	840	160	-	81.0	480	10	-	97.9	20	0.2	-	99.0	1500	315	-	79.0
141	-	1695	220	-	87.0	1100	5	-	99.5	20	0.27	-	98.7	2750	400	-	85.5
142	-	1125	210	-	81.3	515	4	-	99.2	6.0	0.43	-	92.8	1925	380	-	80.3
143	-	490	65	-	86.7	535	4	-	99.3	80	0.47	-	99.4	780	180	-	76.9
144	-	660	80	-	87.9	525	8	-	98.5	50	0.4	-	99.2	1050	160	-	84.8
	Cycle No. 8 - ORNL Module																
149	-	2465	945	-	61.7	750	15	-	98.0	5.1	0.8	-	84.3	3850	1725	-	55.2
150	-	-	-	-	-	280	10	-	96.4	5.8	0.4	-	93.1	870	260	-	70.1
151	-	-	-	-	-	325	10	-	96.9	6.0	0.4	-	93.3	940	285	-	69.7
153	-	1140	335	-	70.6	915	15	-	98.4	35	0.5	-	98.6	1625	560	-	65.5
154	-	-	-	-	-	585	15	-	97.4	4.4	0.4	-	90.9	2100	770	-	63.3
155	-	-	-	-	-	635	20	-	96.9	3.8	0.46	-	87.9	2350	870	-	63.0
	Cycle No. 9 - ORNL Module																
158	-	850	155	-	81.8	315	1	-	99.7	25	0.4	-	98.4	1200	230	-	80.8
159	-	1285	240	-	81.3	670	10	-	98.5	40	0.6	-	98.5	1950	370	-	81.0
160	-	2395	440	-	81.6	1420	25	-	98.2	60	0.65	-	98.9	3230	715	-	77.9
162	-	1760	295	-	83.2	1165	4	-	99.7	90	0.55	-	99.4	2700	580	-	78.5
163	-	2965	500	-	83.1	3500	1	-	99.9	135	0.35	-	99.7	4100	900	-	78.0
164	-	3505	560	-	84.0	2960	4	-	99.9	140	0.4	-	99.7	4900	1050	-	78.6
167	-	4300	780	-	81.9	4400	10	-	99.8	110	0.65	-	99.4	4600	1220	-	73.5
169	-	1320	195	-	85.2	490	2	-	99.6	20	0.35	-	98.3	2150	410	-	80.9
172	-	3490	775	-	77.8	1540	8	-	99.5	25	0.35	-	98.6	4600	1300	-	71.7
179	-	1355	445	-	67.2	715	8	-	98.9	55	0.4	-	99.3	2150	780	-	63.7

Table C-3. (continued)

Sample number	Operating time (hrs)	Dissolved Solids S	Dissolved Solids P	Dissolved Solids C	Dissolved Solids R%	Color S	Color P	Color C	Color R%	Turbidity S	Turbidity P	Turbidity C	Turbidity R%	Conductivity S	Conductivity P	Conductivity C	Conductivity R%
183	-	2500	715	-	71.4	1625	15	-	99.1	60	0.55	-	99.1	3500	1150	-	67.1
188	-	3475	930	-	73.2	3270	8	-	99.8	45	0.35	-	99.2	4200	1500	-	77.1
194	-	3875	1070	-	72.4	4150	20	-	99.5	35	0.30	-	99.1	4500	1750	-	61.1
	Cycle No. 10 - Westinghouse Module #4-291																
165	23	-	-	-	-	585	2	590	99.7	30	0.35	30	98.8	1950	100	2000	94.9
168	95	-	-	-	-	990	1	-	99.9	20	0.4	-	98.0	4100	210	-	94.9
173	143	-	-	-	-	1090	8	-	99.3	15	0.28	-	98.1	4900	325	-	93.4
174	387	-	-	-	-	1880	3	-	99.8	200	0.4	-	99.8	2700	140	-	94.8
176	435	-	-	-	-	2840	2	-	99.9	230	0.3	-	99.9	3650	225	-	93.8
177	502	-	-	-	-	3960	2	-	99.9	210	0.35	-	99.8	4500	260	-	94.2
178	530	2280	115	-	95.0	2100	50	-	97.6	220	15	-	93.2	2650	190	-	92.8
180	545	3040	255	-	91.6	2710	185	-	93.2	230	40	-	82.6	3400	390	-	88.5
	Cycle No. 11 - Westinghouse Module #4-291																
182	556	475	15	-	96.8	310	2	-	99.4	35	0.6	-	98.3	650	50	-	92.3
192	701	4900	225	-	95.4	920	50	-	94.6	20	2.0	-	90.0	5300	825	-	84.4
195	744	4125	270	-	93.5	1560	45	-	97.1	0.02	0.80	-	-	5300	490	-	90.8
	Cycle No. 12 - DuPont Permeator #400600																
203	1	-	-	-	-	160	2	380	98.8	1.5	0.45	12	70.0	6200	215	8000	96.5
204	10	-	-	-	-	110	2	195	98.2	2.6	0.3	3.6	88.5	2000	60	3300	97.0
208	22	-	-	-	-	575	6	1100	99.0	2.2	0.29	0.9	86.8	5600	140	9000	97.5
209	26	-	-	-	-	575	2	1080	99.7	4.8	0.33	5.4	93.1	3700	120	6100	96.8
210	31	-	-	-	-	315	2	490	99.4	0.90	0.40	0.70	55.6	5900	210	8000	96.4
212	48	-	-	-	-	225	2	390	99.1	1.4	0.33	1.1	76.4	2150	70	3700	96.7
218	63	-	-	-	-	40	2	45	95.0	4.5	0.36	3.0	92.0	21000	1550	23000	92.6
220	80	-	-	-	-	265	2	435	99.2	3.5	0.35	4.0	90.0	820	25	1250	97.0
223	105	-	-	-	-	1250	2	2350	99.8	1.8	0.59	2.3	67.2	960	60	1575	93.8
225	128	-	-	-	-	390	2	665	99.5	2.1	0.62	2.0	70.5	4000	275	6200	93.1
230	160	-	-	-	-	725	2	1300	99.7	3.7	0.35	2.0	90.5	2400	150	380	93.8
232	165	-	-	-	-	915	2	1500	99.8	6.3	0.40	5.1	93.7	2150	200	3000	90.7
235	176	-	-	-	-	105	2	160	98.1	3.0	0.38	3.3	87.3	980	140	1500	85.7
236	178	-	-	-	-	590	2	1100	99.7	3.0	0.40	2.5	86.7	1350	215	2150	84.1

Table C-3. (continued)

Sample number	Operating time (hrs)	Dissolved Solids S	Dissolved Solids P	Dissolved Solids C	Dissolved Solids R%	Color S	Color P	Color C	Color R%	Turbidity S	Turbidity P	Turbidity C	Turbidity R%	Conductivity S	Conductivity P	Conductivity C	Conductivity R%
	Cycle No. 13 - ORNL Module																
205	-	-	-	-	-	760	205	-	73.0	60	25	-	58.3	2050	770	-	62.4
207	-	-	-	-	-	635	385	-	39.4	50	35	-	30.0	1950	1250	-	35.9
	Cycle No. 14 - Gulf Module																
239	93	-	-	-	-	135	1	180	99.3	1.3	0.55	1.35	57.7	1300	40	1820	96.9
246	165	-	-	-	-	300	2	375	99.3	6.1	0.64	6.3	89.5	2350	90	2825	96.2
250	193	1285	25	1680	98.1	160	2	200	98.8	3.6	0.55	4.2	84.7	1575	60	2050	96.2
252	252	1200	70	1520	94.2	40	1	45	97.5	1.8	0.5	2.2	72.2	1350	90	1775	93.3
254	272	4950	170	5990	96.6	2800	6	3710	99.8	0.05	0.37	0.04	-	5450	300	6500	94.5
256	316	-	-	-	-	2450	6	3290	99.8	0.02	0.32	0.01	-	5900	290	7100	95.1
257	434	-	-	-	-	2460	5	3300	99.8	0.01	0.30	0.01	-	5500	290	6700	94.7
258	583	-	-	-	-	2680	5	3340	99.8	0.01	0.50	0.01	-	5500	400	6700	92.7
259	631	-	-	-	-	2580	10	3150	99.6	0.01	0.50	0.01	-	5500	360	6700	93.5
260	633	-	-	-	-	960	2	1165	99.8	35	0.34	30	99.0	1575	50	2000	96.8
262	684	-	-	-	-	445	1	555	99.8	4.5	0.22	4.0	95.1	3900	180	4600	95.4
263	708	-	-	-	-	685	1	710	99.9	5.1	0.30	4.4	94.1	5200	165	5900	96.8
264	779	2155	55	2510	97.4	605	1	710	99.8	40	0.20	40	99.5	2550	80	2800	96.9
	Cycle No. 16 - Selas Module																
272	-	970	110	-	88.7	635	4	-	99.4	4.7	0.18	-	96.2	1125	180	-	84.0
273	-	-	150	-	-	-	8	-	-	-	0.20	-	-	-	295	-	-
274	-	-	200	-	-	-	6	-	-	-	0.36	-	-	-	295	-	-
277	-	1300	-	-	-	915	-	-	-	5.3	-	-	-	2200	-	-	-
278	-	-	115	-	-	-	10	-	-	-	0.21	-	-	-	290	-	-
281	-	1665	130	-	92.2	1050	10	-	99.0	6.6	0.31	-	95.3	2450	290	-	88.2
282	-	2010	180	-	91.0	1210	15	-	98.8	7.5	0.55	-	92.7	2100	275	-	86.9
287	-	780	70	-	91.0	295	2	-	99.3	6.3	0.29	-	95.4	1250	160	-	87.2
289	-	1385	115	-	91.7	490	20	-	95.9	8.6	0.3	-	96.5	2350	280	-	88.1
290	-	1970	190	-	90.4	670	30	-	95.5	15	0.45	-	97.0	3200	450	-	85.9

[a] S = supply to module; P = permeate (or product); C = concentrate (or residue); R ≡ 1 - (P/S) = rejection

[b] All results are in mg/ℓ except conductivity (μmho/cm), color (Pt-Co units), and Turbidity (F.T.U.).

Table G-4. PERFORMANCE OF HYPERFILTRATION MODULES IN THE LA FRANCE PILOT PLANT

Rejection and Absolute Values of Calcium, Zinc, Magnesium, and Copper[a]

(mg/ℓ)[b]

Sample number	Operating time (hrs)	Calcium				Zinc				Magnesium				Copper			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
	Cycle No. 1 - DuPont Permeator #7753N																
4	7	5.0	0.3	6.0	94.0	3.0	0.05	4.0	98.3	21.5	0.04	38	99.8	0.3	<0.04	0.6	>86.7
7	16	1.4	0.1	17.0	92.9	1.7	0.06	1.9	96.5	0.4	0.003	2.6	99.3	-	-	-	-
	DuPont Permeator #7725N																
12	13	1.0	<0.1	2.0	>90.0	2.0	<0.02	4.0	>99.0	0.28	0.002	1.22	99.3	-	-	-	-
16	27	2.0	0.5	11.0	75.0	3.8	0.04	10.4	98.9	0.55	0.008	1.6	98.5	-	-	-	-
22	37	1.0	<0.1	7.0	>90.0	3.7	0.05	6.7	98.6	0.59	0.003	2.0	99.5	0.08	0.08	0.16	-
23	49	1.0	<0.1	2.0	>90.0	1.6	0.02	4.7	98.8	0.5	0.002	1.4	99.6	-	-	-	-
24	55	1.0	<0.1	2.0	>90.0	4.3	0.04	8.3	99.1	0.45	0.004	1.1	99.1	-	-	-	-
25	61	2.0	<0.1	2.0	>95.0	4.3	0.02	6.0	99.5	0.77	0.003	1.1	99.6	-	-	-	-
26	70	2.0	<0.1	5.0	>95.0	2.1	0.06	3.7	97.1	0.74	0.003	1.1	99.6	0.12	<0.04	0.18	>66.7
27	76	2.0	<0.1	5.0	>95.0	2.7	0.02	4.0	99.3	0.83	0.003	1.3	99.6	-	-	-	-
28	84	2.0	<0.1	7.0	>95.0	-	-	-	-	0.50	0.005	1.3	99.0	0.20	<0.04	0.44	>80.0
29	88	3.0	<0.1	8.0	>96.7	-	-	-	-	-	-	-	-	-	-	-	-
31	92	2.0	<0.1	7.0	>95.0	-	-	-	-	-	-	-	-	0.24	<0.04	0.32	>83.3
	Cycle No. 2 - DuPont Permeator #7725N																
33	94	-	-	-	-	12.0	0.26	14.5	97.8	3.90	0.16	4.20	95.9	0.48	0.12	0.56	75.0
35	102	-	-	-	-	2.65	0.06	3.50	97.7	3.90	0.05	4.30	98.7	0.08	<0.04	0.16	>50.0
36	106	-	-	-	-	5.0	0.06	11.0	98.8	3.40	0.01	5.40	99.7	0.36	<0.04	0.52	>88.9
37	108	-	-	-	-	5.05	0.08	10.0	98.4	13.0	0.09	16.0	99.3	-	-	-	-
39	119	-	-	-	-	3.25	0.04	3.80	98.8	4.40	0.06	5.30	98.6	-	-	-	-
42	131	-	-	-	-	7.50	0.54	11.0	92.8	12.8	0.40	18.0	96.9	0.24	0.08	0.32	66.7
44	145	2.7	0.7	3.4	74.1	1.50	0.06	1.94	96.0	2.80	0.03	3.70	98.9	0.32	0.08	0.40	75.0
46	150	-	-	-	-	1.70	0.02	2.60	98.8	5.70	0.07	10.1	98.8	-	-	-	-
48	155	8.9	0.14	25	98.4	-	-	-	-	14.6	0.15	24.8	99.0	0.32	0.04	0.32	87.5
50	161	5.6	0.25	6.9	95.5	3.6	0.06	4.65	98.3	8.00	0.10	11.0	98.8	0.12	<0.04	0.20	>66.7
52	170	7.9	<0.13	10.8	>98.4	2.00	0.06	3.20	97.0	13.2	0.15	25	98.9	0.12	<0.04	0.16	>66.7

Table C-4. (continued)

Sample number	Operating time (hrs)	Calcium				Zinc				Magnesium				Copper			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
53	179	25	0.13	40	99.5	1.78	0.04	2.90	97.8	19	0.21	35	98.9	-	-	-	-
	Cycle No. 3 - DuPont Permeator #7725N																
55	188	4.2	0.1	5.6	97.6	0.44	0.10	0.64	77.3	-	-	-	-	0.64	0.04	1.08	93.8
60	209	6.6	0.4	8.5	93.9	-	-	-	-	-	-	-	-	1.96	<0.04	2.56	>98.0
61	217	-	-	-	-	14.8	0.1	18.0	99.3	6.60	0.05	8.80	99.2	0.08	<0.04	0.12	>50.0
65	231	-	-	-	-	1.56	0.18	2.65	88.5	2.02	0.24	3.80	88.1	0.12	<0.04	0.20	>66.7
67	284	1.6	0.2	2.2	87.5	-	-	-	-	-	-	-	-	0.16	<0.04	0.24	>75.0
69	326	-	-	-	-	0.14	0.06	0.24	57.1	-	-	-	-	0.20	0.04	0.28	80.0
71	400	2.2	0.4	3.3	81.8	4.45	0.38	5.20	91.5	2.00	0.44	4.80	78.0	0.44	0.12	0.76	72.7
73	423	-	-	-	-	1.40	0.24	2.05	82.9	2.80	0.66	4.80	76.4	-	-	-	-
75	427	1.9	0.6	2.7	68.4	-	-	-	-	2.20	0.54	4.20	75.5	0.32	0.08	0.48	75.0
	Cycle No. 4 - DuPont Permeator #7753N																
77	24	3.9	0.2	6.8	94.9	7.50	0.06	12.3	99.2	5.60	0.08	10.2	98.6	-	-	-	-
79	28	3.9	0.3	4.8	92.3	11.5	0.06	14.8	99.5	8.00	0.20	13.4	97.5	-	-	-	-
81	37	4.5	0.6	5.7	86.7	2.70	0.08	3.50	97.0	6.10	0.64	10.6	89.5	-	-	-	-
82	41	6.9	0.12	9.5	98.3	5.10	0.02	8.0	99.6	7.8	0.08	11.6	99.0	0.76	0.04	1.24	94.7
84	49	4.0	0.04	5.9	99.0	6.25	0.06	11.0	99.0	5.6	0.02	8.4	99.6	-	-	-	-
86	62	4.2	0.12	5.6	97.1	4.4	0.06	5.5	98.6	5.9	0.08	8.3	98.6	0.40	0.08	0.56	80.0
88	148	4.0	0.04	5.1	99.0	4.85	<0.02	6.5	>99.6	4.0	0.02	5.9	99.5	1.28	0.04	1.72	96.9
89	170	3.5	0.08	4.3	97.7	5.15	0.04	6.25	99.2	5.1	0.06	7.4	98.8	-	-	-	-
91	218	5.0	0.08	6.1	98.4	1.70	0.12	2.06	92.9	6.3	0.06	7.7	99.0	-	-	-	-
	Cycle No. 5 - DuPont Permeator #7753N																
94	236	7.9	0.16	10.1	98.0	3.0	0.1	3.8	96.7	9.3	0.2	13.0	97.8	-	-	-	-
96	251	17.5	0.12	20.0	99.3	3.4	0.16	3.9	95.3	20.6	0.36	25.3	98.3	-	-	-	-
99	275	7.8	<0.04	8.9	>99.5	3.1	0.10	3.5	96.8	16.8	0.16	19.2	99.0	-	-	-	-
101	284	2.48	0.04	2.88	98.4	3.0	0.08	3.30	97.3	10.0	0.17	12.6	98.3	0.40	0.08	0.5	80.0
104	305	25.0	0.16	31.5	99.4	11.0	0.08	14.0	99.3	32.4	0.42	40.8	98.7	-	-	-	-
108	337	2.56	<0.04	2.92	>98.4	2.20	0.1	2.3	95.5	11.1	0.1	14.4	99.1	-	-	-	-
	Cycle No. 6 - DuPont Permeator #7725N																
116	437	2.0	0.4	3.0	80.0	10.0	1.00	12.0	90.0	15.0	2.00	19.0	86.7	-	-	-	-
117	439	1.0	0.3	2.0	70.0	2.00	0.20	2.00	90.0	2.00	0.40	3.00	80.0	-	-	-	-

Table C-4. (continued)

Sample number	Operating time (hrs)	Calcium				Zinc				Magnesium				Copper			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
118	442	1.0	0.4	2.0	60.0	2.00	0.40	3.00	80.0	3.00	0.60	5.00	80.0	-	-	-	-
120	445	1.0	0.3	1.0	70.0	4.00	0.60	4.00	85.0	4.00	0.50	4.00	87.5	-	-	-	-
121	452	2.0	0.7	3.0	65.0	8.00	1.00	10.0	87.5	10.0	2.00	13.0	80.0	-	-	-	-
124	463	1.0	0.2	1.0	80.0	0.40	0.20	1.00	50.0	3.00	0.30	3.00	90.0	-	-	-	-
126	471	2.0	0.6	2.0	70.0	1.00	0.40	2.00	60.0	5.00	0.90	7.00	82.0	1.0	0.2	1.0	80.0
128	503	1.0	0.4	2.0	60.0	4.00	0.80	8.00	80.0	4.00	0.60	5.00	85.0	-	-	-	-
129	506	1.0	0.5	2.0	50.0	6.00	0.90	7.00	85.0	7.00	1.00	10.0	85.7	-	-	-	-
	Cycle No. 7 - ORNL Module																
139	-	0.36	<0.04	-	>88.9	1.30	<0.02	-	>98.5	1.30	0.06	-	95.4	-	-	-	-
141	-	1.40	<0.04	-	>97.1	1.00	0.04	-	96.0	4.50	0.26	-	94.2	-	-	-	-
142	-	0.40	<0.04	-	>90.0	0.80	0.04	-	95.0	1.80	0.04	-	97.8	-	-	-	-
143	-	0.84	<0.04	-	>95.2	3.10	0.02	-	99.4	2.50	0.02	-	99.2	-	-	-	-
144	-	0.60	<0.04	-	>93.3	1.20	<0.02	-	>98.3	2.40	0.06	-	97.5	-	-	-	-
	Cycle No. 8 - ORNL Module																
149	-	5.88	0.78	-	86.7	2.71	<0.02	-	>99.3	8.30	1.70	-	79.5	-	-	-	-
150	-	1.40	0.24	-	82.9	-	-	-	-	4.50	0.51	-	88.7	-	-	-	-
151	-	1.86	0.20	-	89.2	-	-	-	-	5.20	0.53	-	89.8	-	-	-	-
153	-	4.96	0.48	-	90.3	2.35	0.02	-	99.1	10.0	1.50	-	85.0	-	-	-	-
154	-	1.64	0.32	-	80.5	-	-	-	-	2.00	0.54	-	73.0	-	-	-	-
155	-	1.88	0.16	-	91.5	-	-	-	-	2.23	0.35	-	84.3	-	-	-	-
	Cycle No. 9 - ORNL Module																
158	-	1.16	<0.04	-	>96.6	1.16	0.02	-	98.3	2.00	0.09	-	95.5	-	-	-	-
159	-	1.68	<0.04	-	>97.6	-	-	-	-	2.92	0.16	-	94.5	-	-	-	-
160	-	3.12	<0.04	-	>98.7	2.60	<0.02	-	>99.2	4.80	0.33	-	93.1	-	-	-	-
162	-	2.56	0.04	-	98.4	2.32	<0.02	-	>99.1	4.5	0.17	-	96.2	-	-	-	-
163	-	5.82	0.06	-	99.0	-	-	-	-	9.67	0.30	-	96.9	-	-	-	-
164	-	4.32	<0.04	-	>99.1	7.92	0.02	-	>99.7	8.00	0.08	-	99.0	-	-	-	-
167	-	8.00	0.08	-	99.0	13.2	0.02	-	>99.8	13.0	0.38	-	97.1	-	-	-	-
169	-	0.80	<0.04	-	>95.0	-	-	-	-	-	-	-	-	-	-	-	-
172	-	4.32	0.04	-	>99.1	-	-	-	-	6.30	0.21	-	96.7	-	-	-	-
179	-	2.66	0.09	-	96.6	3.00	0.04	-	98.7	3.76	0.28	-	92.6	-	-	-	-

Table C-4. (continued)

Sample number	Operating time (hrs)	Calcium				Zinc				Magnesium				Copper			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
183	-	12.6	0.11	-	99.1	12.0	0.04	-	99.7	7.70	0.70	-	90.9	-	-	-	-
188	-	19.1	0.48	-	97.5	24.0	0.07	-	99.7	16.0	1.22	-	92.4	-	-	-	-
194	-	38.2	0.60	-	98.4	21.1	0.08	-	99.6	19.6	1.60	-	91.8	-	-	-	-
	Cycle No. 10 - Westinghouse Module #4-291																
165	23	2.22	0.12	2.68	94.6	8.00	0.04	8.28	99.5	5.00	0.03	5.33	99.4	-	-	-	-
168	95	6.24	0.16	-	97.4	21.2	0.19	-	99.1	15.8	0.11	-	99.3	-	-	-	-
173	143	8.32	0.16	-	98.1	25.8	0.22	-	99.1	19.0	0.18	-	99.1	-	-	-	-
174	387	1.97	0.03	-	98.5	21.6	0.12	-	99.4	14.2	0.08	-	99.4	-	-	-	-
176	435	2.43	0.03	-	98.8	27.6	0.06	-	99.8	1.96	0.12	-	93.9	-	-	-	-
177	502	2.86	0.09	-	96.9	38.8	0.12	-	99.7	28.8	0.22	-	99.2	-	-	-	-
178	530	2.29	0.17	-	92.6	21.2	0.72	-	96.6	15.6	0.54	-	96.5	-	-	-	-
180	545	0.24	0.50	-	-	26.8	2.00	-	92.5	19.0	1.44	-	92.4	-	-	-	-
	Cycle No. 11 - Westinghouse Module #4-291																
182	556	0.10	0.08	-	92.7	3.92	0.20	-	94.9	2.92	0.04	-	98.6	-	-	-	-
192	701	8.40	0.50	-	94.0	30.8	0.24	-	99.2	31.6	0.50	-	98.4	-	-	-	-
195	744	4.20	0.40	-	90.5	6.80	0.26	-	96.2	11.2	0.38	-	96.6	-	-	-	-
	Cycle No. 12 - DuPont Permeator #400600																
203	1	7.90	0.20	31.0	97.5	5.90	0.02	11	99.7	3.50	0.01	9.60	99.7	-	-	-	-
204	10	2.90	0.03	5.00	99.0	1.80	0.04	2.60	97.8	2.80	0.02	5.10	99.3	-	-	-	-
208	22	5.40	0.17	9.60	96.9	1.10	0.02	2.80	98.2	2.50	0.01	5.40	99.6	-	-	-	-
209	26	8.20	0.09	16.0	98.9	2.60	0.02	5.10	99.2	3.10	0.02	6.40	99.4	-	-	-	-
210	31	4.50	0.07	8.40	98.4	5.10	0.05	7.40	99.0	1.80	0.05	3.40	97.2	-	-	-	-
212	48	3.10	0.05	5.30	98.4	6.40	0.02	8.00	99.7	5.30	0.02	7.10	99.6	-	-	-	-
218	63	4.00	2.50	7.10	37.5	2.90	0.20	3.60	93.1	5.80	1.20	7.50	79.3	-	-	-	-
220	80	1.60	<0.03	2.90	>98.1	1.50	0.02	2.80	98.7	4.50	<0.02	9.30	>99.6	-	-	-	-
223	105	0.86	<0.03	0.98	>96.5	3.00	<0.02	4.90	>99.3	7.40	0.02	12.0	99.7	-	-	-	-
225	128	3.20	0.06	5.60	98.1	1.50	0.02	2.40	98.7	5.50	0.03	9.60	99.5	-	-	-	-
230	160	3.30	0.05	6.50	98.5	3.00	<0.02	4.90	>99.3	3.40	<0.02	7.30	>99.4	-	-	-	-
232	165	3.60	0.06	6.20	98.3	14.0	0.02	21.0	99.9	26.0	0.08	39.0	99.7	-	-	-	-
235	176	6.90	1.30	11.0	81.2	6.00	1.70	7.80	71.7	14.0	0.20	20.0	98.6	-	-	-	-
236	178	7.10	1.40	15.0	80.3	3.20	0.36	4.60	88.8	10.0	0.78	16.0	92.2	-	-	-	-

Table C-4. (continued)

Sample number	Operating time (hrs)	Calcium				Zinc				Magnesium				Copper			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
	Cycle No. 13 - ORNL Module																
205	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
207	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cycle No. 14 - Gulf Module																
239	93	4.40	0.06	6.50	98.6	1.20	0.03	1.60	97.5	5.90	<0.02	8.80	>99.7	2.40	0.08	3.28	96.7
246	165	6.60	0.16	10.0	97.6	1.30	<0.02	1.60	>98.5	7.00	0.02	9.20	99.7	0.24	<0.04	0.36	>83.3
250	193	9.60	0.06	12.6	99.4	0.22	<0.02	0.27	>90.9	3.90	0.03	5.30	99.2	0.12	<0.04	0.12	>66.7
252	252	11,6	0.09	16.2	99.2	0.09	<0.02	0.08	>77.8	4.40	0.03	6.00	99.3	0.20	<0.04	0.22	>80.0
254	272	8.80	0.04	16.0	99.5	0.84	<0.02	0.88	>97.6	18.0	0.04	22.0	99.8	0.48	0.04	0.62	91.7
256	316	8.40	0.04	12.0	99.5	0.40	0.02	0.47	95.0	17.0	0.04	22.0	99.8	0.60	<0.04	0.64	>93.3
257	434	11.0	0.04	12.0	99.6	0.10	0.02	0.06	80.0	16.0	80.0	21.0	99.9	0.40	0.40	0.48	>90.0
258	583	9.80	0.04	12.0	99.6	0.12	<0.02	0.04	>83.3	14.0	<0.02	16.0	>99.9	0.24	0.04	0.36	83.3
259	631	11.0	0.04	13.0	99.6	0.08	<0.02	0.02	>75.0	13.0	0.04	15.0	88.7	0.12	0.04	0.20	66.7
260	633	5.20	0.04	6.60	99.2	0.58	<0.02	0.62	>96.6	7.00	<0.02	10.0	>99.7	2.40	<0.04	3.00	>98.3
262	684	10.8	0.04	12.5	99.6	1.80	<0.02	2.10	>98.9	10.0	<0.02	12.0	>99.8	0.26	<0.04	0.36	>84.6
263	708	15.0	0.04	17.0	99.7	5.80	<0.02	6.80	>99.7	19.0	<0.02	23.0	>99.9	4.80	0.04	6.60	99.2
264	779	3.60	0.10	4.00	97.2	3.04	0.04	3.72	98.7	13.0	0.02	15.0	99.8	1.10	<0.04	1.40	>96.4
	Cycle No. 16 - Selas Module																
272	-	3.50	0.07	-	98.0	1.20	0.04	-	96.7	3.40	0.10	-	97.1	-	-	-	-
273	-	-	0.10	-	-	-	0.04	-	-	-	0.13	-	-	-	-	-	-
274	-	-	0.12	-	-	-	0.05	-	-	-	0.19	-	-	-	-	-	-
277	-	5.10	-	-	-	1.20	-	-	-	4.40	-	-	-	-	-	-	-
278	-	-	0.07	-	-	-	0.02	-	-	-	0.07	-	-	-	-	-	-
281	-	6.00	<0.03	-	>99.5	1.40	0.02	-	98.6	5.10	0.07	-	98.6	-	-	-	-
282	-	7.70	0.08	-	99.0	1.50	<0.02	-	>98.7	6.70	0.14	-	97.9	-	-	-	-
287	-	5.20	0.05	-	99.0	0.94	0.03	-	96.8	4.40	0.04	-	99.1	-	-	-	-
289	-	10.2	0.13	-	98.7	1.40	0.05	-	96.4	7.50	0.14	-	99.5	-	-	-	-
290	-	14.2	0.20	-	98.6	1.90	0.02	-	98.9	11.0	0.26	-	97.6	-	-	-	-

[a] S = supply to module; P = permeate (or product); C = concentrate (or residue); R ≡ 1 - (P/S) = rejection

[b] All results are in mg/ℓ.

Table C-5. PERFORMANCE OF HYPERFILTRATION MODULES IN THE LA FRANCE PILOT PLANT

Rejection and Absolute Values of Iron, Sodium, Sulfate, and Suspended Solids[a]

(mg/ℓ)[b]

Sample number	Operating time (hrs)	Iron				Sodium				Sulfate				Suspended Solids			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
	Cycle No. 1 - DuPont Permeator #7753N																
4	7	-	-	-	-	1500	90	2800	94.0	-	-	-	-	-	-	-	-
7	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	DuPont Permeator #7725N																
12	13	<0.3	<0.3	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-
16	27	<0.3	<0.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
22	37	-	-	-	-	2.32	21	640	90.0	-	-	-	-	-	-	-	-
23	49	-	-	-	-	300	25	745	91.7	-	-	-	-	-	-	-	-
24	55	<0.2	<0.2	<0.2	-	335	30	780	91.0	-	-	-	-	-	-	-	-
25	61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	76	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-	-	-	-	-
28	84	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-	-	-	-	-
29	88	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-	-	-	-	-
31	92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cycle No. 2 - DuPont Permeator #7725N																
33	94	0.63	<0.13	0.88	>79.4	-	-	-	-	-	-	-	-	-	-	-	-
35	102	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	106	-	-	-	-	640	50	1040	92.2	-	-	-	-	-	-	-	-
37	108	0.38	0.13	0.50	65.8	-	-	-	-	-	-	-	-	-	-	-	-
39	119	0.25	<0.13	0.38	>48.0	-	-	-	-	-	-	-	-	-	-	-	-
42	131	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	145	<0.13	<0.13	<0.13	-	-	-	-	-	-	-	-	-	-	-	-	-
46	150	0.13	<0.13	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-
48	155	-	-	-	-	780	80	1040	89.7	-	-	-	-	-	-	-	-
50	161	-	-	-	-	400	40	600	90.0	-	-	-	-	-	-	-	-
52	170	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table C-5. (continued)

Sample number	Operating time (hrs)	Iron				Sodium				Sulfate				Suspended Solids			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
53	179	-	-	-	-	760	65	5120	91.4	-	-	-	-	-	-	-	-
	Cycle No. 3 - DuPont Permeator #7725N																
55	188	-	-	-	-	560	45	860	92.0	-	-	-	-	-	-	-	-
60	209	-	-	-	-	1060	125	1240	88.2	-	-	-	-	-	-	-	-
61	217	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-
65	231	0.1	<0.1	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-
67	284	<0.1	<0.1	<0.1	-	220	75	300	65.9	-	-	-	-	-	-	-	-
69	326	<0.1	<0.1	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-
71	400	-	-	-	-	360	105	680	70.8	-	-	-	-	-	-	-	-
73	243	<0.15	<0.15	<0.15	-	400	180	520	55.0	-	-	-	-	-	-	-	-
75	427	-	-	-	-	360	175	660	51.4	-	-	-	-	-	-	-	-
	Cycle No. 4 - DuPont Permeator #7753N																
77	24	-	-	-	-	780	105	1600	86.5	-	-	-	-	-	-	-	-
79	28	-	-	-	-	840	115	1220	86.3	-	-	-	-	-	-	-	-
81	37	-	-	-	-	580	150	660	74.1	-	-	-	-	-	-	-	-
82	41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
84	49	-	-	-	-	320	45	680	86.0	-	-	-	-	-	-	-	-
86	62	-	-	-	-	140	45	480	67.9	-	-	-	-	-	-	-	-
88	148	-	-	-	-	620	80	800	87.1	-	-	-	-	-	-	-	-
89	170	-	-	-	-	620	75	960	87.9	-	-	-	-	-	-	-	-
91	218	-	-	-	-	720	60	940	91.7	-	-	-	-	-	-	-	-
	Cycle No. 5 - DuPont Permeator #7753N																
94	236	-	-	-	-	1260	250	1600	80.2	-	-	-	-	-	-	-	-
96	251	-	-	-	-	1720	230	2040	86.6	-	-	-	-	-	-	-	-
99	275	-	-	-	-	1140	100	1300	91.2	-	-	-	-	-	-	-	-
101	284	-	-	-	-	590	100	720	83.1	-	-	-	-	-	-	-	-
104	305	-	-	-	-	1740	240	2125	86.2	-	-	-	-	-	-	-	-
108	337	-	-	-	-	1280	150	1480	88.3	-	-	-	-	-	-	-	-
	Cycle No. 6 - DuPont Permeator #7725N																
116	437	-	-	-	-	340	100	430	70.6	-	-	-	-	-	-	-	-
117	439	-	-	-	-	230	50	315	78.3	-	-	-	-	-	-	-	-
118	442	-	-	-	-	310	80	450	74.2	-	-	-	-	-	-	-	-

Table C-5. (continued)

Sample number	Operating time (hrs)	Iron				Sodium				Sulfate				Suspended Solids			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
120	445	-	-	-	-	180	35	240	80.6	-	-	-	-	-	-	-	-
121	452	-	-	-	-	480	110	620	77.1	-	-	-	-	-	-	-	-
124	463	-	-	-	-	175	40	210	77.1	-	-	-	-	-	-	-	-
126	471	-	-	-	-	500	110	765	78.0	-	-	-	-	-	-	-	-
128	503	-	-	-	-	150	35	255	76.7	-	-	-	-	-	-	-	-
129	506	-	-	-	-	275	65	310	76.4	-	-	-	-	-	-	-	-
	Cycle No. 7 - ORNL Module																
139	-	4.0	<0.1	-	>97.5	290	55	-	81.0	-	-	-	-	-	-	-	-
141	-	26	<0.1	-	>99.6	610	85	-	86.1	-	-	-	-	-	-	-	-
142	-	-	-	-	-	330	70	-	78.8	-	-	-	-	-	-	-	-
143	-	-	-	-	-	130	25	-	80.8	-	-	-	-	-	-	-	-
144	-	-	-	-	-	195	30	-	84.6	-	-	-	-	-	-	-	-
	Cycle No. 8 - ORNL Module																
149	-	8.0	<0.1	-	>98.8	800	390	-	51.3	-	-	-	-	-	-	-	-
150	-	0.5	<0.1	-	>80.0	160	45	-	71.9	-	-	-	-	-	-	-	-
151	-	2.0	<0.1	-	>95.0	170	55	-	67.6	-	-	-	-	-	-	-	-
153	-	22.0	<0.1	-	>99.5	290	115	-	60.3	-	-	-	-	-	-	-	-
154	-	1.0	<0.1	-	>90.0	455	150	-	67.0	-	-	-	-	-	-	-	-
155	-	4.0	0.1	-	97.5	470	175	-	62.8	-	-	-	-	-	-	-	-
	Cycle No. 9 - ORNL Module																
158	-	-	-	-	-	265	55	-	79.2	57	2.3	-	96.0	15	0	-	100
159	-	6.67	<0.11	-	>98.4	400	75	-	81.3	63	2.3	-	96.3	5	0	-	100
160	-	-	-	-	-	800	150	-	81.3	128	8.9	-	93.0	5	0	-	100
162	-	-	-	-	-	580	95	-	83.6	64	9.6	-	85.0	145	0	-	100
163	-	17.8	<0.11	-	>99.4	920	165	-	82.1	253	30	-	88.1	265	0	-	100
164	-	-	-	-	-	1080	185	-	82.9	240	30	-	87.5	400	0	-	100
167	-	-	-	-	-	1230	270	-	78.0	555	55	-	90.1	370	0	-	100
169	-	5.00	<0.13	-	>97.4	390	75	-	80.8	150	2	-	98.7	40	15	-	62.5
172	-	31.0	<0.13	-	>99.6	1250	255	-	79.6	615	30	-	95.1	65	25	-	61.5
179	-	-	-	-	-	465	130	-	72.0	-	-	-	-	30	0	-	100
183	-	-	-	-	-	670	215	-	67.9	-	-	-	-	45	10	-	77.8

Table C-5. (continued)

Sample number	Operating time (hrs)	Iron				Sodium				Sulfate				Suspended Solids			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
188	-	-	-	-	-	1170	330	-	71.8	-	-	-	-	40	0	-	100
194	-	-	-	-	-	1360	470	-	65.4	-	-	-	-	75	10	-	86.7
	Cycle No. 10 - Westinghouse Module #4-291																
165	23	-	-	-	-	370	14	375	96.2	-	-	-	-	-	-	-	-
168	95	-	-	-	-	1130	20	-	98.2	-	-	-	-	-	-	-	-
173	143	-	-	-	-	1140	55	-	95.2	-	-	-	-	-	-	-	-
174	387	-	-	-	-	745	25	-	96.6	-	-	-	-	-	-	-	-
176	435	-	-	-	-	1280	35	-	97.3	-	-	-	-	-	-	-	-
177	502	-	-	-	-	1520	65	-	95.7	-	-	-	-	-	-	-	-
178	530	-	-	-	-	695	30	-	95.7	-	-	-	-	85	0	-	100
180	545	-	-	-	-	720	60	-	91.7	-	-	-	-	75	0	-	100
	Cycle No. 11 - Westinghouse Module #4-291																
182	556	-	-	-	-	170	2.5	-	98.5	-	-	-	-	-	-	-	-
192	701	-	-	-	-	1855	65	-	96.5	-	-	-	-	-	-	-	-
195	744	-	-	-	-	1600	80	-	95.0	-	-	-	-	-	-	-	-
	Cycle No. 12 - DuPont Permeator #400600																
203	1	-	-	-	-	1760	65	3280	96.3	-	-	-	-	-	-	-	-
204	10	-	-	-	-	400	5	745	98.8	-	-	-	-	-	-	-	-
208	22	-	-	-	-	1390	25	2945	98.2	-	-	-	-	-	-	-	-
209	26	-	-	-	-	815	14	1600	98.3	-	-	-	-	-	-	-	-
210	31	-	-	-	-	1425	30	2135	97.9	-	-	-	-	-	-	-	-
212	48	-	-	-	-	520	7	1120	98.7	-	-	-	-	-	-	-	-
218	63	-	-	-	-	6080	385	7520	93.7	-	-	-	-	-	-	-	-
220	80	-	-	-	-	210	3	360	98.6	-	-	-	-	-	-	-	-
223	105	-	-	-	-	250	7	390	97.2	-	-	-	-	-	-	-	-
225	128	-	-	-	-	1070	60	1705	94.4	-	-	-	-	-	-	-	-
230	160	-	-	-	-	745	35	1120	95.3	-	-	-	-	-	-	-	-
232	165	-	-	-	-	625	60	895	90.4	-	-	-	-	-	-	-	-
235	176	-	-	-	-	255	30	410	88.2	-	-	-	-	-	-	-	-
236	178	-	-	-	-	360	50	570	86.1	-	-	-	-	-	-	-	-
	Cycle No. 13 - ORNL Module																
205	-	16.9	3.8	-	77.5	-	-	-	-	-	-	-	-	-	-	-	-

Table C-5. (continued)

Sample number	Operating time (hrs)	Iron				Sodium				Sulfate				Suspended Solids			
		S	P	C	R%	S	P	C	R%	S	P	C	R%	S	P	C	R%
207	-	11.9	6.0	-	49.6	-	-	-	-	-	-	-	-	-	-	-	-
	Cycle No. 14 - Gulf Module																
239	93	<0.17	<0.17	<0.17	-	350	5	495	98.6	-	-	-	-	-	-	-	-
246	165	<0.17	<0.17	<0.17	-	655	20	830	96.9	-	-	-	-	-	-	-	-
250	193	<0.17	<0.17	<0.17	-	440	10	600	97.7	-	-	-	-	-	-	-	-
252	252	2.20	<0.17	3.30	>92.3	390	20	495	94.9	-	-	-	-	-	-	-	-
254	272	<0.17	<0.17	<0.17	-	1620	60	1890	96.3	-	-	-	-	-	-	-	-
256	316	<0.17	<0.17	<0.17	-	2175	45	2495	97.9	-	-	-	-	-	-	-	-
257	434	<0.17	<0.17	<0.67	-	1855	60	2335	96.8	-	-	-	-	-	-	-	-
258	583	<0.17	<0.17	3.30	-	2175	65	2400	97.0	-	-	-	-	-	-	-	-
259	631	<0.17	<0.17	<0.17	-	1825	60	2210	96.7	-	-	-	-	-	-	-	-
260	633	<0.17	<0.17	0.67	-	465	9	610	98.1	-	-	-	-	-	-	-	-
262	684	<0.17	<0.17	<0.17	-	1310	30	1570	97.7	-	-	-	-	-	-	-	-
263	708	<0.17	<0.17	<0.17	-	1345	35	1730	97.4	-	-	-	-	-	-	-	-
264	779	<0.14	<0.14	<0.14	-	335	15	800	95.5	-	-	-	-	-	-	-	-
	Cycle No. 16 - Selas Module																
272	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
273	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
274	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
277	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
281	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
282	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
287	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
289	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
290	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[a] S = supply to module; P = permeate (or product); C = concentrate (or residue); R ≡ 1 - (P/S) = rejection

[b] All results are in mg/ℓ.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-76-060	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Hyperfiltration for Renovation of Textile Finishing Plant Wastewater		5. REPORT DATE March 1976
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Craig A. Brandon and John J. Porter		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS LaFrance Industries, Riegel Textile Corporation, LaFrance, SC 29656		10. PROGRAM ELEMENT NO. 1BB036; ROAP 21AZT-006
		11. CONTRACT/GRANT NO. Grant S800929
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 7/72-8/75
		14. SPONSORING AGENCY CODE EPA-ORD

15. SUPPLEMENTARY NOTES Project officer for this report is T. N. Sargent, ERL-Athens.

16. ABSTRACT The report gives results of experimental work showing that wastewater from a textile dyeing and finishing operation can be recycled. The wastewater was run through a set of hyperfiltration membranes, which separated it into purified water and a very concentrated dye residue fraction. Over the 15-month evaluation, up to 90% of the wastewater was recovered and was found to be a satisfactory substitute for the normal water supply in all parts of the dyeing operation. A total of 1,348 meters of first quality fabric was produced during this period. The concentrated dye residue can also be used to dye fabric in the dyeing operation. The cost of recycling the wastewater was projected to be $0.121 per cubic meter of wastewater. However, reusing the wastewater results in a potential savings of $0.234 per cubic meter, offsetting the operating cost. The textile industry presents an excellent opportunity for recycling industrial wastewater after treatment with hyperfiltration membranes. The direct recycle will achieve pollution abatement with significant reduction in operating costs brought about by savings in water, chemicals, and energy. Results are being studied further by EPA at several other textile plants in cooperation with the South Carolina Textile Manufacturers Association and Clemson University.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Circulation	Pollution Control	13B	
Textiles	Filtration	Stationary Sources	11E	07D
Textile Processes	Cost Effectiveness	Recycling	13H	14A
Dyeing		Hyperfiltration		
Finishing				
Waste Water				

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 155
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)