Closed-cycle Textile Dyeing: Full-scale Hyperfiltration Demonstration (Design)

by

LaFrance Industries
La France, South Carolina 29656

CARRE, Inc.
Seneca, South Carolina 29678

EPA Grant No. S805182
EPA Program Element No. 1BB610

DOE Project Officer: William Sonnett
DOE Project Officer: Frank Coley
EPA/IERL-Cin Technical Advisor: Robert Mournighan

EPA/IERL-RTP Project Officer: Robert Hendriks

Industrial Environmental Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, NC 27711

Prepared for

U.S. Department of Energy
Industrial Programs
Washington, DC 20585

U.S. Department of the Interior
Office of Water Research and Technology
Washington, DC 20240

U.S. Environmental Protection Agency
Office of Research and Development
Washington, DC 20460

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
ABSTRACT

Hyperfiltration (HF) is a membrane separation technique that has been used successfully in desalination of natural water. Because energy, process chemicals and water are discharged from industrial processes in large quantities, the application of various types of membranes to recover through recycle has been studied in a series of government sponsored research projects. The results of the research led to the current project of joining a full scale dynamic membrane HF system with an operating dye range into an integrated production unit. The dye range is a multi-purpose unit having a variety of effluents from preparation and dyeing of textile fabric.

On site pilot scale tests of three membrane types led to the selection of the dynamic membranes on porous sintered stainless steel tubular supports. Also the testing led to conversion of the washing to counterflow thereby reducing the water use from 400 m$^3$/d (75 gpm) to 190 m$^3$/d (35 gpm) without any loss in effectiveness. Water recycle, up to 95% of waste water, is now routinely used. Over a million meters of fabric have been produced with recycle water. Two 4000 meters lots of fabric have been produced with the recycled chemical concentrate.

The project developed capital and operating costs and savings for one year of operation. A payout time of 3.5 years will be realized when chemical recovery is fully implemented and membrane washing procedures are better developed. Both these areas will be further developed during an extension of this project to September, 1983.

The results of this demonstration and other related information has shown that an HF recovery system will yield a payout time in the range of one to five years in situations where there are simultaneous benefits for water, energy, and chemical recovery and/or where significant waste treatment costs can be abated.

This report describes the design and construction of the hyperfiltration equipment; presents and evaluates data from one year of operation; gives costs for equipment, installation and operation, and credits for savings due to recycle; and describes the primary objectives of an 18 month project continuation.
SUMMARY

Hyperfiltration (reverse osmosis) is a membrane separation technique that has been used effectively in desalination of seawater. Successful salination membranes were not applicable in many cases to the more harsh industrial effluents. Because expensive energy, process chemicals and water are used in industrial processes and then are discharged, the application of membranes to recover water, energy, and process chemicals was studied in a series of government sponsored research projects. The results of the research led to the current project of joining a full scale dynamic membrane hyperfiltration (HF) system with an operating dye range to produce an integrated unit. The dye range is a multi-purpose machine having a variety of effluents presenting a good test situation for demonstrating HF recovery equipment on industrial process effluents. The equipment has been in operation for over twelve months and recycled water is now routinely used. Laboratory tests of the dye and auxiliary chemicals reused have been completed and an initial full scale reuse of chemicals has been tested.

RANGE PROCESS AND EFFLUENT CHARACTERISTICS

The dye range is used for dyeing, bleaching and scouring a variety of velour fabrics. The range operates three shifts per day, five to seven days per week, at speeds of 9 to 36 m/min selected as required by the process. Cotton, acrylic, nylon, rayon, polyester fabrics and their blends are processed. Although several classes of dyes are used, (i.e., direct, basic, disperse, acid, and reactive) and the wash water effluent components vary in dye type and concentration, the types of auxiliary chemicals are common to all wash water effluents from the dyeing operations. The dye formulations contain dyes, a thickener, surfactants, and in some cases dye solvents. While about 85% of the dyes are exhausted on the fabric, the remaining dye and most of the auxiliary chemicals are removed by the washing process. An important part of the project was the successful reduction of the flow rate of wash water through the range by converting to counterflow and using higher temperatures. The resulting wash water flow was reduced from about 400 m³/d (75 gpm) to about 190 m³/d (35 gpm) without loss of washing effectiveness.

RECOVERY PROCESS

The wash water is collected continuously. Despite the lapse of time between each production lot, for cleaning the equipment and filling the dye pad, the water flow is continued to reduce the color in the water in the washers (by about 30%). The washing section effluent (HF supply) is usually highly colored. Removal of 97% of the dyes is considered necessary to avoid possible staining of the fabric subjected to recycled water. The auxiliary components must also be removed sufficiently to provide wash water with concentration differences suitable for the effective washing of the
The concentrate produced by the HF unit contains dye concentrations much lower than those in the dye pad solution, but comparable concentrations of auxiliary chemicals. Reuse of the HF concentrates in dye formulation is possible with approximately 75% savings in auxiliary chemicals and about 20% savings in dyes depending upon the dye class. Effective reuse of the residual dyes and auxiliary chemicals in the HF concentrate depends on the ability to add dyes to achieve the required shades, hue, and crocking characteristics needed in production. Reuse of the HF concentrate can be enhanced by judicious scheduling of dyeing lots, as to shade and dye class. To this end, appropriate scheduling has been suggested and initiated, but is often interrupted by production demands. Two 4,000 meter lots of fabrics have been produced using recovered auxiliary chemicals.

HF UNIT DESCRIPTION

Range wash water is supplied at a rate of 190 m³/d (35 gpm) and collected during the dyeing runs in the 23 m³ (6,000 gallons) accumulator tank. The permeate storage (rinse water) tanks is also 23 m³ to prevent overflow from the system.

The HF unit is a Single Pass (patented) system consisting of zirconium oxide-polyacrylic (ZOPA) membranes dynamically formed on the interior of 70 sintered stainless steel support tube bundles, arranged in ten modules. The total membrane area is 139 m² (1,500 ft²) pressurized by a positive displacement pump fed from the wastewater tank. The concentrate varies to a set upper limit at which an automatic bypass valve bleeds feed to the pump section reducing the feed flow to the HF unit.

There is also a 0.75 m³ (200 gallon) tank following the accumulator tank which permits circulation of a solution for cleaning the membranes.

HF PERFORMANCE

The HF unit was designed from pilot test data to treat wash water at a process temperature of 85°C with color removal of at least 97% at high volumetric recycle.

Installation of the HF unit was completed May 1, 1981. For about one year the HF unit performance, recycle efficiency, range product quality, and economic evaluation have been monitored. The HF unit is used routinely for full scale permeate recycle. Regenerative heat exchangers have been installed to allow operation of the HF at 85-95°C while the range effluent temperature is varied from 55-85°C. A maximum inlet pressure of about 8.5 MPa (1,230 psig) is being used. Recoveries of from 85-95% are being used depending on range speed to return HF concentrate at dye pad strength.
Over a million meters of fabric have been produced with recycle water. There has been no adverse effect on fabric quality as determined by the normal production quality control. Some permeate from very concentrated dye formulations are considered by the range operator and rejected for reuse. In one case cross staining occurred when the dye concentration ratio between consecutive production lots was over 100 to 1. Two lots of 4,000 meters each have been produced with HF concentrate plus dye additives to match the production shade for each lot.

Extensive membrane fouling has been experienced. In the attempts to remove the various foulants, washing has involved the use of detergents and emulsifiers to remove silicones (antifoams), enzymes to remove carbohydrates (undissolved guar gum, the dye thickener), acetic acid and citric acid at pH 4 to remove hard water scaling and dye solvents to remove deposited dye particles and precipitates of the reaction of basic and direct dyes.

Design capacity of the unit would enable completely closed cycle operation, and in fact, the HF unit has equaled 150% of the requirements immediately after each cleaning of the membranes. Membrane fouling, however, has limited the average production of the HF unit to about 60% of the capacity required for a complete closed cycle operation. The problem of membrane fouling (which will be the subject of continued investigation during the extension of the project) may be solved by one or more of three methods of approach: (1) a modification of frequency and duration of cleaning procedures, (2) modifications of present methods of removing membrane foulants by the use of various cleaning agents not now employed, (3) by substitution for the currently used chemicals and components employed in the dyeing process to avoid or reduce membrane fouling.

ECONOMICS

An aspect of the practicality being demonstrated is the economics. HF is a technology that affects pollution control by recycle and recovery. The capital, including installation, costs, and the operating costs, including membrane maintenance, have been determined. The savings from recycle of energy, chemicals and water and the reduction of waste treatment or disposal costs are dependent on the specific conditions at any site. The potential savings at La France, when chemical recovery is implemented and membrane washing procedures are better developed to maintain 100% unit capacity, result in a payout time of 3.5 years. In other selected industrial situations where hot (to 100°C) waste streams contain chemicals up to $0.025/liters ($100/1000 gallons) and water and waste treatment costs up to $0.001/liters ($4/1000 gallons), the payout time can be as short as 1.3 years after taxes. The payout time for HF can vary from a year to several years, but when properly applied there will be a positive, and attractive, rate of return on the investment in HF. HF is best applied where there are simultaneous benefits for water, energy and chemical recovery and/or where significant waste treatment costs can be abated by reuse and/or volume reduction of the pollutant for ultimate disposal.
TABLE OF CONTENTS

FOREWORD
ABSTRACT
SUMMARY
FIGURES
TABLES
METRIC CONVERSIONS
ACKNOWLEDGEMENTS

Section
1 INTRODUCTION
   HYPERFILTRATION
   ENERGY RELATED PROBLEMS
   PURPOSE AND SCOPE
   METHOD OF STUDY
   OVERALL RESULTS

2 CONCLUSIONS

3 RECOMMENDATIONS

4 TEXTILE PROCESS DESCRIPTION
   DYE RANGE
   PRODUCTION HISTORY BASELINE
   EFFLUENT CHARACTERISTICS

5 RECOVERY SYSTEM
   DESIGN
   OPERATION
   INSTALLATION

6 H. F. UNIT PERFORMANCE
   PERMEATE QUALITY (MEMBRANE REJECTION)
   PERMEATE QUALITY (MEMBRANE FLUX)
   LONG TERM EFFECTS
   H. F. UNIT AVAILABILITY

7 RECOVERY PROCESS
   PERMEATE REUSE
   CONCENTRATE REUSE

8 POLLUTION ABATEMENT
   DISPOSAL TECHNIQUE DESCRIPTION

9 RECOVERY SYSTEM COST ANALYSIS
   COST DATA FOR LA FRANCE
   FACTORS WHICH INFLUENCE COSTS AND SAVINGS
   MEASURES OF MERIT

REFERENCES

APPENDICES
A
B
C
D
E
F
FIGURES

1. Schematic of Dye Range and Recovery System
2. Dye Range Consumption and Production Characteristics
3. Dye Range Production Characteristics for Lot Size and Dye Class
4. Schematic of Dye Range and Recovery System with Design Flow Rates
5. Estimated Drug Room and Make Up Flow Rate
6. Single Pass Membrane Flow Configuration
7 (a). Differential Membrane Element
7 (b). Single Pass Membrane System Arrangement
8. Single Pass System Pressure Profile
9. Relative Permeability versus Time for the Upstream Seven Modules
10. Relative Permeability versus Time for the Downstream Three Modules
11. Flux versus Total Solids Concentration – Concentrate Disposal Membrane Performance
12. Flux versus Pressure – Concentrate Disposal Membrane Performance
14. Payout Time (POT), Internal Rate of Return (IRR), and Return on Original Investment (ROI) versus Savings for the Demonstration
15. Effect of Flux on Measures of Merit for Demonstration Recovery System
TABLES

1. Energy & Material Recovery Potential for the U. S. Textile Industry
2. Project Milestones
3. Chemical Characteristics of the Dye Range Effluent
4. Selected Membrane Performance Parameters Throughout the Course of the Demonstration
5. Relative Membrane Permeability on Water After Washing
6. Recovery System Availability
7. Total Solids Analysis for Concentrate Disposal Testing
8. Results of EP Toxicity Testing on Hyperfiltration/Evaporation Sludge and Incinerated Ash
9. Capital Cost Data for Hyperfiltration Demonstration
10. Capital Cost Data for Subsequent Hyperfiltration Applications Based on this Demonstration
11. Annual Operating Expense Data for Demonstration
12. HF/Dye Range - Energy and Water Use Summary
13. Current Annual Savings Data for Demonstration
14. Summary of Factors Affecting Costs & Savings for Textiles
ENGLISH-METRIC CONVERSION TABLE*

<table>
<thead>
<tr>
<th>To Convert From</th>
<th>To</th>
<th>Multiply by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inch</td>
<td>Meter</td>
<td>$2.54 \times 10^{-2}$</td>
</tr>
<tr>
<td>Feet</td>
<td>Meter</td>
<td>$3.05 \times 10^{-1}$</td>
</tr>
<tr>
<td>Square inch</td>
<td>Square meter</td>
<td>$6.45 \times 10^{-4}$</td>
</tr>
<tr>
<td>Square feet</td>
<td>Square meter</td>
<td>$9.29 \times 10^{-2}$</td>
</tr>
<tr>
<td>Cubic feet</td>
<td>Cubic meter</td>
<td>$2.83 \times 10^{-2}$</td>
</tr>
<tr>
<td>Gallon</td>
<td>Cubic meter</td>
<td>$3.79 \times 10^{-3}$</td>
</tr>
<tr>
<td>Pound</td>
<td>Kilogram</td>
<td>$4.54 \times 10^{-1}$</td>
</tr>
<tr>
<td>Pound per sq. inch (psi)</td>
<td>Atmosphere</td>
<td>$6.80 \times 10^{-2}$</td>
</tr>
<tr>
<td>Horsepower (Hp)</td>
<td>Watt</td>
<td>$7.46 \times 10^{-2}$</td>
</tr>
<tr>
<td>Gallon per day</td>
<td>Cubic meter per day</td>
<td>$3.79 \times 10^{-3}$</td>
</tr>
<tr>
<td>Gallon per minute (GPM)</td>
<td>Cubic meter per day</td>
<td>5.45</td>
</tr>
<tr>
<td>Gallon per sq. ft-day (GFD)</td>
<td>Cubic meter per sq. meter-day</td>
<td>$4.10 \times 10^{-2}$</td>
</tr>
<tr>
<td>Gallon per minute per sq. ft</td>
<td>Cubic meter per sq. meter-day</td>
<td>$5.87 \times 10^{1}$</td>
</tr>
</tbody>
</table>

*The units most familiar to the projected readership of this report have been maintained.*
ACKNOWLEDGEMENTS

This study was conducted by a team and major contributions were made by a number of people. The cooperation and assistance of the La France staff members is particularly acknowledged: Mike Drummond, Perry Lockridge, Charles Smith, Al Whitney and many machine operators and laboratory technicians. Dr. Jim Bostic, Jr., Mr. Ted Meyer and Mr. Ernie Freeman of Riegel Corporate staff provided valuable advice.

This demonstration is an interagency program and thus benefited from the guidance of Dr. Max Samfield and Robert Hendriks, U. S. Environmental Protection Agency, as Principal Project Officers; John Rossmeissl and William Sonnett, Department of Energy, and Frank Coley, Department of the Interior, as Project Officers; and Mr. Robert Mournighan, U. S. Environmental Protection Agency, as Technical Advisor. Dr. J. S. Johnson, Jr., of the Oak Ridge National Laboratory has served as membrane technology consultant on this and all the previous related research and development projects.

CARRE, Inc. provided overall program management and engineering design of the recovery system. The contributions of staff members at CARRE, Inc. are acknowledged. Staff members making major contributions are Drs. J. L. Gaddis and H. G. Spencer; Donald K. Todd and Daniel A. Jernigan, engineers; and Roger Hunt, Don King and Cindy Cochran, technicians.

Dr. J. J. Porter and Mr. Grant Goodman of Texidyne, Inc. made significant contributions in providing chemical analyses and textile process consultation. Dr. E. Harrison served as a consultant on control and instrumentation.

The detailed design and bid specifications were provided by the J. E. Sirrine Company. The membrane equipment vendors made significant contributions in technical comments and advice.
SECTION 1
INTRODUCTION

The technical feasibility of using hyperfiltration to renovate textile wastewater for direct recycle has been shown, at pilot scale, in a series of research projects conducted as part of a cooperative program between the textile industry and the U.S. Environmental Protection Agency which began in 1972.

The current project to demonstrate at full scale, the use of hyperfiltration with a production dye range establishes the practicality of hyperfiltration. This project is funded by a cooperative agreement between the Departments of Energy, and Interior, the Environmental Protection Agency and La France Industries, a Division of Riegel Textile Corporation. This report summarizes the results of the demonstration program.

The wide scale application of hot process effluent recycle/reuse has a large potential impact on pollution abatement. The cost of achieving this pollution abatement with hyperfiltration will be offset by a combination of savings from the simultaneous recovery of energy, water, and chemicals. If subsequent waste treatment is required of all or a portion of the chemicals, the cost of this treatment will probably be less because of the volume reduction achieved by hyperfiltration.

HYPERFILTRATION

Hyperfiltration is a membrane separation process operating on the principle of selective diffusion through a semi-permeable membrane, achieved by pressure differential. Since the separation is achieved without a change of phase, membranes are inherently energy efficient. The optimized Single Pass arrangement (U.S. Patent No. 4200533 of CARRE, Inc.) which requires no recirculation of any concentrated material, utilizes approximately four BTU's per pound of water passing through the membrane. The energy used is generally electrical energy to operate the pumping system. Converted to an equivalent thermal basis this would be approximately 12 BTU's per pound of water separated. Change of phase technologies such as freezing and evaporation, require four to forty times as much energy per pound of water separated.

Initial interest in membrane separation was largely directed to reverse osmosis of sea and brackish water. Attempts to utilize the technology thus developed in industrial situations encountered limitations dictated by
temperature and composition of the typical individual waste streams. The innovation of high temperature zirconium oxide/polyacrylic acid membranes (U. S. Department of Energy Patent Nos. 3,431,201, 3,449,245, and 3,503,789, licensed to CARRE, Inc.) dynamically formed on sintered stainless steel tubes, which operate under a wide range of corrosive conditions at high pressure and temperature, and are able to withstand high suspended and dissolved solids as well as bacteriological attack, constitutes a breakthrough in membrane separation technology that relaxes these limitations. These high temperature membranes are utilized in the hyperfiltration system being demonstrated.

ENERGY RELATED PROBLEMS

Two trillion gallons of hot water are discharged by industry each year. Thus literally about 6% of all the energy consumed by industry goes down the drain. Much of this hot water is "contaminated" with chemicals and other dissolved or suspended material which not only constitute a hazard to the environment, but represent an additional "waste" of materials which requires substantial energy to produce or replace. Additionally, much energy is expended by industry to remove water from the industrial waste stream to achieve desired levels of chemical concentration to permit reuse, or to reduce the volume of materials to be stored, processed, or transported.

Many, if not most, industrial situations in which the manufacturing process involves industrial waste water have similar requirements:

1. A contaminate level that requires reduction to permit hot water recycle; and/or

2. A water content of the dissolved chemicals or suspended solids that requires reduction to permit the simultaneous recycle or recovery of both the water and the solids.

Often, the simple separation between the water and solids in the typical industrial waste stream will permit the simultaneous recycle or recovery of both the water and the solids.

Despite this similarity, each industrial waste stream contains unique features which must be considered not only as to the type of separation but the economic soundness of a program of recycle and recovery. The uniqueness may be in the type of corrosiveness (i.e., acid, base, oxidant, etc.); the specific separation required; the type of foulants which may lead to reduction of the performance of the separation equipment; and other characteristics of the particular industrial waste stream.

The ultimate impact on industry could approach 5% of present energy
THIS PAGE
WAS INTENTIONALLY
LEFT BLANK
### TABLE 1. ENERGY AND MATERIAL RECOVERY POTENTIAL FOR THE U. S. TEXTILE INDUSTRY

<table>
<thead>
<tr>
<th></th>
<th>Water Discharge ($10^3$ m$^3$/d)</th>
<th>Dyes ($10^3$ kg/d)</th>
<th>Auxiliary Chemicals ($10^3$ kg/d)</th>
<th>Salt ($10^3$ kg/d)</th>
<th>Process Thermal Energy ($10^9$ BTU/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1978 Study Total</strong></td>
<td>120</td>
<td>27</td>
<td>13$^b$</td>
<td>12</td>
<td>38</td>
</tr>
<tr>
<td><strong>Industry Total</strong></td>
<td>2700$^c$</td>
<td>1000</td>
<td>270</td>
<td>264</td>
<td>784</td>
</tr>
<tr>
<td><strong>Recycle Potential</strong></td>
<td>2400</td>
<td>60</td>
<td>222</td>
<td>220</td>
<td>352</td>
</tr>
<tr>
<td><strong>Estimated Annual Savings</strong> ($\times 10^6$/yr)</td>
<td>120</td>
<td>158</td>
<td>36</td>
<td>2.6</td>
<td>616</td>
</tr>
</tbody>
</table>

*a* EPA Report No. EPA-600/2-78-047  
*b* Exclusive of 80,000 kg. of NaOH used daily at these plants.  
*c* 1972 census of manufacturers, assuming 250 days/year.  
*d* Unit costs: water @ $0.2 m$^3$; dye @ $213/kg$; auxiliary chemicals @ $0.66/kg$; salt @ $50/1,000$ kg.; process stream @ $7/10^6$ BTU.
equipment and installation. They also received and reviewed the quotations.

The method of study is illustrated in the List of Milestones, Table 2. Initially the period of the project was September 23, 1977 to April 22, 1982. (Currently the project is being continued through September, 1983). There was no project activity from September, 1978 through March, 1979 while the decision was being made about continuation following Phase I, the design phase.

OVERALL RESULTS

A Phase I design report was published, EPA 600/2-80-055. The two major results of the study and design activities of Phase I were:

1. The selection of the continuous dye range instead of the dye becks for the full scale demonstration.

2. The determination that hyperfiltration, based on the quotations for installed costs, had the potential to achieve a practical approach to zero discharge with a positive rate of return on the investment when energy and chemical conservation were fully realized.

The continuous dye range was selected because it is the more modern dyeing equipment technology and is representative of the trend in the industry due to the lower production costs associated with this method. At the demonstration site, the dye range has largely replaced the becks as the standard production equipment.

During Phase II and Phase III, the Single Pass hyperfiltration unit was installed beginning in January, 1981, and is producing water for recycle. Over a million yards of velour fabrics have been washed with recycled water. The hyperfiltration unit is being operated by production personnel. The procedures for reuse of the dyes and auxiliary chemicals have been developed on a laboratory basis. Initial tests with production lots of 4,000 yards of velour have been achieved in the first quarter of 1982. This project initially scheduled to be concluded in April, 1982, is being extended through September, 1983 to better establish the reuse of chemicals in production. During this extended period the performance of the membrane system will continue to be monitored to further establish membrane lifetime and operating cost. The initial membranes installed in January, 1981 are still in operation as of March 1, 1982. The study of membrane fouling will be a major study effort during the extended period with the goal of increasing average unit capacity.

The capital costs, including installation, were $484,000. The operating costs including membrane maintenance are $119,900/year. The savings have not been fully realized because procedures for chemical reuse in production are still being developed and the capacity of the HF unit is limited by fouling to a time average of about 60% of design capacity. When the potential savings are realized, the payout time will be 3.5 years. Even at current levels of reuse and HF performance there is a net savings of over $40,000 per year.
TABLE 2. PROJECT MILESTONES

<table>
<thead>
<tr>
<th></th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Detailed Work Plan Completed</td>
<td>11 November 1977</td>
</tr>
<tr>
<td>2. Process Selected</td>
<td>31 May 1978</td>
</tr>
<tr>
<td>4. Equipment &amp; Installation Bids Received</td>
<td>31 August 1978</td>
</tr>
<tr>
<td>5. Project Continuation Authorized</td>
<td>6 April 1979</td>
</tr>
<tr>
<td>6. Auxiliary System Installed</td>
<td>30 November 1980</td>
</tr>
<tr>
<td>7. Hyperfiltration Unit Installed</td>
<td>1 May 1981</td>
</tr>
<tr>
<td>8. Permeate Recycle on Production Basis</td>
<td>12 May 1981</td>
</tr>
</tbody>
</table>
CONCLUSIONS

For twelve months a production size HF unit has been integrated with a manufacturing dye range resulting in the full scale recycle of hot wash water from a dynamic membrane hyperfiltration system. The results have demonstrated satisfactory use of permeate recovery from all types of effluents from this multi-purpose range. One million meters of fabric have been produced with recycle wash water.

Full scale use of the HF concentrate to formulate solutions for dyeing has been demonstrated in selected cases. Two lots of 4,000 meters each have been dyed with HF concentrate plus dye additives. The eventual extent of such reuse of HF concentrate will depend on experience and the economic incentive.

Throughout the twelve months of demonstration, the membranes have remained stable with respect to rejection. It has been demonstrated that stainless steel tube bundles may be used in reforming membranes after several months of exposure to wash water. Although permeate is always used when available, because of membrane fouling its availability is limited to about 60% of the production. Membrane cleaning and foulant removal procedures will be developed during the extended evaluation period.

No build up of solute components was observed in the permeate during a continuous recycle run of four hours, thus the expected normal continuous recycle period of eight to twenty-four hours should not be limited by component build up.

The capital and operating costs of HF were found to be about as projected in 1977. The payout time for the capital cost of this demonstration will be 3.5 years (after taxes) when the full potential for reuse is achieved. In situations where there are simultaneous benefits for water, energy, and chemical recovery and/or where significant waste treatment costs can be abated by reuse or by volume reduction of pollutants, HF will yield a payout time as short as 12-15 months (after taxes).

Disposal of HF concentrate was studied. The technical feasibility of incineration after further concentration and drying was shown. Thus a method of complete on-site disposal was shown. Further study is required to determine the practicality of incineration because of the cost of commercial units which are not designed for the small capacities required. (There are no disposal problems in biological treatment created by the HF concentrate.)
SECTION 3

RECOMMENDATIONS

Hyperfiltration should be considered a practical technology for a wide variety of industrial applications. When applied in situations where energy, water, and material conservation can be achieved simultaneously the payout time can be as little as 12-15 months after taxes. Pollution abatement meeting the 1983 national discharge goals can be achieved practically, in that:

(1) reuse and recycle will reduce pollution discharges, and

(2) the volume reduction achieved (by factors of 10 or more) by hyperfiltration will permit cost effective disposal by evaporation, incineration and/or land disposal.

(3) The value of savings will replay the capital and maintenance costs of the HF recovery system.

The extended period of this project will permit continued investigation of foulant removal and the development of chemical reuse techniques at the demonstration site. The success of this demonstration has encouraged research and development of other applications in the textile industry and in other industrial situations.

The dynamic membrane formation techniques permit the possibility of tailoring membranes to a wide variety of industrial environments. Research and development in the area of membrane tailoring is a promising area of investigation to accelerate the wide use of this potentially cost effective technology to meet the 1983 national discharge goals by recycle/reuse and/or volume reduction of pollutants for ultimate disposal.
SECTION 4

TEXTILE PROCESS DESCRIPTION

The wash water, HF supply, is characterized by being highly colored and quite "hard." The hardness is the result of chemicals added in the dye formulations because both the plant water and HF permeate are relatively soft. The wide pH range is the result of the inclusion of the scouring and bleaching effluents along with the dye wash water. The organic content of the wash water is not large, as indicated by the TOC and COD parameters. Simple dilution of the dye pad would indicate higher values of organics. However, of course, most the dyes are exhausted into the fabric and do not appear in the wash water. This exhaustion is also indicated, qualitatively, by a comparison of the color in the pad and wash water.

DYE RANGE

The textile processes involved in this project are conducted on a continuous dye range. The range and its operation are described in this section. The production history beginning in January, 1980, forms the baseline for evaluating this demonstration project. The chemical characteristics of the range effluent, the supply to the hyperfiltration membrane, are also presented.

Most of the dyeing production is done on the continuous range. The range is also used for bleaching and scouring and consists of a dye applicator, a spiral atmospheric steamer, and a washing section shown in Figure 1. The types of fabrics processed include cotton, acrylic, nylon, rayon, and polyester fabrics as well as their blends. The range is fully automated to control cloth speed, process temperature and water flow rate. The range processes fabric from 9 to 36 meters per minute depending on the type and the process details. The range is operated three shifts per day, five to seven days per week.

Fabric moves sequentially through the dye range components beginning with the dye pad. Process formulations are mixed in the drug room and pumped to the pad where they are applied to the fabric. No formulation is applied to fabric during the scouring operation. The applicator is a 50 meter tank in which the fabric is saturated. Excess chemicals are removed from the fabric by squeeze rollers as it leaves the pad and before entering the steamer. The temperature is maintained at 100°C in the steamer for all range processes. The steamer holds approximately 150 meters of fabric so range speed is a function of residence time required by process details.

Fabric moves from the steamer to a series of washers where excess dyes and process chemicals are removed. The washing train consists of jet washer, dip box, and two rotojet washers. Squeeze rollers follow the dip box and each rotojet washer. The jet washers and the two rotojet washers incorporate large recirculation flow rates which pass through 100 mesh lint filters. The
Figure 1. Schematic of Dye Range and Recovery System
The majority of range wash water enters the second rotojet which overflows to the first rotojet which in turn overflows into the jet washer. A smaller amount of water enters the dip box and overflows to the jet washer. The jet washer overflow becomes the supply to the recovery system. Water flow to the range is automatically controlled at the operator control panel. Steam is injected into the dip box and rotojet washers to maintain the controlled process temperature.

**PRODUCTION HISTORY BASELINE**

Records of range production were kept beginning in 1980 before process modifications and the installation of the recovery system. These records comprise a baseline of data to determine the effects of the changes made in range operation by counterflow, reduced wash water flow and by recycle of wash water.

Figure 2 shows specific consumption of water, steam, and dyes and chemicals beginning in January, 1980. Normalized production numbers are included to show relative rates of production during each week. The baseline portion of the data extends from January 1, 1980, to April 1, 1981 (63 weeks) after which the rate of water flow delivered to the range washers was reduced from about 400 m^3/d (75 gpm) to 200 m^3/d (35 gpm). Energy use dropped with the reduction of water use as expected.

The baseline of dye range production characteristics which could influence recycle of concentrate and permeate is included on a monthly basis in Figure 3. The figure includes the normalized average dye lot size for each month and a breakdown of production type as a fraction of total production. Larger production lots result in larger volumes of a concentrate increasing the ease of chemical reuse. The membrane color rejection is different for the various production types so a significant shift in production trends could influence permeate recycle.

**EFFLUENT CHARACTERISTICS**

Several classes of dyes are used: direct, basic, disperse, acid and reactive. The wash water effluent components vary in dye class and concentration but the types of components are common to all the wash water from the dyeing operations. The dye formulations contain dyes, a thickener (guar gum), surfactants, and in some cases, dye solvents. While about 85% of the dyes are exhausted on the fabric, the remaining dyes and most of the auxiliary components are removed by the washing process. Practical analysis of composite effluents from the dye pad applicator, the washing section and the plant tapwater, are presented in Table 3. Fabric washing studies showed that the amount of water used could be reduced by 50% or more without a loss in washing efficiency. Water flow to the range has been reduced to as low as 113 liters per minute (30 gpm) for long periods of time without any observed affect on quality of produced goods. The standard operation is now set at 138 liters per minute (35 gpm).
Figure 2. Dye Range Consumption and Production Characteristics
Figure 3. Dye Range Production Characteristics for Lot Size and Dye Class
TABLE 3. CHEMICAL CHARACTERISTICS OF THE DYE RANGE EFFLUENT

<table>
<thead>
<tr>
<th>ASSAY</th>
<th>Average concentration or flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dye Pad</td>
</tr>
<tr>
<td>Flow, l/min.</td>
<td>12-35&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>BOD, mg/l</td>
<td>5,400</td>
</tr>
<tr>
<td>COD, mg/l</td>
<td>23,900</td>
</tr>
<tr>
<td>Conductivity, μS/cm</td>
<td>1580-28,000&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Alkalinity, mg/l</td>
<td>4,150</td>
</tr>
<tr>
<td>Color, ADMA</td>
<td>98,800</td>
</tr>
<tr>
<td>Hardness, mg/l</td>
<td>-c</td>
</tr>
<tr>
<td>pH</td>
<td>3.6-10.9&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Phenols, mg/l</td>
<td>0.84</td>
</tr>
<tr>
<td>TOC, mg/l</td>
<td>6,250</td>
</tr>
<tr>
<td>Total Solids, mg/l</td>
<td>20,900</td>
</tr>
<tr>
<td>Suspended Solids, mg/l</td>
<td>1,730</td>
</tr>
<tr>
<td>Dissolved Solids, mg/l</td>
<td>19,200</td>
</tr>
<tr>
<td>Chromium, mg/l</td>
<td>5.3</td>
</tr>
<tr>
<td>Copper, mg/l</td>
<td>19.2</td>
</tr>
<tr>
<td>Iron, mg/l</td>
<td>2.8</td>
</tr>
<tr>
<td>Manganese, mg/l</td>
<td>0.2</td>
</tr>
<tr>
<td>Nickel, mg/l</td>
<td>0.1</td>
</tr>
<tr>
<td>Zinc, mg/l</td>
<td>2.7</td>
</tr>
<tr>
<td>Magnesium, mg/l</td>
<td>10.4</td>
</tr>
<tr>
<td>Calcium, mg/l</td>
<td>7.4</td>
</tr>
</tbody>
</table>

<sup>a</sup>Dye pad flow depends on cloth pickup. Pad drops bypass recovery system to join HF concentrate.

<sup>b</sup>These data were estimated without averaging.

<sup>c</sup>Sample color interferes with analytical procedure.

<sup>d</sup>Too few data were taken for a meaningful average.
The recovery system is designed to collect all water from the dye range and supply the fluid to the hyperfiltration (HF) system. The permeate from the HF system is returned to the range as hot wash water and the concentrate is collected for reuse or disposal. The design provides operation of the range independent of operation of the HF system. Automatic controls allow for continuous operation. Additional instrumentation is installed to record operation parameters of economic importance.

In the discussion which follows, only a portion of the detailed design specifications are mentioned. (Detailed specifications used as a basis for the quotation are available from the EPA Project Officer.) Emphasis is given to the aspects of design which affect the system function rather than materials and other design aspects.

DESIGN

The design wash water flow rate, as shown in Figure 4, was 174 liters per minute (46 gpm). The assumed fabric speed was 18 meters per minute. At 18 meters per minute speed, 159 liters per minute of water is supplied to the washers and 18 liters per minute of dye formulation is applied to the fabric. The moisture added in the steamer less the amount of drag out from the last washer and the vapor loss from the hot fabric comprise the total mass balance of water.

The average lot size was taken as 10 pieces of fabric (one piece = 50 meters). Each lot is separated by approximately 20 minutes from the next lot. During this 20 minutes time the wash water flow is continued. (In the original design it was assumed that the washers would be drained.) The total volume drained during this average cycle results in an average flow rate of 174 liters per minute.

The tanks were sized to accommodate surges representing maximum deviations in water use and also provide for about two hours of membrane system down time. The maximum deviation envisioned was two consecutive shifts with consecutive 80 piece lots. The concentrate tank was sized to accept one loading of an 80 piece dye run, 3000 liters (800 gallons).

The range was modified for counter-flow operation with overflow to drain from the jet washer. The flow scheme is also shown in Figure 4. The drains and overflows are collected in a sump and pumped to the recovery system feed accumulator tank. The drain system is designed to accept short term surges of up to 1,514 liters per minute (400 gpm) during system draining.

Of the total flow supplied to the range, a substantial fraction is used to remove lint by reverse spray of three rotating filters. Approximately 23
Figure 4. Schematic of Dye Range and Recovery System with Design Flow Rates.
liters per minute (6 gpm) is used at each filter with one third escaping from the system along with the separated lint cake. Rather than using permeate for this backwash function, water is diverted from the washer circulationumps. Lint baskets of screen wire are provided to catch the separated lint from the filters. The baskets are fitted with a fluid collection pan. The fluid draining from the lint is routed to the sump.

A pump is provided to transfer the dye pad formulation left in the applicator pad and the 75 meter line supplying the pad including washdown water to the hyperfiltration concentrate tank.

These range modifications result in a nearly complete capture of all fluids emanating from the range. Spillage still occurs with foam overflow. Adjustments to the internal circulating flows of the washers have resulted in a reduction in the amount of foam spillage.

The recovery system was designed to provide a balance in the wash water system. The flow requirements outlined above are based on assumed demands. The variations are accommodated by control of the flow to range, the HF concentrate flow control and automatic provisions for use of plant water as required. For continuous HF system operation the design concentrate flow was 11.4 liters per minute (3 gpm). The flow rate to the dye applicator was estimated to be 17 liters per minute (4.5 gpm), but varies substantially depending on the fabric type being processed. This relation, as calculated for one fabric speed and water pick-up percentage, is depicted in Figure 5. As indicated the design situation required water to be added even during short runs. This provision was designed to provide for water in the addition of chemicals to a reuse dye solution.

OPERATION

Conceptually, the cycle of operation begins with washers empty and no flow. The operator commands "high flow" and the flow valve opens completely. The rinse system pump is energized to provide permeate to fill the washers. If the permeate tank is empty, plant water automatically enters the system. When the washers are full, the range operator stops the flow by the command "interrupt." The operator signals for dye solution, sets the temperature controls (independent system) and fabric speed (also an independent system). The fabric leading edge exits the steamer several minutes after operation starts. The operator commands "controlled flow" which admits flow from the recycle water tank or the plant water supply. The counterflow overflow enters the drain system and is pumped to the HF feed accumulator tank (unless a decision has been made not to process the particular wash water in which case the water overflows the sump and enters the plant waste system.)

The HF system starts automatically when the fluid level in the accumulator tank reaches a set point. The wastewater is pumped through a regenerative heat exchanger and a steam heater where it is heated to the design temperature at 85°C before it enters the positive displacement pump.
Figure 5. Estimated Drug Room and Make Up Flowrates
When the fabric trailing edge passes the washers, the operator may elect to drain the wash boxes or allow wash water to continue to flow depending on the next color to be dyed.

Controls and Meters

Controls are provided for operating temperature of the HF system and flow of wash water to the range. The system automatically switches to plant water when the level in the rinse tank drops to a set point. An array of flow meters, liquid level indicators, temperature elements, steam meters, electric power meters and on time indicators were selected to allow evaluation and documentation of the recovery system performance. A more complete description and a list of controls and instruments may be found in Appendix A.

HF Unit Configuration

The HF unit is a Single Pass system consisting of zirconium oxide-polyacrylic (ZOPA) membranes dynamically formed on the interior of 70 segments of sintered stainless steel support tubes, arranged in ten modules. The total membrane area is 139 m$^2$ ($1,500$ ft$^2$).

The positive displacement pump pressurizes a constant flow rate into the membranes. The concentrate flow rate from the HF unit is controlled so the inlet pressure varies to a set upper limit at which an automatic bypass valve opens and returns feed to the pump suction reducing the feed flow to the HF unit. A light indicates the reason for any cessation of operation and warns of operation with the bypass open.

The high pressure flow from the positive displacement pump enters a manifold which distributes the flow into an initial section comprised of seven parallel paths of 1.6 cm diameter tubes. The seven streams from this section are collected in a manifold and divided into four parallel paths in the second section of 1.6 cm tubes. Similarly the third section has three parallel paths; the fourth section, two; and the last section has only one. Each path has several tube segments connected in series. The flow path lengths are indicated in Figure 6. The first three sections are composed of 1.6 cm diameter tubes while the last two sections are 1.3 cm diameter tubes. The tapered arrangement of the segments is depicted in Figure 6. This arrangement was designed to yield a low velocity, low pressure drop system through the 1.6 cm diameter tubing. At the point where concentration becomes high enough to produce a significant effect, 1.3 cm diameter tubing has been used to increase the fluid velocity and minimize the concentration effect. The velocity range in the 1.6 cm diameter tubing was designed to be 1.5 - 2 m/sec and in the 1.3 cm tubing was 2 - 3 m/sec.

INSTALLATION

The recovery system installation began during the July, 1979, plant shutdown concurrent with the replacement of three existing washers with two
Figure 6. Single Pass Membrane Flow Configuration.
rotojet washers (which utilize circulating flows screened by lint filters). Recovery system work included piping to incorporate counterflow water use on the range and piping to connect washer and lint filter drains to the recovery system. A design modification was made in the recovery system at this time to incorporate a surge tank to collect the wash water from the range and to pump it to the recovery system. This surge tank replaced a diverter valve on the jet washer circulating stream. A mechanical totalizing water meter was installed at this time to measure total water used on the range.

Work continued in December, 1979, including piping on the range and foundation work for the recovery system building. Foundation problems were discovered resulting in a project delay while civil engineering studies were made and alternate locations proposed. It was decided to locate the recovery system inside the plant near the range. Preparation of the new site included cutting floor drains, installing guard rails, and fabricating pump and tank concrete pads. The 23 m$^3$ (6,000 gallon) feed and rinse make-up tanks had to be cut and field fabricated because the new location had limited access doors. A 0.75 m$^3$ (200 gallon) stainless steel wash tank was added to facilitate membrane cleaning. Equipment installation and associated piping and electrical work continued through November, 1980. At this time membranes had not been installed, however, the recovery system controls affecting range operation, particularly the flow rate to the washers, were operational.
Membrane Washing: Membranes are subject to fouling due to both dissolved and undissolved components in the membrane system feed stream. In many cases particular feed constituents can be identified as foulants and can be washed from the membrane surfaces at time intervals such that the time averaged membrane performance is increased. Membrane washing during this project has been complicated by the large number of industrial chemicals used in the dye range processes, particularly when new chemicals are introduced with no knowledge of their potential as foulants. The following paragraphs describe washing conducted through February, 1982. Membrane washing studies will continue as the project continues.

Water washing, especially at high temperatures (up to 100°C) and at high velocity over the membrane surface, can be effective and has been used in this project. High temperatures increase solubility and diffusion rates of most substances and high flow rates cause increased shear stress at the membrane surface. While the recovery system membranes were being installed over a ten-week period, water was run at frequent intervals when range effluent from direct dye lot runs was not available (range effluents from other dye types were introduced later). Soon after the final membrane segment was installed a steam coil was added to the wash tank and hot water (up to 95°C) could be used on the membranes. To compare the results of washing, membrane performance data were recorded while operating on water and used to calculate a system average membrane permeability. A list of membrane system permeabilities on water following various washes are listed for several times during the project in Table 5. Before April 24, 1981, the system operating temperature was limited to 60°C. The membrane permeability increase between April 24 and May 11 could have resulted from increased washing temperatures.

Between May and October, 1981, the recovery system operating time increased to 3 shifts per day on all range processes except bleach. An intensive effort to wash the membranes was made in October, 1981, a summary of which is listed in Table 5. Water washing over a weekend (approximately 30 hours) resulted in lower membrane permeability than previously obtained after water washing (October 12, 1981, versus May 11, 1981). Waste was then run on the system for 8 hours followed by an overnight and water wash (approximately 16.5 hours) resulting in a membrane permeability on October 13, 1981, of nearly half that obtained in May, 1981. Washing with a water and acetic acid solution at a pH of 4.0 was conducted to remove hardness components. Analysis of the cleaning solution after washing indicated that nearly a kilogram of hardness as CaCO₃ was removed from the membrane surfaces and the membrane permeability was increased to within 10% of the previous best system permeability in a fraction of the washing time required to wash with water alone, Table 5. Results of a second pH 4 wash after operating with waste resulted in the same membrane permeability as after the first pH 4 wash.

The washing sequence continued with another pH 4 wash followed by an enzyme wash aimed at removing organic foulants such as gums. The combination
### TABLE 5. MEMBRANE PERMEABILITY ON WATER AFTER WASHING

<table>
<thead>
<tr>
<th>Date</th>
<th>Washing Procedure</th>
<th>Relative Permeability*</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-24-81</td>
<td>Water at 60°C</td>
<td>0.046</td>
</tr>
<tr>
<td>5-11-81</td>
<td>Water at 85°C</td>
<td>0.061</td>
</tr>
<tr>
<td>10-12-81</td>
<td>Water at 85°C, 30 hours</td>
<td>0.046</td>
</tr>
<tr>
<td>10-13-81</td>
<td>Water at 85°C, 16.5 hours</td>
<td>0.031</td>
</tr>
<tr>
<td>10-13-81</td>
<td>Acetic acid solution, pH = 4</td>
<td>0.055</td>
</tr>
<tr>
<td>10-16-81</td>
<td>Acetic acid solution, pH = 4</td>
<td>0.055</td>
</tr>
<tr>
<td>10-20-81</td>
<td>Acetic acid solution plus enzyme</td>
<td>0.084</td>
</tr>
<tr>
<td>2-10-81</td>
<td>Sodium bicarb. + detergent</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acetic acid solution, pH = 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>enzyme</td>
<td></td>
</tr>
<tr>
<td></td>
<td>water at 85°C, 16.5 hours</td>
<td></td>
</tr>
<tr>
<td>2-11-82</td>
<td>Acetic acid solution, pH = 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sodium hydroxide + detergent</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acetic acid solution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Citric acid solution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water at 85°C, 16.5 hours</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acetic acid solution</td>
<td>0.074</td>
</tr>
</tbody>
</table>

*Relative Permeability = permeate volume generated per day per unit membrane area. Relative permeability at full design capacity is 0.034.*
of washes resulted in the highest permeability thus far on October 20, 1981, 150% of design capacity.

In February, 1982, the membranes had been exposed to more waste without washing than at any previous time. Also, an oily substance was found in the wash tank. The oily substance was suspected to be the residual from antifoam chemicals used on the range. A sodium bicarbonate (pH = 9) and anionic detergent solution was used to wash as recommended by the antifoam supplier. A series of washes over a 3-day period including water, solutions of acetic acid, citric acid, sodium bicarbonate and detergent, and sodium hydroxide and detergent resulted in a membrane permeability of within 12% of the maximum permeability obtained in October. No one washing procedure caused a substantial flux increase which could indicate none were particularly effective in removing the foulant. However, if the foulants are layered on the membrane surface and the various washing procedures remove particular foulants, the sequential washing may be necessary. For example, the oil coating would prevent a pH = 4 wash or an enzyme from being effective on hardness scale or a gum layer.

Recovery system membrane washing procedures appear to restore membrane permeability even after prolonged operation with effluents from the many range processes and variations within given processes. The time required to wash may depend on the amount of effluent processed and/or the type of foulants in the fluid. Membrane washing in this complex and varying fluid is not fully understood at this time and studies will continue as the project continues. The study will include investigation of possible substitution of chemicals in production.

Two modules have been kept out of service for periods of time to study membrane washing. Because of the severe fouling problem discussed in this section, the development of effective washing procedures is important. Only a test section exposed to the history of the recovery system can provide credible results in the study of washing procedures.

Membrane Stability

Of the 70 membrane segments in the recovery system, 46 segments have remained in continuous service since their installation, see Table 6. The oldest now being in place for 13 months (from January 17, 1981, through February 25, 1982). Of the remaining 24, 11 have been re-membraned after replacing a broken tube (each segment contains 12 or 16 tubes); four segments have been re-membraned after being used in washing studies, four are currently bypassed with (suspected) tube breaks, and 6 are being re-membraned after being used in washing studies. One of the segments currently bypassed is in Module #8 that was re-membraned, thus this accounting totals 71, instead of 70.

The membranes in Module #9 were originally thought to have "failed" because the color rejection was observed to decrease quickly without a corresponding major increase in permeate flow rate - as would be expected
<table>
<thead>
<tr>
<th>Module</th>
<th>Installed</th>
<th>Removed from Service</th>
<th>Returned to Service</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1/17/81</td>
<td>12/3/81 - 7 segments</td>
<td></td>
<td>Continuous Service</td>
</tr>
<tr>
<td>9</td>
<td>1/29/81</td>
<td>12/3/81 - 7 segments</td>
<td></td>
<td>Replace 1 broken tube; Reform membrane. Module being used in washing studies.</td>
</tr>
<tr>
<td>8</td>
<td>3/11/81</td>
<td>6/16/81 - 3 segments</td>
<td>1/8/82</td>
<td>Replace 3 broken tubes; Reform membranes. Module used in washing studies.</td>
</tr>
<tr>
<td>7</td>
<td>2/24/81</td>
<td></td>
<td></td>
<td>Continuous Service</td>
</tr>
<tr>
<td>6</td>
<td>3/3/81</td>
<td>7/17/81 - 1 segment</td>
<td>9/24/81</td>
<td>Replace 1 broken tube.</td>
</tr>
<tr>
<td>5</td>
<td>3/16/81</td>
<td>6/3/81 - 1 segment</td>
<td>9/18/81</td>
<td>Replace 3 broken tubes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6/9/81 - 1 segment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6/18/81 - 1 segment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10/5/81 - 1 segment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3/20/81</td>
<td></td>
<td></td>
<td>Continuous Service</td>
</tr>
<tr>
<td>3</td>
<td>3/27/81</td>
<td>5/19/81 - 1 segment</td>
<td>9/3/81</td>
<td>Replace 1 broken tube.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/25/82 - 1 segment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4/8/81</td>
<td></td>
<td></td>
<td>Continuous Service</td>
</tr>
<tr>
<td>1</td>
<td>4/10/81</td>
<td>4/14/81 - 1 segment</td>
<td>9/15/81</td>
<td>Replaced 2 broken tubes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4/22/81 - 1 segment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/25/82 - 1 segment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
from a broken tube. Only after dismantling the module following washing experiments was a tube crack found — tightly plugged by fine lint — thus explaining the lack of high flow rate indicative of a broken tube.

There is no clear evidence of membrane deterioration during the more than one year of operation. And even allowing for module #9, there was no indication of membrane instability for at least 10 months to date (February 1982).

HF UNIT AVAILABILITY

The hyperfiltration unit availability reflects the reliability of the components. The availability of a particular segment of the membrane area is determined by the membrane itself and by the integrity of the support structure. The availability of the hyperfiltration unit is enhanced by the design that:

1. incorporates only 1.5% of the membrane area within one segment,
2. provides for quick identification and location of a failure and includes the ability to bypass the single segment containing the failure, and
3. provides for rapid replacement of the failed segment at a time scheduled for convenience.

The composite permeate from each of 10 modules is monitored in terms of flow rate and quality (qualitative color) using sight glass flow meters. In the event of a tube failure, the module can be immediately identified and bypassed (requiring the entire unit to be off-line for less than 30 minutes). By individually checking in turn each of three groups of membrane segments within a module and then each segment of the group containing the failure, the single segment can be bypassed and the full system (minus the segment containing the failure) can be returned to service within 2 hours. (The 23 m³ capacity of the wastewater and recycle water tanks allow for over 3 hours of normal range operation with the HF system off.)

Three segments are stored as spare parts. A module can be bypassed, removed from the system, dismantled, and reassembled with a spare membrane segment and returned to the recovery system within four hours.

These procedures have been demonstrated during the course of this project. The experience with membrane availability is summarized in Table 6. A total of 11 tubes, of the 1,000 in the unit, have been replaced. Four additional segments require replacement at this time. We believe that the failure rate of tubes will approach zero as the initial flaws in the tubes are eliminated.
SECTION 6

HF UNIT PERFORMANCE

The membrane performance of the HF unit is judged in terms of quantity of wash water filtered for recycle and the quality of the water, i.e., the removal of chemicals (dyes, gums, etc.) from the filtered water, permeate. The performance of the HF membranes is a function of the operating variables that produce instantaneous effects, e.g., chemical concentrations, temperature, etc., and long term effects such as fouling accumulation and membrane stability. The effective life of the HF unit is defined as the time interval that component failure does not impair the utility of the total unit. The effective life of a membrane is defined as the time interval that the levels of quantity and quality of water are acceptable for recycle.

In this section, membrane performance is discussed in light of a mathematical model developed to describe (predict) the quantity of water produced as a function of the wash water characteristics: chemical concentrations, temperature, pressure, and fluid velocity. The experience with foulant accumulation and membrane washing is also presented. The buildup of chemicals in the wash water during a period of closed cycle operation of the dye range is presented. The replacement history of membranes and porous tubes are also presented in the discussion of membrane and HF unit life.

The plans for study and improvement of membrane performance during the continuation of this project through September, 1983 are mentioned.

PERMEATE QUALITY (MEMBRANE REJECTION)

Definitions

The quality of separation achieved by a membrane is defined by a term called "rejection." Rejection is defined as the fraction of a particular material that does not pass through the membrane. This definition is illustrated in Figure 7(a) for a differential membrane element. The Single Pass membrane system arrangement is illustrated in Figure 7(b). In the Single Pass system the fluid progresses continuously from the feed pump to the final discharge through the concentrate control valve. The water that permeates the membrane is removed from modules, segments of the system, or as a composite whichever is most convenient. The demonstration HF unit has provisions for sampling the water permeate from each of ten modules. For recycle the water from all modules is pumped into a common collection tank thus forming a composite. The rejection in terms of the composite permeate quality is related to the rejection of each membrane element integrated over the total membrane area of the system. This relationship is presented in Figure 7(b). The degree of conversion from wash water to permeate is called
**Process Water**

**Permeate**

**CONCENTRATION OF MATERIAL IN THE PERMEATE**

**CONCENTRATION OF MATERIAL IN THE PROCESS WATER**

Figure 7(a). Differential Membrane Element.

**Motor**

**Pump**

**Control Valve**

**Carre DWG. NO. 3134**

**Recovery, R** = \( \frac{\text{Volume Flow of Permeate}}{\text{Volume Flow of Inlet Process Water}} \)

**Composite Permeate Concentration** (\( C_p \)) = \( \frac{1}{R} \left( 1 - (1 - R)^{1 - y} \right) \)

**Inlet Process Water Concentration** (\( C_f \))

**Concentrate Concentration** (\( C_C \)) = \( (1 - R)^{-y} \)

Figure 7(b). Single Pass Membrane System Arrangement.
"recovery," (R). Recovery is simply the ratio of the volume of the permeate to the volume of wash water being supplied to the HF unit, Figure 7(b).

The material rejected by the membrane is concentrated as the wash water passes down the Single Pass system. The degree of concentration depends on the recovery as well as the rejection. This relationship is also shown in Figure 7(b).

Stability of Membrane Rejection

During the course of this project, samples have been collected for chemical analyses to document the membrane performance in terms of rejection. The parameter of primary interest for reuse of the permeate is the color. In Table 4 a list of selected data and results indicate that the color rejection of the membrane system has remained essentially constant throughout the course of this demonstration. Included in Table 4 are data for conductivity. The rejection of conductivity is included as an indicator of the rejection of species (e.g. salt) other than the larger organic molecules represented by the dyes, i.e. color.

Build Up of Chemicals

Closed cycle operation of the dye range raises the question of build up of chemicals in the wash water. Build up could occur because rejection is less than 100%. The build up is limited, however, by the introduction into the system of fresh water. Fresh water enters with the dye pad solutions that are mixed in the drug room with plant water. This flow of water varies from about 9 liters per minute to 35 liters per minute depending on the details of a particular production lot. Of course, a corresponding amount of water is removed from the washers since the fabric is initially dry but leaves the last washer saturated containing about one kilogram of water for each kilogram of fabric.

To date, complete closed operation of the dye range has occurred only for periods of 2-4 hours duration, after which no recycle occurs for a corresponding time period while permeate is accumulated. A detailed evaluation of the chemicals introduced in the dye pad, the composition of wash water from the range, and the quality of permeate generated by the hyperfiltration unit were, however, monitored during a controlled period of complete recycle. The analysis of the results are presented in Appendix B. Taking into account the time lag involved from when the dye solution is deposited on the fabric to when pumped into the hyperfiltration unit, there is no accumulation of material in the wash water. There is, however, a relationship between the quality of the permeate and the quantity of chemicals introduced in the dye pad. For example, during the course of the controlled recycle experiment, the concentration of dyes being used varied by 50 to 1. The concentration of dissolved solids in the permeate varied in a way predicted simply by the rejection of the membrane system. Consequently it is concluded that there will be no significant build up of chemicals in the wash water.
TABLE 4.
Selected Membrane Performance Parameters
Throughout the Course of the Demonstration

<table>
<thead>
<tr>
<th>DATE</th>
<th>FEED</th>
<th>PERMEATE</th>
<th>REJECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COND</td>
<td>ABS</td>
<td>COND</td>
</tr>
<tr>
<td>6-2-81</td>
<td>510</td>
<td>1.1</td>
<td>175</td>
</tr>
<tr>
<td>7-30-81</td>
<td>740</td>
<td>0.65</td>
<td>200</td>
</tr>
<tr>
<td>8-18-81</td>
<td>480</td>
<td>0.75</td>
<td>85</td>
</tr>
<tr>
<td>9-30-81</td>
<td>360</td>
<td>0.20</td>
<td>195</td>
</tr>
<tr>
<td>10-9-81</td>
<td>475</td>
<td>0.76</td>
<td>195</td>
</tr>
<tr>
<td>11-24-81</td>
<td>480</td>
<td>0.96</td>
<td>200</td>
</tr>
<tr>
<td>12-15-81</td>
<td>860</td>
<td>1.0</td>
<td>295</td>
</tr>
<tr>
<td>1-20-82</td>
<td>250</td>
<td>0.23</td>
<td>61</td>
</tr>
<tr>
<td>2-19-82</td>
<td>1250</td>
<td>2.7</td>
<td>410</td>
</tr>
<tr>
<td>3-2-82</td>
<td>320</td>
<td>0.68</td>
<td>120</td>
</tr>
</tbody>
</table>
A quasi-steady state condition of permeate quality with dye solution is established in less than 2 hours. This quasi-steady state involves a wide variation in permeate quality but it is a variation that essentially is in equilibrium with the concentration of material having been introduced into the dye pad formulation at an appropriate interval of time preceding the generation of the permeate. Thus, it is possible for the fabric production to be sequenced in such a manner that the permeate would be unsatisfactory for recycle if a very heavy production shade were to be followed by a very light shade. The effects of production on the reuse of permeate are discussed more completely in Section 7, Recovery Process.

In summary, the membrane rejection has proven to be stable during the demonstration period, to date approximately twelve months.

PERMEATE QUANTITY (MEMBRANE FLUX)

The quantity of permeate generated by the recovery system is a function of the operating conditions at any given moment and a function of longer terms effects such as fouling, and possibly membrane modification including deterioration.

Definitions

The quantity of permeate generated is expressed as membrane flux (i.e., the volume of permeate per unit of membrane area per unit of time). Common units are m$^3$/m$^2$/day or m/d. This measure of flux may further be normalized by dividing by pressure to give permeability (i.e., flux per unit of pressure, m/d/Pa.)

Short Term Effects

The principle operating conditions that are known to have essentially an instantaneous effect on membrane flux are temperature, pressure, and concentration of gum. Depending on the concentration of gum, there may also be an effect of fluid velocity. A mathematical model describing the effects of these variables on membrane flux has been developed. This model is discussed in Appendix C.

The measured pressure distribution is compared in Figure 8 with the calculations using the model. The model requires as input the inlet pressure and the flow rate. Experience has indicated that the membrane performance is insensitive to instantaneous values of chemical concentration but may be diminished by long term accumulative effects, e.g., fouling.

LONG TERM EFFECTS
Figure 8. LaFrance Single Pass Hyperfiltration System Pressure Profile Modeled versus Measured. (Outlet module, 330m, is not installed. Total system length is 1140 meters.)
The two major long term effects on membrane performance are the accumulation of deposited foulants and possibly membrane chemical deterioration, including deterioration.

Membrane Fouling and Washing

Membrane fouling is defined as a decrease in flux that is not an instantaneous reversible effect of pressure, temperature, velocity, concentration, or other controlled operating variable. Fouling is usually categorized as (1) an alteration in the membrane due to chemical reaction with the waste stream or (2) an accumulation of a deposited layer. An example of alteration in the membrane are reactions between the charged membrane and metal ions Cu++, Mg++, Ca++, Fe+++ etc. that commonly occur in the wash water. Reactions can also be possible with polymers. Examples of the type of deposits that may occur are:

(1) undissolved dye particles
(2) calcium carbonate, or similar insoluble compounds of the metals
(3) undissolved fraction of the guar gum which could form a carbohydrate film
(4) fine lint and other suspended solids, perhaps in combination with the gum,
(5) the insoluble reaction products of basic and direct dyes (the two major classes of dyes in use on the dye range),
(6) silicone and other oils used as anti-foam agents, and
(7) biological material that may be formed in the storage tanks.

Because the removal of foulants depends on the nature of the foulant, the washing procedures tested have been selected to attack one or more of the types of fouling potentially present. The sequence of cleaning is also important, for example an oil coating will interfere with the acid cleaning for calcium carbonate and will also interfere with enzyme removal of a carbohydrate film.

Membrane fouling: By October, 1981 the membrane system had been operated without cleaning for 100 hours at low temperature and was thus fouled. During October a great deal of attention was given to cleaning the membranes. The washing techniques employed and their results are detailed. The results are also indicated in Figure 9 and 10 where apparent membrane permeability, based on the inlet pressure, is plotted for the period of October, 1981 through February, 1982. Figure 9 shows this information for the first seven modules of the ten module membrane system. Figure 10 shows similar information for the outlet section of the membrane recovery system. This outlet section contained at various times two modules, three modules, and one module. The exact configuration at any time is indicated in Figure 10. Examination of the two figures indicates that perhaps different phenomena are being experienced in the two portions of the membrane system. The fouling rate seems to have progressed to a greater extent and in a somewhat different manner in the first seven modules of the membrane system. The reason for the difference in the performance of the two sections of the
Figure 9. Relative Permeability versus Time for the Upstream Seven Modules
Figure 10. Relative Permeability versus Time for the Downstream Modules
membrane system is not well understood. There are some obvious differences in operation that may be contributing factors. It is not trivial to say that seven modules are upstream in the system and provide a large surface area for the possible adsorption or deposition of foulants. It is also true that the fluid velocity in this first section is lower than fluid velocity in the outlet sections of the system.

The system was designed to have lower velocities in the initial sections because pilot plant test data indicated limited velocity effects in the regions where the concentrations had not progressed extensively. Consequently, the initial sections of the membrane system were designed to have velocities in the range of 1.5 to 2 m/sec. The outlet section of the membrane system where the concentration of gum is highest, was designed to have velocities ranging up to 3 m/sec. However, as fouling progresses to the point that the membrane system is not capable of handling the full pump output, the velocity field in the inlet section of the membrane system actually decreases while the velocity in the outlet section is maintained constant. The outlet velocity is constant because the volume of concentrate leaving the system is controlled. Thus any fouling effects that are associated with velocity will become progressively worse in the inlet section. At the flux levels indicated in January and February, 1982, the maximum velocity entering the first portion of the membrane system had decreased to about 1 m/sec.

In the outlet section of the membrane system the velocity is dependent on the number of modules installed. With three modules in place, the velocity varies from 2.5 m/sec at the entrance of the section to about 3 m/sec at the exit of the membrane system (when controlled at 5 gallons per minute of concentrate). With two modules in place, the velocities are about 3.5 m/sec to 3 m/sec. And with one module in place, the inlet velocity goes as high as 5 m/sec. While there is a lot of scatter in the data presented in Figure 10, there is clearly an increased unit output associated with the period in early December, 1981, when there was only one module in place.

After the extensive cleaning that took place in October, there was a decline in membrane performance in the outlet section corresponding very closely to that occurring in the inlet section of the system. However, in early December the performance of the outlet section of the membrane system began to improve. And even though there is a large scatter in the data, the membrane performance has remained high (more than 50% higher than the permeability on December 1) throughout the period when two modules were again subsequently introduced in the system.

In summary, the flux performance of the membrane system is not well understood. The differences in the performance of the inlet section and outlet section of the membrane system is also not well understood. The effects of washing are discussed in the next paragraph. The role of foulants and the effects of velocity and membrane position in the Single Pass system will be studied further during the extension period of this demonstration project.
The recovery system is shown in Figure 1 with the dye range. The recovery system consists of a feed accumulator tank, pumps, hyperfiltration modules and concentrate and wash water tanks. The waste water flows by gravity from the dye range to a surge tank and is pumped to the wastewater tank. There is a period of time between each production lot for cleaning the range equipment and filling the dye pad. However, the water flow is continued during the down period to reduce the color in the water in the washers by about 30%. A production lot can be treated in the hyperfiltration system as a batch containing chemicals from a single dye formulation when this knowledge of the composition is important in reuse or disposal of the chemicals.

The wash water effluent (HF supply) is usually highly colored and removal of at least 97% of the dyes is considered necessary to avoid possible staining of fabric during reuse. The auxiliary components must also be removed sufficiently to provide wash water with concentration differences suitable for effective washing of the fabric.

The HF concentrate contains dyes at concentrations much lower than those in the dye pad solution, but with comparable concentrations of the auxiliary chemicals. Based on pilot studies, reuse of the concentrates in the dye formulations is feasible with about 75% savings in auxiliary chemicals and an average of about 10-20% in dyes depending on the dye class\(^2\). Effective reuse of the HF concentrate depends on the ability to add dyes to achieve hue and crocking characteristics needed in production. HF concentrate reuse can be enhanced by judicious scheduling of dyeing lots by shade and dye class and by using the experimentally determined guideline of using only 25% of auxiliary components in every reuse dye formulation. Appropriate scheduling has been initiated but is often interrupted by production demands.

Laboratory tests were conducted to evaluate reuse in preparation for the full scale demonstration. The results of these laboratory tests have been updated. These results are included in Appendix D for the convenience of the reader.

PERMEATE REUSE

Wash water from all of the production processes, except bleaching, have been reused after hyperfiltration. Bleaching effluents are excluded until the pH adjustment can be accomplished to permit its reuse. The permeate has been used in all classes of processes performed on the range; washing of all dye classes, bleaching, and scouring.

Over one million meters of fabric have been washed or scoured with permeate. Permeate at the desired temperature is intermittently supplied to
the range during all full scale operations. In normal operation permeate is automatically used when it is available. Plant water is automatically provided as the alternative source.

In recent weeks, with the unit operating with 80% or more of the membrane area in place, full-strength permeate has been used on 50-60% of the fabric produced. Although the HF unit is capable of matching the wash water requirement of the range for a period following cleaning of the membranes, its average supply of permeate has been sufficient to wash only about 60% of production.

Interruptions in the HF unit operation occur during membrane cleaning and evaluations of the HF unit performance characteristics. In addition, the range operator discontinues the supply of waste water to the HF unit whenever the range wash boxes are normally emptied and refilled when a dark shade is followed by a light shade or a difficult process crossover occurs. These judgements have been included in the standard operating procedures to utilize operator experience.

This operator experience rule is conservative. In one observation period covering two weeks, the wash boxes were emptied and refilled 43 times. Despite the operating instructions (stated above), the wash water was supplied to the HF unit during the production of 27 of these lots. Only one was not successfully hyperfiltrated and reused. The single case of staining occurred when wash water from a lot dyed a dark shade (the formulation contained 32.5 grams per liter of basic and direct dyes) was reused on a lot dyed a light shade (the formulation contained only 0.3 grams per liter of direct dyes). This 108:1 ratio in dye formulation concentration normally produces an even greater ratio in the dye concentrations in the wash boxes because the dye exhaustion is relatively less for the dark shades of basic/direct dyes than for the light direct shades. Such a large ratio in the dye concentration for consecutive lots is a severe test for the hyperfiltration unit where basic dye overall rejections of about 90% and direct dye overall rejections of 97% are routinely obtained. This single result combined with the successful hyperfiltration and reuse of hundreds of effluents suggest very few redyes would result if all range effluents were hyperfiltered without operator selection (See Appendix E).

CONCENTRATE REUSE

The full scale use of HF concentrates in production dye formulations has been initiated in a manner designed to minimize complications by utilizing hue and dye class in the reuse.

Reuse Concept

A substantial percentage of the production is fabric dyed to one of three hues of tan to brown. These print base dyeings normally occur in 80 piece (4,000 meter) lots. Because there are only three shades involved, concentrate reuse between these shades can be standardized using formulas
developed in the dye laboratory. The initial efforts at full scale reuse of HF concentrate is emphasizing these three shades.

Laboratory Formulations

Formulations were developed in the dye laboratory with HF concentrate generated from washing the medium and the dark shades. The laboratory procedure began by striking a fabric sample using as received HF concentrate. A strike consists of running a fabric sample in a prototype of the dye range dye pad and steamer. Striking with as received HF concentrate indicates the dye content available for reuse. HF concentrate from the medium and dark shades contain too much dye to allow formulation to the lightest shade. They could, however, be reformulated to their original shades respectively and to each other. HF concentrate from the lightest shade contains so little dye that it can be reformulated to itself and to any production shade by adding without altering the dye in the standard formulations. The reuse formulations developed in the laboratory indicated that only 25% of the auxiliary chemicals are needed when HF concentrate is used on a production basis.

Full Scale Reuse

HF concentrate from the darkest of the three brown shades was collected and reformulated to dye a 4,000 meter lot of the medium shade. Only 2,400 liters of HF concentrate was returned to the drug room so 1,600 liters of water were added to the concentrate to make the 4,000 liter volume necessary.

After the initial 4,000 liter of formulation was mixed, based on the laboratory formula, three dye additions were necessary. The initial formulation produced a strike that was too light (probably because of the 1,600 liters of water added to achieve required volume) so the first addition was made. Results after the first addition of dye were still slightly too light so the second dye addition was made. This resulted in too much orange so an additional add was required resulting in the proper shade. When the 4,000 meter lot was run on the dye range it came out slightly dark indicating too much dyes were used. No auxiliary chemicals were added to the formulation. The total amount of dyes used was 25% more than would have been required in a standard formulation (starting with plant water only). However, assuming that after the first dye add the shade would have been acceptable (based on dye house supervisor comments), a dye savings of 5% would have resulted. HF concentrate reuse will continue on a production scale among these three tan to brown shades before expanding the effort to other shades.
SECTION 8
POLLUTION ABATEMENT

The HF concentrate stream will not be reusable in every instance because of production schedules. Because of the high concentration of chemicals and corresponding small volume of the HF concentrate, treatment methods not generally applicable to textile wastewater may be considered. Several treatment methods that may be applicable due to the smaller volume include application to agriculture land, additional concentration by membranes followed by drying for land fill or incineration and oxidation by exposure to ozone. Cost estimates from commercial organizations for direct land application are presented in the Section 9 of this report. Because land application may not be allowed, further volume reduction followed by incineration was studied as part of this project.

DISPOSAL TECHNIQUE DESCRIPTION

Discharge from the range occurs in two forms: the wash water discharged continuously and the drop from the dye pad following each production lot. The dye pad drop occurs in a time expected to allow direct addition to the corresponding HF concentrate. The combined concentrate and pad drop is of known composition and its reuse or disposal can be planned with that knowledge. This combined concentrated fluid becomes feed for a disposal system when the mixture cannot be reused in dye formulations. The waste stream is still too dilute at this point to go directly into a dryer so further concentration by membranes was studied. Permeate from this membrane separation may not be suitable for wash water because of the dye content but it can be reprocessed through the full scale recovery system. Overhead vapors from the dryer can be condensed in a feed preheater to recovery the energy and the water then recycled. Solids from the dryer can be incinerated or disposed of by some other method.

DRYER TESTING

A thin-film dryer was tested with various solutions of HF concentrate and dye pad drop mixtures in 200 liter batches. Two concentrations were tested, 4 and 6 percent total solids. A third solution contained 1.5 percent total solids and was too dilute for successful processing with the dryer test equipment. The 4 and 6 percent solutions were obtained by concentrating dye pad drops with no HF concentrate. Dye pad drops were used instead of range rinse water because limited membrane area made it impractical to process the 10,000 and 14,000 liters needed to generate the 4 and 6 percent solutions respectively.

It was possible to obtain steady-state data for various flow rates and dryer operating conditions for each batch of feed tested. The dryer operating temperature was selected to equal that of standard process steam
Data were also obtained for a steam temperature of 185° C. Flow rates were limited by the quality of bottoms and amount of entrainment in the overhead vapors.

Low feed rates yield bottom products that had properties like tar in appearance and handling characteristics. The highest flow rates resulted in entrainment of feed solution into the overhead vapor flow. The point of entrainment provides an upper limit to feed flow rate. Preheating feed material to greater than 100° C also caused entrainment due to flashing. Between these operating limits, bottom product varies in quality from friable powder to powder plus "tar-like" material.

The results of total solids analysis for bottom and condensed overhead vapors are listed in Table 7. Bottoms characterized as "tar-like" contained between 1 and 2 percent moisture by weight. Bottoms consisting of powder plus "tar-like" material contained between 5 and 10 percent moisture by weight. Bottoms samples consisting of only friable powder contained between 16 and 17 percent moisture by weight. This powder appears damp but retains friability even after being compressed by hand. Because the powder was easier to handle for disposal by incineration, flow rates for various sized dryers were determined to deliver bottoms with approximately 15 percent moisture. Test results indicate an optimum feed flow rate of 0.013 liters per minute per square meter for steam temperature of 175° C with a preheat temperature of 95° C for 8 percent total solids feed to the dryer.

**MEMBRANE TESTING**

Membrane performance data was obtained with the unused concentrate from the dryer testing. For this test a combination of 1.5 and 4 percent total solids solution was concentrated with membrane equipment to 7 percent total solids. Samples were taken at specified recoveries to determine the concentration of solids in the feed and to evaluate total solids rejection.

Flux versus total solids concentration is plotted in Figure 11. The flux declines with feed concentration. Flux versus pressure is shown in Figure 12 for several levels of concentration. The curves are typical of HF of high molecular weight solutes. Flux becomes increasingly less dependent on pressure as the pressure increases. (Velocity variation effects were not studied because the highly colored solution obscured the float in the flow meter.) Color rejection was constant at about 97%.

**MEMBRANE/DRYER INTERFACE**

Membrane sizing can be based on an average flux for concentrating the waste stream from 2 percent to 10 percent total solids in a single pass system. With an average membrane flux of 1 m/d, the area required to deliver 2 liters per minute at 10 percent total solids from 10 liters per minute of 2 percent is approximately 12 square meters. The membrane cost is $24,000 with about $10,000 for pumping and controls if the additional area cannot be attached to the existing hyperfiltration unit. The dryer area required to
<table>
<thead>
<tr>
<th>Sample</th>
<th>Total Solids (%)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distillate:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1D</td>
<td>.072</td>
<td>(b)</td>
</tr>
<tr>
<td>2D</td>
<td>.054</td>
<td>(a)</td>
</tr>
<tr>
<td>3D</td>
<td>.011</td>
<td>(c)</td>
</tr>
<tr>
<td>4D</td>
<td>.060</td>
<td>(c)</td>
</tr>
<tr>
<td>5D</td>
<td>.050</td>
<td>(a)</td>
</tr>
<tr>
<td>6D</td>
<td>.030</td>
<td>(b)</td>
</tr>
<tr>
<td>7D</td>
<td>.020</td>
<td>(b)</td>
</tr>
<tr>
<td>8D</td>
<td>.035</td>
<td>(b)</td>
</tr>
<tr>
<td>9D</td>
<td>.020</td>
<td>(b)</td>
</tr>
<tr>
<td>10D</td>
<td>.055</td>
<td>(b)</td>
</tr>
<tr>
<td>Bottoms:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2B</td>
<td>91.86</td>
<td>(b)</td>
</tr>
<tr>
<td>3B</td>
<td>85.00</td>
<td>(a)</td>
</tr>
<tr>
<td>4B</td>
<td>99.07</td>
<td>(c)</td>
</tr>
<tr>
<td>5B</td>
<td>98.64</td>
<td>(c)</td>
</tr>
<tr>
<td>6B</td>
<td>82.59</td>
<td>(a)</td>
</tr>
<tr>
<td>7B</td>
<td>82.32</td>
<td>(a)</td>
</tr>
<tr>
<td>8B</td>
<td>91.59</td>
<td>(b)</td>
</tr>
<tr>
<td>9B</td>
<td>94.25</td>
<td>(b)</td>
</tr>
<tr>
<td>10B</td>
<td>93.95</td>
<td>(b)</td>
</tr>
</tbody>
</table>

(a) powder
(b) powder plus "tar-like" material
(c) "tar-like" material
Figure 11. Flux versus Total Solids Concentration - Concentrate Disposal
Membrane Performance

- 2758 KPa
- 4136 KPa
- 5515 KPa
- 6894 KPa
- Estimated from Pressure Scan Data

\[ T = 85^\circ C \]
\[ Q_f = 0.02 \text{ m}^3/\text{min} \]
Initial feed volume = 0.15 m$^3$
- 0.06 m$^3$ remains (3.4% T.S.)
- 0.04 m$^3$ remains (4.7% T.S.)
- 0.03 m$^3$ remains (7.05% T.S.)

$T = 85^\circ C$

$Q_f = 0.02 m^3/min$

Figure 12. Flux versus Pressure - Concentrate Disposal Membrane Performance
achieve 85 percent solids is 1.4 square meters. Standard dryer sizes are 1 square meter and 2 square meters. The smaller dryer should be adequate because the system can be operated as a batch process. The equipment cost (commercial estimates) for the dryer is about $73,000. An entrainment separator is estimated to cost $7,500.

INCINERATION TESTING

Disposal of sludge generated from the testing with the dryer and the hyperfiltration pilot unit was investigated. A laboratory study was conducted to evaluate the incineration characteristics of the sludge, the ash volume generated by incineration, and the toxic characteristics of the sludge and the incinerated ash.

A mixture of power and "tar-like" material was evaluated. A sample of this material was dried at 105°C for 24 hours to determine the moisture content, and a sample of the residue was ignited in a muffle furnace at 815°C to determine the ash content. These analyses are presented in Table 8.

The sludge ignited readily and generated a yellowish white smoke that was slightly irritating to the nose and throat. Burning the residue in open air over a flame generated a black soot probably due to incomplete combustion. The residue was fluid at incineration temperature, but solidified on cooling to a hard black solid that crumbled easily and had a sulfur-like odor. The ash was scraped from the ceramic dishes, weighed, and subjected to the extraction procedure required to determine EP toxicity. A sample of the residue before incineration was also subjected to the extraction procedure. The results of the chemical analysis of the extracts are presented in Table 8 along with the allowable concentration levels. It should be noted that dried residue from the membrane/dryer equipment remains water soluble and contains substantial amounts of dyes. Leachant from this residue would be highly colored and might cause problems in a landfill disposal application.

It was noted that the initial pH of the sludge extract was 5.5; the initial pH of the ash extract was 12.5. The sludge extract was adjusted to pH of 5.0 by the addition of 5 mls of 0.5N acetic acid. The addition of the maximum amount of acid recommended by the extraction procedure, 4 mls acid/gram of solid, reduced the pH of the ash extract from 12.5 to pH 9.8. During the extraction procedure, a sulfide odor was generated by the incinerated ash sample; the sulfide concentration in the extract at the conclusion of the extraction was 850 mg/liter.

SUMMARY

The introduction of the HF concentrate to the biological waste treatment has caused no problems. There is a large dilution (> 40 to 1) of the HF concentrate in the well stirred 150 m³ sump tank ahead of the aeration basin.
<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Allowable Concentration, mg/l</th>
<th>Dye Waste (As Received), mg/l</th>
<th>Incinerated Ash, mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>5.0</td>
<td>&lt;0.03</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Barium</td>
<td>100.0</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Cadmium</td>
<td>1.0</td>
<td>0.03</td>
<td>0.10</td>
</tr>
<tr>
<td>Chromium</td>
<td>5.0</td>
<td>0.28</td>
<td>0.07</td>
</tr>
<tr>
<td>Lead</td>
<td>5.0</td>
<td>0.35</td>
<td>0.77</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.2</td>
<td>0.0008</td>
<td>&lt;0.0002</td>
</tr>
<tr>
<td>Selenium</td>
<td>1.0</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Silver</td>
<td>5.0</td>
<td>0.08</td>
<td>0.09</td>
</tr>
<tr>
<td>Endrin</td>
<td>0.02</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lindane</td>
<td>0.4</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Methoxychlor</td>
<td>10.0</td>
<td>&lt;0.010</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Toxaphene</td>
<td>0.5</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>2,4-D</td>
<td>10.0</td>
<td>&lt;0.01</td>
<td>&lt;0.010</td>
</tr>
<tr>
<td>2,4,5-TP</td>
<td>1.0</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>
The disposal of the HF concentrate on agricultural land is economically attractive, but may not be desirable because of potential liability. Incineration, after appropriate drying, has been shown to be technically feasible with on-site disposal of the ash. The cost of incineration with commercially available equipment is high. Smaller units designed for the small capacities of a typical textile plant might reduce the costs significantly.
Economics of this hyperfiltration demonstration project and other hyperfiltration applications in the textile industry are considered in this chapter.

There are four elements of purpose for this chapter: (1) to present the cost and savings of this project, (2) to estimate the cost and savings for future hyperfiltration applications in the textile industry based on the data of this demonstration, (3) to evaluate the sensitivity of costs to certain process and operational variables, and (4) to discuss the economic aspects of hyperfiltration as applied to other industrial processes.

The actual capital expended for the installation of the demonstration unit is reported and examined in some detail. Because this is a demonstration project, certain costs were incurred that are greater than would normally be expected for a non-demonstration application. These include such items as recording instrumentation to allow reporting of results and engineering costs incurred through changes of scope in the demonstration project. The experience of this demonstration is used as the basis for capital cost projections for other applications.

Hyperfiltration economics are sensitive to a number of parameters; some of these will be examined. In this demonstration, the hyperfiltration recovery system was a retrofit to an existing textile plant. Therefore, waste treatment facilities were in place and only savings in waste treatment due to reduced operating cost could be counted. In the case of a new plant where a recovery system would result in a smaller waste treatment system, the reduced capital cost could be taken as a savings against the hyperfiltration system capital cost. Savings through recycle result from reduced consumption of water and reduced water treatment costs, energy conservation, and chemical recovery. Other applications may be more or less conducive to recycling of any of these constituents.

All analyses for this report are done in 1981 dollars with no direct effects of inflation.

A major emphasis for this chapter is on establishing capital and operating costs and savings information based on the demonstration. Example measures of merit are given: internal rate of return, pay out time, and return on original investment are calculated.
Elements of capital cost and operating expenses are those recommended by the United States Environmental Protection Agency and their standard procedure for cost analysis of pollution control operations.

OST DATA FOR THE DEMONSTRATION

Capital Costs Data

Table 9 lists elements of capital costs for the recovery system. The hyperfiltration membrane modules, their support structures, and the high pressure pumping and its associated controls including a pH control system were provided by a single equipment vendor. Both the control panel and a monitoring or display panel were provided independently by another vendor. Engineering was provided by a local architectural/engineering firm. All other items were provided by a prime contractor with the exception of heat exchangers which were a retrofit to the recovery system provided by a second contractor. All other direct costs were taken from invoices submitted by the prime contractor. Freight, sales tax and construction overhead were also taken from these invoices as was the contractor fee.

The total recovery system plant cost $558,000. This is the total depreciable investment since neither interest nor start-up costs were capitalized or provided for. No value was placed on the space required for the hyperfiltration unit and recovery system.

Because this is a demonstration unit, certain of these capital costs were incurred because of special reporting requirements, delays and changes of scope in the project, and engineering design changes. Table 10 is a revision of Table 9 in which some of the capital costs have been changed to remove the demonstration project effects and to reflect, in the case of the hyperfiltration unit, a 1981 price.

The following are comments on Table 10 and are listed by number (superscript) shown in the table.

1. The revised hyperfiltration unit price reflects an updated 1981 quotation from the vendor. The 1981 price also includes a feed booster pump and a 0.75 m³ stainless steel wash tank.

2. While the control panel requirements did not change, the monitoring (display) panel was eliminated from Table 10. The panel housed instruments (not included in the panel price) that are necessary only for the special data collection and reporting of the demonstration project.
Table 9. Capital Cost Data for Hyperfiltration Demonstration

1. Purchased Equipment Cost for each major plant item
   a. Hyperfiltration Unit $244,000
   b. Control Panel 12,000
   c. Monitoring Panel 10,000
   d. Heat Exchanger 10,000
   e. Other Items 37,000
   TOTAL $313,000

2. Direct Field Materials
   a. Piping 42,000
   b. Instrumentation 32,000
   c. Electrical 37,000
   d. Excavation 12,000
   e. Insulation 10,000
   f. Equipment Rental 5,000
   TOTAL $138,000

3. Direct Field Labor 30,000

4. Adjunct Facilities
   TOTAL DIRECT COSTS $491,000

5. Indirect Costs
   a. Freight 2,000
   b. Insurance 2,000
   c. Sales tax 4,000
   d. Construction O.H. 11,000
   e. Engineering 30,000
   TOTAL $50,000

6. Contractor's Fee 17,000
   TOTAL PLANT COSTS $558,000

7. Interest during construction if capitalized -0-

8. Start-up cost, if capitalized -0-
   TOTAL DEPRECIABLE INVESTMENT $558,000

9. Land -0-

10. Working Capital -0-
    TOTAL CAPITAL INVESTMENT $558,000
Table 10. Capital Costs for Subsequent Hyperfiltration Applications Based on this Demonstration

1. Purchased Equipment Costs for Major Plant Item
   a. Hyperfiltration Unit\(^1\)  $300,000
   b. Control Panel  12,000
   c. Monitoring Panel\(^2\)  -0-
   d. Heat Exchanger  10,000
   e. Other Items\(^3\) (pumps, tanks, etc.)  14,000

   **TOTAL**  $336,000

2. Direct Field Materials
   a. Piping\(^4\)  28,000
   b. Instrumentation\(^5\)  10,000
   c. Electrical\(^6\)  25,000
   d. Excavation\(^7\)  -0-
   e. Insulation  10,000
   f. Equipment Rental  5,000

   **TOTAL**  $78,000

3. Direct Field Labor  30,000

4. Adjunct Facilities  -0-

   **TOTAL DIRECT COSTS**  $444,000

5. Indirect Costs
   a. Freight\(^8\)  1,500
   b. Insurance\(^8\)  1,500
   c. Sales tax\(^8\)  3,000
   d. Construction O.H.\(^9\)  7,000
   e. Engineering\(^10\)  15,000

   **TOTAL**  $28,000

6. Contractor’s Fee\(^11\)  12,000

   **TOTAL PLANT COSTS**  $484,000

7. Interest during construction, if capitalized  -0-

8. Start-up Costs, if capitalized  -0-

   **TOTAL DEPRECIABLE INVESTMENT**  $484,000

9. Land  -0-

10. Working Capital  -0-

   **TOTAL CAPITAL INVESTMENT**  $484,000

*superscripts refer to items in text describing changes for Table 9
3. Because the decision to locate the recovery system inside the plant was a mid-project change, two major cost items can be removed from the "other items" category. These are $17,000 for the external structure and $6,000 required to modify existing tanks so that they would fit through the plant doors.

4. Two items were eliminated from the piping cost. One was a $6,000 wash tank now included in the cost of the hyperfiltration unit; the other was $8,000 in piping changes associated with the decision to locate inside plant.

5. $18,000 for instruments in the monitoring (display) panel were eliminated. Additionally the $4,000 cost incurred as restocking charges for instruments returned when the design was changed to eliminate a recovery system for the fix chemicals was eliminated.

6. A $12,000 cost to install the monitoring (display) panel was eliminated.

7. Excavation and foundation rework costs of $12,000 are eliminated. (The decision to move the hyperfiltration unit inside the plant was made when, following excavation, it was discovered that the soil foundation would not support the recovery system).

8. The indirect cost reductions associated with the direct costs items are estimated.

9. $4,000 in construction overhead is deleted based on 6 1/2% of $58,000 in direct cost deletions.

10. Additional engineering costs totaling $15,000 above the bid price were deleted. These costs were incurred due to the project changes previously mentioned.

11. The $5,000 reduction in the contractor fee is due to the previously summarized reduction in direct and indirect cost.

The revised capital cost, Table 10, is $484,000. The cost for equipment, other than the hyperfiltration equipment, is $184,000 or 60% of the cost of the hyperfiltration equipment. This number is consistent with CPI estimates and with published installation costs from the vendor of the demonstration unit, hyperfiltration unit and other hyperfiltration vendors.
Table 10 will be used as the capital cost basis for the remainder of this report.

Annual Operating Expenses and Savings

The demonstration phase of the project is presently in progress. While capital costs are firmly established, data on annual operating expenses and savings are presently being accumulated with preliminary results available. In particular, reuse of chemicals will be further developed during the extension of this project to September 1983. The operating costs for maintenance and membrane replacement will also continue to be documented during this extended project period. At this writing, the hyperfiltration system operates automatically on a full-time basis. Daytime operation is frequently interrupted to carry out studies on membrane cleaning and other aspects of operation aimed at optimizing the recovery. Studies are also carried out on a longer term at other than standard operating conditions; this adversely affects the impact of recycle. Concentrate reuse techniques have been developed in the laboratory. Full-scale techniques are presently being developed. Concentrate reuse trials have been successfully run but none in sufficient quantities to significantly affect savings.

The demonstration period has been extended for 18 months during which additional data on savings and operating expenses will be collected. Annual expense and savings data presented here incorporate all data available to date. Where insufficient data exists to document a cost or savings, data to date are extrapolated to obtain an annual figure.

Operating Costs--

Table 11 summarizes the annual operating expenses for the demonstration. The cost categories set forth by the Environmental Protection Agency Standard Procedures for Cost Analysis are used.

There are no raw materials required for this operation. Direct labor has been provided under the demonstration grant through one part-time technician at the site. It is estimated that one-half time is devoted to unit operation and data collection. Another one-quarter time is devoted to unit maintenance. Additional recovery unit operation is done by dye range operators via the recovery unit control panel which is adjacent to their work station. No additional manpower was required for the recovery system operation.

Maintenance material costs are taken from a maintenance log book kept by the on-site technician. The majority of the maintenance labor is provided by the on-site technician. Based on experience to date, it is estimated that an additional $2,000 in direct labor is needed for maintenance. Sixteen percent
## TABLE 11.
### ANNUAL OPERATING EXPENSE FOR DEMONSTRATION

1. **Raw Materials**

2. **Processing Expenses**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating</td>
<td></td>
</tr>
<tr>
<td>Direct Labor</td>
<td>$8,000</td>
</tr>
<tr>
<td>Direct Supervision</td>
<td>2,000</td>
</tr>
<tr>
<td>Maintenance Labor</td>
<td>2,000</td>
</tr>
<tr>
<td>Maintenance Material</td>
<td>3,100</td>
</tr>
<tr>
<td>Operating Supplies</td>
<td>1,600</td>
</tr>
<tr>
<td>Steam</td>
<td>6,000</td>
</tr>
<tr>
<td>Electricity</td>
<td>15,000</td>
</tr>
<tr>
<td>Concentrate Treatment &amp; Disposal</td>
<td>20,000</td>
</tr>
<tr>
<td>Membrane Replacement</td>
<td></td>
</tr>
</tbody>
</table>

3. **Plant Overhead\(^1\)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Laboratory</td>
<td></td>
</tr>
<tr>
<td>Engineering</td>
<td></td>
</tr>
<tr>
<td>Plant Overhead at 88% of labor</td>
<td>$8,800</td>
</tr>
<tr>
<td>Other</td>
<td>66,500</td>
</tr>
</tbody>
</table>

4. **Fixed Charges**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insurance</td>
<td>2,500</td>
</tr>
<tr>
<td>Property Tax</td>
<td>2,500</td>
</tr>
<tr>
<td>Royalty</td>
<td>71,500</td>
</tr>
</tbody>
</table>

5. **General Expense**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Annual Operating Expenses</td>
<td>$71,500</td>
</tr>
</tbody>
</table>

6. **Annual Depreciation\(^1\)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Annual Operating Expenses</td>
<td>$119,900</td>
</tr>
</tbody>
</table>

\(^1\)Straight line 10 years
of the direct labor cost are labor additives. Electricity required to run the hyperfiltration system is metered. The primary user of electricity is the high pressure pump for the hyperfiltration system. Additional electrical power is used for small centrifugal pumps in the pipe and tank system and to the power control panels. Electricity consumption costs are based on the week ending 12/21/81 during which 4200 kilowatts of power were used. At 50 weeks/year and $0.028 per KWH, the annual cost is $5,880.

The concentrate disposal cost item is based on estimates for hauling for use on agricultural land. This number assumes that no concentrate is reused. Significant use of concentrate would lower the concentrate disposal cost.

Operation of the hyperfiltration system for more than one year and observation of the membrane replacement rate required during that period allowed the membrane system supplier to offer a $20,000 per year service contract for membrane replacement during the project extension.

Concentrate reuse techniques developed and tested to date for concentrate reuse indicate that reformulating the concentrate for subsequent dyeings involves no more labor than the standard color matching technique now employed for new and standard dyeing. Therefore, no additional laboratory expenses are included. Plant overhead is taken as 17% of direct costs. Insurance, property tax, and overhead costs figures are based on capital costs and reflect the current percentages.

Annual depreciation is calculated using a ten year, straightline method.

Savings—

Potential savings occur in three main areas: savings of dyes and chemicals occur through concentrate reuse; water and waste treatment costs are reduced when process water is returned to the dye range; and energy is saved when hot water from the dye range is recycled at full process temperature thus avoiding the need to heat plant water. Boiler feed chemicals are saved with energy savings because make-up water to the boiler is reduced. Table 12 presents a summary of annual savings.

Savings possible through reuse of dyes and chemicals is $130,000 a year. At present, the concentrate reuse program is just getting under way. Full scale trials have been run with three shades which make up about 20% of production (based on an analysis of production between October and December of 1981). Actual savings are calculated by comparing dye and auxiliary chemical formula sheets, with the derived formula sheets using HF concentrate. Chemicals costs are based on actual invoice cost for 1981. The
Table 12.

HYPERFILTRATION/DYE RANGE

ENERGY AND WATER USE SUMMARY
WEEK ENDING MIDNIGHT
12 / 21 / 81

ENERGY

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY REQUIRED</td>
<td>299 MILLION BTU</td>
</tr>
<tr>
<td>STEAM SUPPLIED TO WASHER</td>
<td>135 MILLION BTU</td>
</tr>
<tr>
<td>STEAM SUPPLIED TO HEAT EXCHANGER</td>
<td>37 MILLION BTU</td>
</tr>
<tr>
<td>SAVINGS (REQUIRED-SUPPLIED)</td>
<td>127 MILLION BTU</td>
</tr>
</tbody>
</table>

WATER

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER REQUIRED</td>
<td>432240 GALLONS</td>
</tr>
<tr>
<td>WATER SUPPLIED</td>
<td>278208 GALLONS</td>
</tr>
<tr>
<td>SAVINGS (REQUIRED-SUPPLIED)</td>
<td>154032 GALLONS</td>
</tr>
</tbody>
</table>

CHEMICALS
per meter savings is then applied to the projected product of the three shades in the year 1982. Trials to date have shown that approximately 30% of the concentrate derived from these dye lots will not be able to be reused because of scheduling and other production difficulties. When this is taken into account the savings for these three shades is $24,000 per year.

Energy savings are taken from the data from instruments provided to monitor flows and temperatures throughout the recovery system. Temperature and flow information from strip charts is examined and integrated on a weekly basis to determine the actual savings. The weekly energy saving varies widely at present, due to start-up and operation of the unit at off-standard conditions for experimental reasons. Table 13 is the computer output showing energy savings for the week ending December 21, 1981. This week represents a typical weekly energy saving at this time. Using the 1981 average energy cost for La France of $7.15 per million BTU's (as steam), and projecting 50 weeks per year operation, the annual savings in energy is 6300 M Joules. The potential energy savings from the dye range, based on range flow rates and average plant water temperature, is approximately 18,000 M Joules per year. As the demonstration continues the energy savings will more nearly approach the maximum of $125,000 per year. Because less steam is used, boiler feed chemical savings of $3,000 per year can also be approached.

Table 13 also presents the total water savings. The operating cost savings for water from the on-site treatment plant is 0.116/m³. The indicated water recycle results in a savings of $3,400 per year. The operating savings for the reduced flow to the water treatment is $0.12/m³ which results in an annual savings of $3,500. As the amount of use increases the two savings will approach $20,000/year.

It is assumed that all fixed charges are unaffected by the savings. There is no change in annual depreciation. Therefore, the total annual savings for demonstration, at present, is $90,000. This represents only 30% of the total projected savings possible through recovery. As the demonstration progresses, and concentrate reuse is more fully implemented, the savings will more nearly approach the potential of $275,000/yr.

Data Quality

The costs and savings data used in this report represent the present situation as closely as possible. Since actual invoices are used, capital cost information is correct. Because expenses were incurred in this demonstration project that would not normally exist in subsequent applications, a more representative capital cost is established in Table 10. Annual operating expenses were collected from plant records and operator logs. Operating techniques and procedures are still being developed so these expenses are subject to revision as more data is compiled during the extension of this project. Indirect costs are based on current plant procedures.
<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Labor</td>
<td>$24,000</td>
</tr>
<tr>
<td>Direct Supervision</td>
<td>0</td>
</tr>
<tr>
<td>Maintenance Labor</td>
<td>0</td>
</tr>
<tr>
<td>Maintenance Material</td>
<td>0</td>
</tr>
<tr>
<td>Dyes and Chemicals</td>
<td>0</td>
</tr>
<tr>
<td>Labor Additives</td>
<td>$1,000</td>
</tr>
<tr>
<td>Steam</td>
<td>45,400</td>
</tr>
<tr>
<td>Water</td>
<td>3,400</td>
</tr>
<tr>
<td>Effluent Treatment &amp; Disposal</td>
<td>3,500</td>
</tr>
<tr>
<td>Boiler Chemicals</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total Annual Operating Savings</strong></td>
<td>$77,000</td>
</tr>
</tbody>
</table>

2. Plant Overhead

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Laboratory</td>
<td>0</td>
</tr>
<tr>
<td>Engineering</td>
<td>0</td>
</tr>
<tr>
<td>Plant Overhead</td>
<td>13,000</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>13,000</td>
</tr>
</tbody>
</table>

3. Fixed Charges

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insurance</td>
<td>0</td>
</tr>
<tr>
<td>Property tax</td>
<td>0</td>
</tr>
<tr>
<td>Royalty</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0</td>
</tr>
</tbody>
</table>

4. General Expense

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Annual Operating Savings</td>
<td>$90,000</td>
</tr>
</tbody>
</table>

TABLE 13.
CURRENT ANNUAL SAVINGS DATA FOR DEMONSTRATION
Savings are estimated from operating logs and data from rip charts. As operating techniques develop further, on-stream factors will increase and savings will accrue at a faster rate.
Table 14.
Summary of Factors Affecting Costs and Savings for Textiles

**Costs - Equipment:** 250 m³/day

- **Basis:** $300,000 Hyperfiltration
- $184,000 Installation

1. Hyperfiltration system cost varies inversely with membrane flux.
2. Complexity of system external to hyperfiltration system affects cost.
3. In areas where water is in short supply or discharges are limited, recycle can enable plant expansion.
4. Reuse of hazardous material will reduce disposal costs.
5. The scale factors for the hyperfiltration system is nearly linear. Auxiliary system scale up factor may be taken as 0.6 - 0.7*

* A scale or capacity factor is used as follows:

\[
\text{New Cost} = \text{Old Cost} \times \frac{\text{Capacity of New}}{\text{Capacity of Old}}
\]

**Savings - Engineering:** $125,000/year

- 75,000 m³/yr at 55°C temperature difference

1. Hyperfiltration is not a good alternative to heat exchangers for heat recovery only.
2. Savings are proportional to the difference between process and tap water temperatures.

**Water:** $8,000

- 75,000 m³/yr @ $0.16/m³.

1. No significant problems encountered in reuse of 95% of water.
2. Savings vary with local water costs.

**Waste Treatment:** $9,200

- 75,000 m³/yr @ $0.12/m³.

1. Only treatment plant operation savings are available for existing direct dischargers. For indirect dischargers monthly user charges may be reduced.
2. New plant, direct dischargers, can save full BAT costs for recycle costs.
3. Existing direct dischargers save a proportional part of costs for equipment upgrading.
4. Indirect Dischargers may not save direct treatment charges.
5. Recycle of hazardous material can save disposal costs.

Material: $130,000
Reused of 2/3 of concentrate at $0.33/liter

2. Cannot be done at all plants
2. Has been done on limited production basis at La France.

FACTORS WHICH INFLUENCE COSTS AND SAVINGS

Economics of recovery depend on specific situations which vary widely from plant to plant. Table 13 summarizes the major factors which influence hyperfiltration costs and savings.

Hyperfiltration membrane costs vary inversely with membrane flux (volume productivity per unit area). Since flux values are specific for each process stream and depend on the characteristics of the process water being filtered, individual tests performed for each application are required to determine membrane flux. In this demonstration membrane flux is largely controlled by the concentration of a thickening agent used in the dye pad formula and the membrane fouling.

While membrane system costs are largely determined by membrane flux, a significant portion of the capital cost is represented by auxiliary equipment. The auxiliary system and installation represented 40% of the total capital cost of the demonstration. Each recovery application will have its own specific auxiliary system requirements and the complexity can vary widely from plant to plant. The dyeing operation is intermittent with significant down time between production lots. It was therefore desirable to incorporate large holding tanks and a complex control system to allow the hyperfiltration unit to operate in a steady fashion. In a more continuous operation the auxiliary system complexity can be reduced according to the economics and consequences of down time.

Recycle in areas where water is in short supply or plant discharges are restricted, may permit plant expansion. If discharge is limited because of hazardous materials, recycle of the hazardous material becomes particularly attractive. For instance, hyperfiltration is presently being used to filter contaminants from strong caustic solutions in a textile preparation process. This filtering allows the caustic to be reused in the process rather than discharged.

Energy savings are proportional to the difference between the process and the supply water temperatures. While for hot process effluents, the savings due to energy recovery are significant, hyperfiltration is not a good alternative to heat exchangers for heat recovery alone. Hyperfiltration is an economically attractive technology when water, waste treatment, and
Operating at 85°C with regenerative heat exchangers
95% Conversion to recycle

Figure 13. Energy Savings per Volume Processed versus Process Temperature for High Temperature Recovery of Hot Water.
Materials recovery are combined with energy recovery. Particularly since the cost of hyperfiltration is reduced by higher fluxes achieved at higher temperatures, hyperfiltration is ideally suited for recycle of hot water. Figure 12 shows the influence of process temperature on energy savings for a system operating similarly to the demonstration unit. It is assumed that regenerative heat exchangers are used to allow the hyperfiltration unit to operate at 85°C. It is also assumed that energy added to the concentrate is lost. Savings depend on the plant water temperature since this influences the increment of heating that would have to be added without recovery. The plant water temperatures shown represent extremes of summer and winter operation. Potential savings vary by a factor of five between 40°C process temperature and 85°C process temperature.

Savings through reduced water and waste treatment can vary widely depending on specific situations. For this demonstration water and waste treatment costs are minimal, therefore savings are minimal. Because the demonstration is a retrofit of recovery to an existing direct discharger, only treatment plant operational savings (excluding labor) are be counted. If treatment plant upgrading is necessary, then capital savings can be taken for the reduced upgrade cost. New plants who must construct new, best available technology (BAT) treatment facilities can credit the reduced treatment facility cost against the cost of the recovery system. Indirect dischargers may or may not save direct treatment cost. If fair-share costs are assessed against indirect dischargers for upgrade of municipal or regional treatment systems, then these charges are reduced by recovery.

Material recovery potential varies widely from process to process. To implement material recovery, a development program may have to be undertaken for new recovery applications. The economics of the development program depend on the value of the recovered material. While the potential value of the recovered chemicals at demonstration site is about $0.005/liter, the value for other applications (for instance textile size recovery, or caustic recovery) may approach $0.025/liter.

Since the hyperfiltration membrane system is modular in nature, capital cost varies nearly linear with system size. (See Table 13 footnotes). The installation and auxiliary system costs can be scaled up using a scale factor of 0.6 to 0.7. Since savings are directly proportional to flow rates, economics improve with larger systems.

MEASURES OF MERIT

Internal rate of return, payout time, and return on original investment are calculated in this section using standard techniques. Example calculations are given in Appendix F. For these calculations an income tax of 46% is assumed. While more rapid depreciation techniques are available, a ten-year straight line depreciation method is used.

Figure 14 shows the variation for the three measures of merit with savings for the demonstration system. Potential annual savings total
Figure 14. Payout Time (POT), Internal Rate of Return (IRR), and Return on Original Investment (ROI) versus Savings for the LaFrance Recovery System.
approximately $275,000 which would represent a payout time between 3 and 4 years, a return on original investment of 15-20%, and an internal rate of return on 20-30%. Presently the system is operating at approximately the break even point.

Figure 15 shows the effect of changes in flux on the overall measures of merit for the recovery system. The savings were assumed constant and the effects of capital cost changes on the measures of merit are given.
Figure 15. Effect of Flux on Measures of Merit for the LaFrance Recovery System.
REFERENCES


