EPA-600/2-77-241
December 1977

Environmental Protection Technology Series

CLOSED PROCESS WATER LOOP IN NSSC CORRUGATING MEDIUM MANUFACTURE

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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CLOSED PROCESS WATER LOOP
IN NSSC CORRUGATING MEDIUM MANUFACTURE

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require the new and increasingly more efficient pollution control methods be used. The Industrial Research Laboratory - Cincinnati (IERL-CI) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report describes means and methods employed to develop a nearly closed system for wastewaters produced from the manufacture of neutral sulfite semi-chemical corrugating medium, a significant portion of the effort concerning in-plant recycling and control. This program has been supplemented by the first full-scale commercial reverse osmosis system operating in the pulp and paper industry. The reverse osmosis facility is employed to process those accidental losses not controlled by the in-plant recycling system. The combination of tight in-plant control and reverse osmosis processing has permitted the industry to satisfy discharge permit requirements without the use of any external treatment for wastewaters. The information will be of value to other segments of the industry, consultants and reverse osmosis equipment suppliers. For further information please contact the Food and Wood Products Branch of the Industrial Environmental Research Laboratory, Cincinnati.

David G. Stephan
Director
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ABSTRACT

From 1972 to 1976, the Green Bay Packaging corrugating mill was redesigned to reuse enough water to nearly close the process water system. Less water enters the system during the cooking of chips and repulping of secondary fiber than leaves the system with the sheet to the paper machine dryers. Many small, dilute water streams, therefore, can be brought into the system without upsetting the water balance.

When extraneous water inputs do upset the system balance, the condition is correctable by removing water, using either thermal evaporation or reverse osmosis. The reverse osmosis plant design operating performance and economics are described. Although many reverse osmosis operating problems have been solved, flux rates are somewhat lower than had been predicted. Other system additions and revisions for process water entrapment, recycling, and surge protection are described.

A monitoring system is in use for early spill detection and problem correction. Included in key areas is standby equipment for use to correct failures quickly.

Levels of BOD loss have been reduced from the 9072 kg per day range (20,000 lb/day) of 1971 to less than 454 kg per day (1000 lb/day) as a monthly average for 1975. The daily maximum of 1814 kg (4000 lb) had not been exceeded in any mill-operating day during 1975.

This report was submitted in fulfillment of Grant Number S-800520 under (partial) sponsorship of the Office of Research and Development, U.S. Environmental Protection Agency. This report covers the period from July 19, 1972, through February 2, 1976. Progress will be reported annually for an additional five-year period.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

BOD_5	-- five-day biochemical oxygen demand
Btu	-- British thermal unit
E.D.T.A. Na_4	-- sodium salt of ethylenediaminetetra acetic acid
gfd	-- flux units--gallons per ft^2-day
gpm	-- gallons per minute
Hp	-- horsepower, electrical
MGD	-- million gallons per day
NSSC	-- Neutral Sulfite SemiChemical
pH	-- hydrogen ion concentration, logarithmic form
psi	-- measure of pressure--pounds per square inch
#	-- pounds, mass

SYMBOLS

HCl	-- hydrochloric acid
Mg	-- magnesium
Na_2CO_3	-- sodium carbonate
Na_2SO_4	-- sodium sulfate

ACKNOWLEDGMENTS

This project was performed under the direction of Mr. Ralph H. Scott, Chief, Wood Products Staff, U. S. Environmental Protection Agency, federal Project Officer. Project Director for Green Bay Packaging was Mr. William R. Nelson; Project Manager was Mr. Gerald O. Walraven. Other Green Bay Packaging personnel participating in the project were Messrs. David C. Morris (now with Weyerhaeuser Co.), Scott Brown (now with Simons-Eastern Co.), and Peter E. DeRossi, Chemical Engineers; Messrs. Orv Rautmann and Dave Meverden, Chemists; Mr. Richard Wisneski, Engineering Technician; Mr. Frank Piechota, Process Technician; and Mrs. Kathy Pitts, Secretary.

The close cooperation and assistance of Universal Oil Products, Fluid Systems Division (previously Fluid Sciences Division), is gratefully acknowledged. Key personnel were Messrs. Kenneth E. Anderson, Richard A. Walker, Richard B. Hartupee, and Dr. Jay Sobel of Corporate Research.

The long-standing and excellent support of the staff of the Institute of Paper Chemistry is also acknowledged.

The privilege to present project interim reports through both the Technical Association of the Pulp and Paper Industry and American Institute of Chemical Engineers, Environmental Division, is gratefully acknowledged.

SECTION 1

INTRODUCTION

Green Bay Packaging Inc. operates a pulp and paperboard mill adjacent to the Fox River in Green Bay, Wisconsin. The mill produces approximately 270 metric tons per day of corrugating medium from a combination of virgin mixed hardwood, neutral sulfite semichemical (NSSC) pulp, and recycled corrugated box plant waste fiber.

The organic products of reaction (pulping liquors) from the sodium NSSC pulping operations are separated at their highest concentration from the virgin pulp fibers produced. The strong pulping liquors are screened to minimize the loss of usable fiber, inventoried, and eventually burned in a Dorr-Oliver fluid bed combustion plant to destroy the organics and produce a marketable inorganic ash. The residual (approximately 25%) pulping liquor organics remaining with the pulp fibers subsequently leach into the process water, which conveys the fibers through the conventional fiber processing and papermaking process.

The corrugated box plant wastes are returned to the paperboard mill process for reuse by repulping in excess paper machine process water at elevated temperature. Residual soluble materials become redissolved in the process water as the waste fibers are separated and resuspended. The resulting recycled fiber is eventually combined with the NSSC pulp fiber and passed through the normal processing stages, finally being made into corrugating medium at the paper machine.

Earlier construction and operation of the fluid bed combustion plant had satisfactorily solved the strong NSSC pulping liquor waste problem. It has been necessary to address the problem of residual pollutional losses as they appear in both variable and constant excess process water losses containing low concentrations of solubles from both the virgin NSSC and the recycled pulping and papermaking operations.

The efforts of the company to further reduce the pollutional effect of the mill discharge to the Fox River have been directed primarily at identifying, in both quality and quantity parameters, the many uses of the process water system and to identify methods of collection and control, reuse, or treatment to prevent the losses of such excess process waters to the river.

Encouraging progress had been made in the reuse of excess process waters at the Green Bay mill concurrent with a pilot plant evaluation project on the reverse osmosis process for concentrating such excess process waters under a Demonstration Grant from the Office of Research and Monitoring of the U. S. Environmental Protection Agency. The information generated at that time has been reported in Water Pollution Control Research Series 12040 FUB, published by the U. S. Environmental Protection Agency in January, 1972. The results achieved during that time are the basis for the project here reported.

In June, 1972, a Research, Development, and Demonstration Grant offer was made to Green Bay Packaging Inc. in support of a mill scale, multifaceted effort to demonstrate a "Closed Process Water Loop in NSSC Corrugating Medium Manufacture." The project objective was to accomplish the maximum closure of water use loop in an integrated pulp and paperboard mill by recycling contaminated process waters for direct reuse; by providing a protective collection and surge system for such excess surge volumes as might occur during both normal operations and process upset conditions; by providing a continuous system of loss monitoring capability to support operator decisions; and by providing a reverse osmosis plant of appropriate capacity to separate pollutional constituents from such excess volumes as might occur, prior to their discharge from the mill, while recycling permeate so produced to the maximum practical extent.

A secondary objective of the project was to demonstrate the results of paperboard making operations under such high water reuse conditions and to report useful techniques of operating. The project was visualized as a one-year operation under maximum closure conditions to fully demonstrate the effects on production efficiency, maintenance, product quality, and mill pollutional control. A further objective of the project was to report the operating performance of the reverse osmosis facility over one year of continuous operation, together with capital and operating costs of the reverse osmosis facility.

Although the project completion was anticipated in 32 months, actual completion has required 48 months due to time consuming problem analysis and correction in certain areas. In general, the time extensions were required to allow for experience in proprietary reverse osmosis equipment corrections, which in turn allowed for a more comprehensive evaluation of the overall system performance. The application of membrane technology in this instance is a direct substitution for conventional thermal evaporation procedures. In addition, the project objectives present an opportunity to evaluate membrane separation performance, as well as a cost competitive technology, in comparison with water removal operations of another form.

SECTION 2

CONCLUSIONS

Intensive recycling to minimize system losses has proven to be the simplest and best course for our mill. For three years, the program to entrap, contain, and reuse water has proven successful, as demonstrated by continued low losses while maintaining production of a quality corrugating medium. This approach can apply generally, but even a simple change in equipment--batch to continuous digesters, screw presses to washers--may change the water balance to preclude complete recycling, through either cost or physical impracticability.

All constituents of a closed process water system tend to increase in concentration to a new equilibrium, depending on system conditions. Calcium can reach a concentration where objectionable scale will form in the process water or liquor systems. Sodium chloride, at increased concentrations, can accelerate corrosion to the point where replacement materials of construction are required, or it may interfere with a liquor burning operation. The modifications necessary for recycling will necessarily be highly dependent on the existing plant and process configuration. An option of excess contaminated process water collection, containment, and reuse open to one plant may not be a valid option for another.

A small commercial reverse osmosis plant has been able, on demand, to maintain the reuse system volume within the limitations of the available surge storage. Although most reverse osmosis operating problems have been solved, flux rates are somewhat lower than had been predicted. The actual operating flux was 3.02 liters per square meter-hr (5.13 gal/ft^2-day) compared to the predicted flux of 3.94 liters per square meter-hr (6.68 gal/ft^2-day).

The life expectancy of the reverse osmosis module hardware has been greatly improved through the efforts of our supplier. The project objective to identify module and membrane life expectancy has not yet been realized. The substitution of reverse osmosis for conventional steam evaporation has been successfully demonstrated.

The low energy need for water removal from the process water system has been offset by a higher capital cost for equipment.

The relative economics prevailing at a given plant site will determine whether membrane separation can offer advantages over thermal evaporation.

The large number of process modules necessary to build reverse osmosis capacity presents serious problems to the application of membrane technology to high volume, continuous duty applications. The experience of this project suggests continued efforts be directed towards improving reliability of reverse osmosis support structures and their associated equipment.

The issue of trace contamination in tightly closed mill water reuse systems deserves further attention. Relatively rapid changes in unexplained membrane fouling and the forms of fouling experienced suggest that transient contaminants can seriously affect the overall performance (and costs) of a reverse osmosis operation processing internal plant reuse waters.

The project experience demonstrates the ability to recycle process waters in the Green Bay Packaging mill without serious detrimental effects on production or product quality. Changes in raw materials, such as a high calcium water supply or inputs of higher amounts of sodium chloride in cooking chemicals, will create new equilibrium conditions in a closed system. This conclusion only applies to the solubles present in this water reuse system. Application to another system must be predicated on pilot experience on the reuse stream existing in that system. Therefore, it should not be presumed that our experience is directly applicable to all unbleached board mills or even those producing the same grade of NSSC corrugating medium because of the vast differences in the raw materials used and the construction and age of many of these facilities.

SECTION 3

RECOMMENDATIONS

To become more economically attractive, vendors of reverse osmosis equipment should produce membranes both capable of higher flux rates and functional over wider ranges of pH and temperature. These advances in membrane technology would lead to reduced capital costs for equipment and lower plant operating costs, hopefully to a point where much broader application will be realized. Also, even though much progress has been made in membrane support structures, there is still a need to improve reliability and increase module life by improving the chemical resistance of the materials presently used. Module maintenance and replacement costs, although not yet available from our project data, will represent a large part of overall operating costs.

The causes and mechanisms of membrane fouling are not well understood. Additional efforts are needed to develop more understanding of fouling and methods of prevention and effective, rapid cleaning.

Development of better, higher volume high pressure pumps is needed for all applications, particularly for feed streams which act chemically to deteriorate existing industrial materials of pump construction.

When planning new installations or expanding old ones, more consideration should be given to higher consistency pulp processing methods. The costs and advantages of maintaining a balanced water system with internal disposal of pollutants should be weighed against existing conventional systems, typically utilizing end-of-the-line treatment systems.

The corrosion problems associated with tightly closed water reuse systems, inherently more severe because of increased temperatures and electromotive activity, should be addressed by basic equipment manufacturers and process design engineers. Improved chemical resistance of all materials exposed to recycled process water is a necessary objective to improve system reliability and to reduce maintenance and operating costs.

SECTION 4

MATERIALS AND METHODS

PROCESS DESCRIPTION

The mill produces 272 metric tons (300 short tons) per day of corrugating medium from NSSC pulp with mixed hardwoods and from recycled box plant clippings. Figure 1 shows the mill process. Four rotary digesters produce about 181 metric tons (200 short tons) per day of pulp using a vapor phase cook. Paper machine process water is added to the chips during the blow-down period to aid in the recovery of spent liquor. Partially pulped chips leave the screw presses at about 55% solids. Paper machine process water is used for washing in the presses. This process water is also used to dilute the pressed chips to 26% consistency for primary refining. Secondary fiber, slurried in process water, is added to the pulp prior to finish refining. Further dilution to headbox consistencies with paper machine process water precedes both a coarse cleaner and a two-stage final centrifugal cleaning system before the paper machine.

Figure 2 shows a more detailed layout of the process streams in the pulp mill, as well as those going to the fluidized bed reactor liquor system. In the pulp mill, liquor is separated from the cooked chips by two screw presses, combined with digester wash and blow liquor, and screened to reclaim usable fiber.

The screened liquor, containing about 18% dissolved solids and 8.4 grams per liter (70 lb/1000 gal) of very fine suspended solids, is stored in a 227.1-cubic meter (60,000-gal) insulated tank before going to the evaporators. The smaller portion is fed to the Aqua-Chem spray-film evaporators and concentrated to about 25% solids. The evaporated liquor can be stored in either of two large insulated tanks. The smaller of the two is the normal process storage and can hold a maximum of 557.7 cubic meters (150,000 gal). The other tank is used for long-term storage for reactor shutdowns and can store up to 946.2 additional cubic meters (250,000 gal). The combined liquor storage will allow for a reactor shutdown of as long as ten days. The normal turnaround time for reactor shutdown, cleanout, and repairs is about five days.

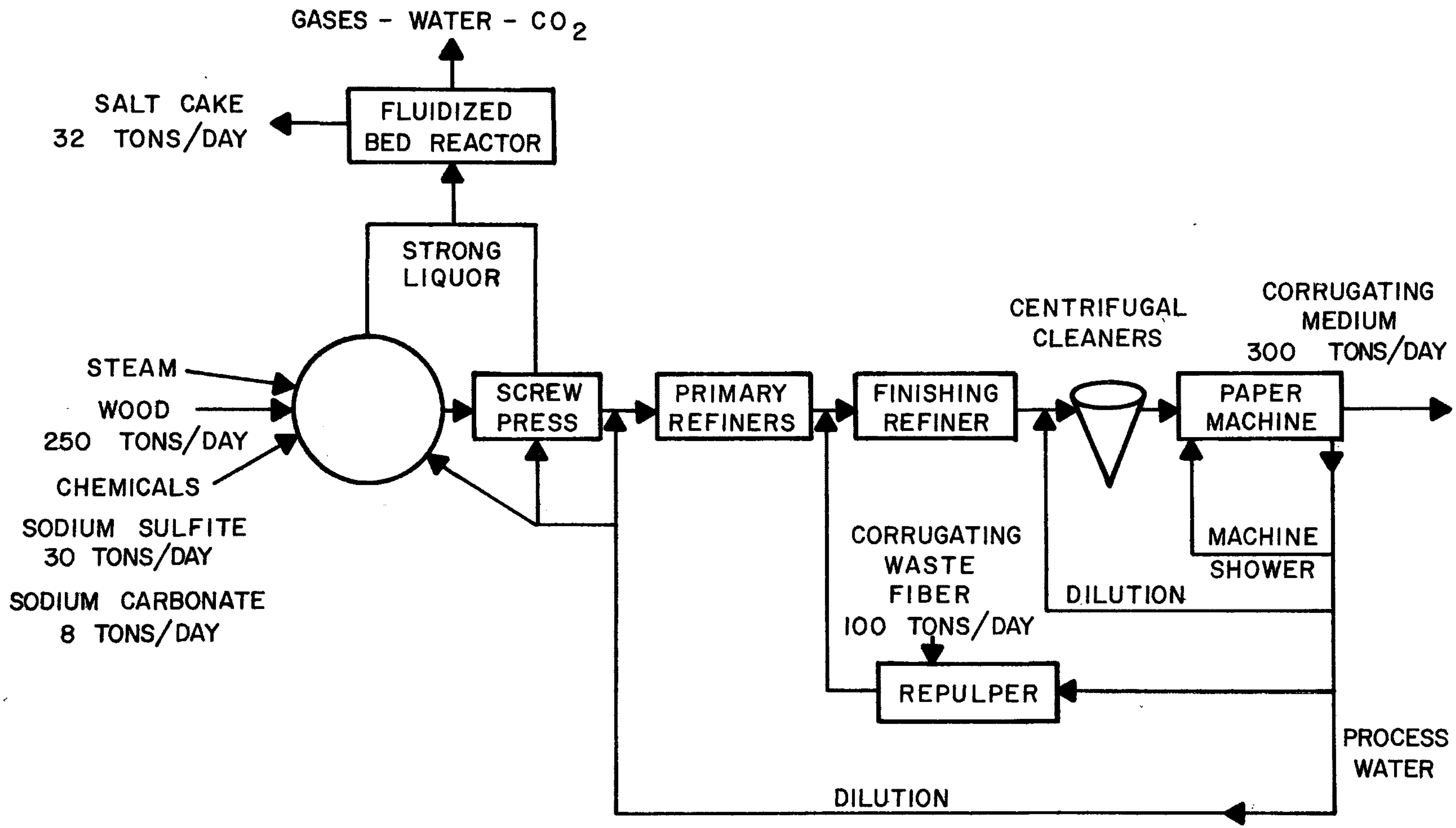

Figure 1. Mill process.

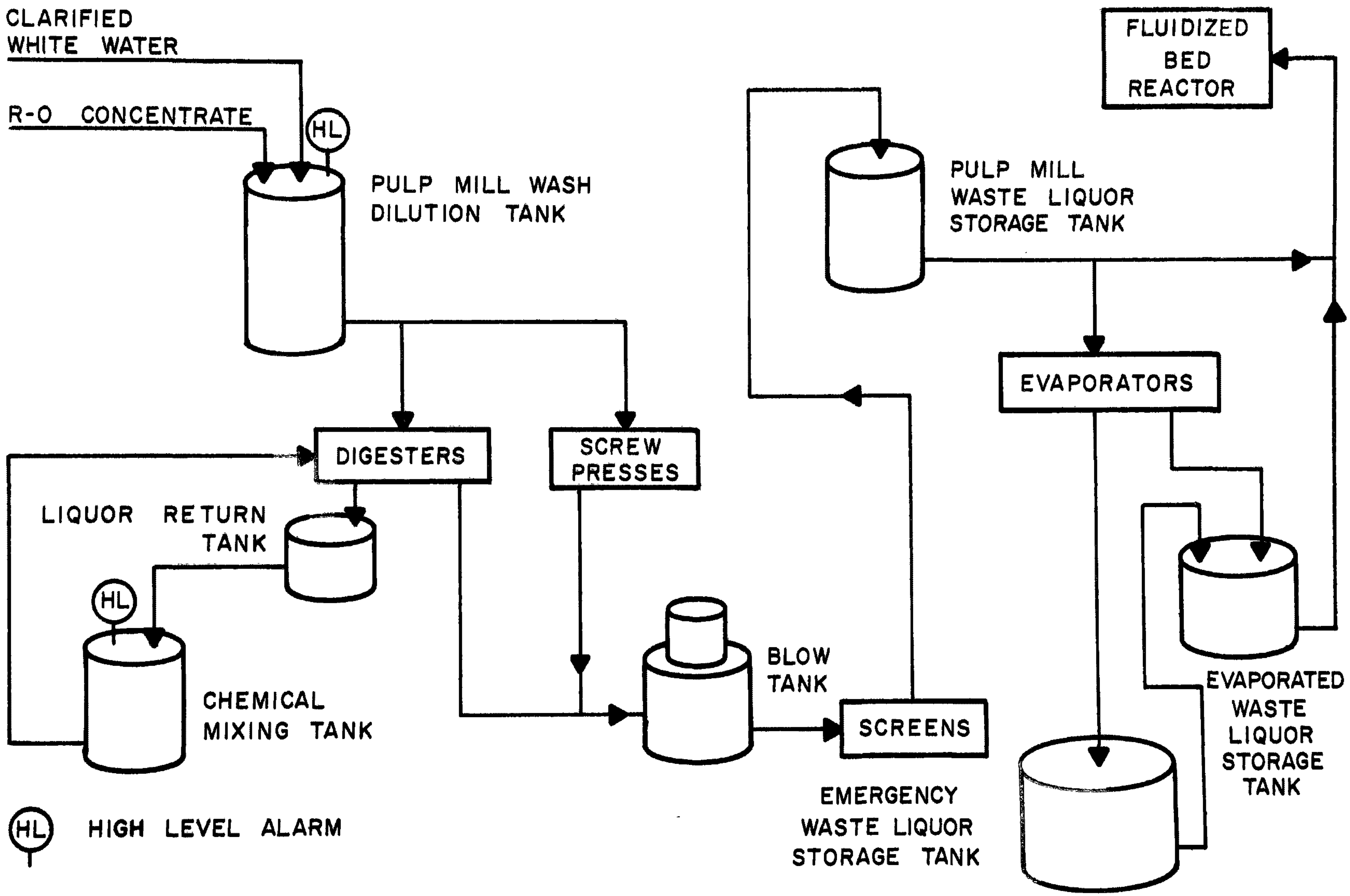

Figure 2. Pulp mill--combustion plant liquor flow.

Pulp mill liquor is combined with the 25% liquor, and the mixture is fed to the Venturi scrubber/evaporator and concentrated to 43% by the reactor hot gas stream. A portion of the 43% liquor is fed to the reactor as fuel. The ratio of 18% and 25% liquor is adjusted for solids and water inventory control in the reactor Venturi loop. Additional information on the Dorr-Oliver Fluidized Bed Reactor system can be found in the August 17, 1970, issue of Paper Trade Journal.(1)

PROCESS WATER SYSTEM CLOSURE

Much progress has been made since 1971 in reducing BOD discharge from the mill by a series of steps leading to an essentially closed process water reuse system (Figure 3). Levels have been reduced from the 44,091 kilograms per day (20,000 lb/day) range in early 1971 to less than 2200 kilograms per day (1000 lb/day)--monthly average--for 1976. The total mill BOD generated approximates 99,000 kilograms per day (45,000 lb/day). Note also the progress in reducing daily maxima so that 8800 kilograms per day (4000 lb/day) has not been exceeded in any mill operating day in the last year.

Figures 4 and 5 are averages of the discharge streams from the operating segment of the mill for 1971 and 1975, respectively. Keys for the losses for each stream are in Tables 1 and 2. A major step had already been accomplished by the spring of 1971, with process water successfully replacing fresh water on most of the paper machine showers. Table 1 indicates the magnitude of the losses that still existed in 1971 after the shower conversion. That year, the evolution of a closed process water system started in earnest with the preparation of an inventory of discharge streams according to priorities. The improvements obtained from 1971 to 1975 are observed by comparing the differences in each outfall and the total mill discharge in Table 2 with those of Table 1.

Figure 6, the paper machine basement trench system diagram in 1971, is an example of the type of inventory for losses which proved extremely useful in conquering the problems that existed at a given outfall. The steps taken to eliminate losses and revise the paper machine system are indicated in Tables 3, 4, and 5. When completely revised, the paper machine water collection system appeared as is shown in Figure 7.

The highest priority was assigned to those contributions whose elimination was necessary to reach 1973 permit limits. These included pit and tank overflows and gutter or floor drain flows that could be recycled by the addition of more pumps and tankage. Uncontaminated cooling water was repiped to bypass the recycle loop (see Table 5, Inventory of Dilution Streams). Additional screened process water washup hoses were added at the paper machine so that city water is used only at the final step

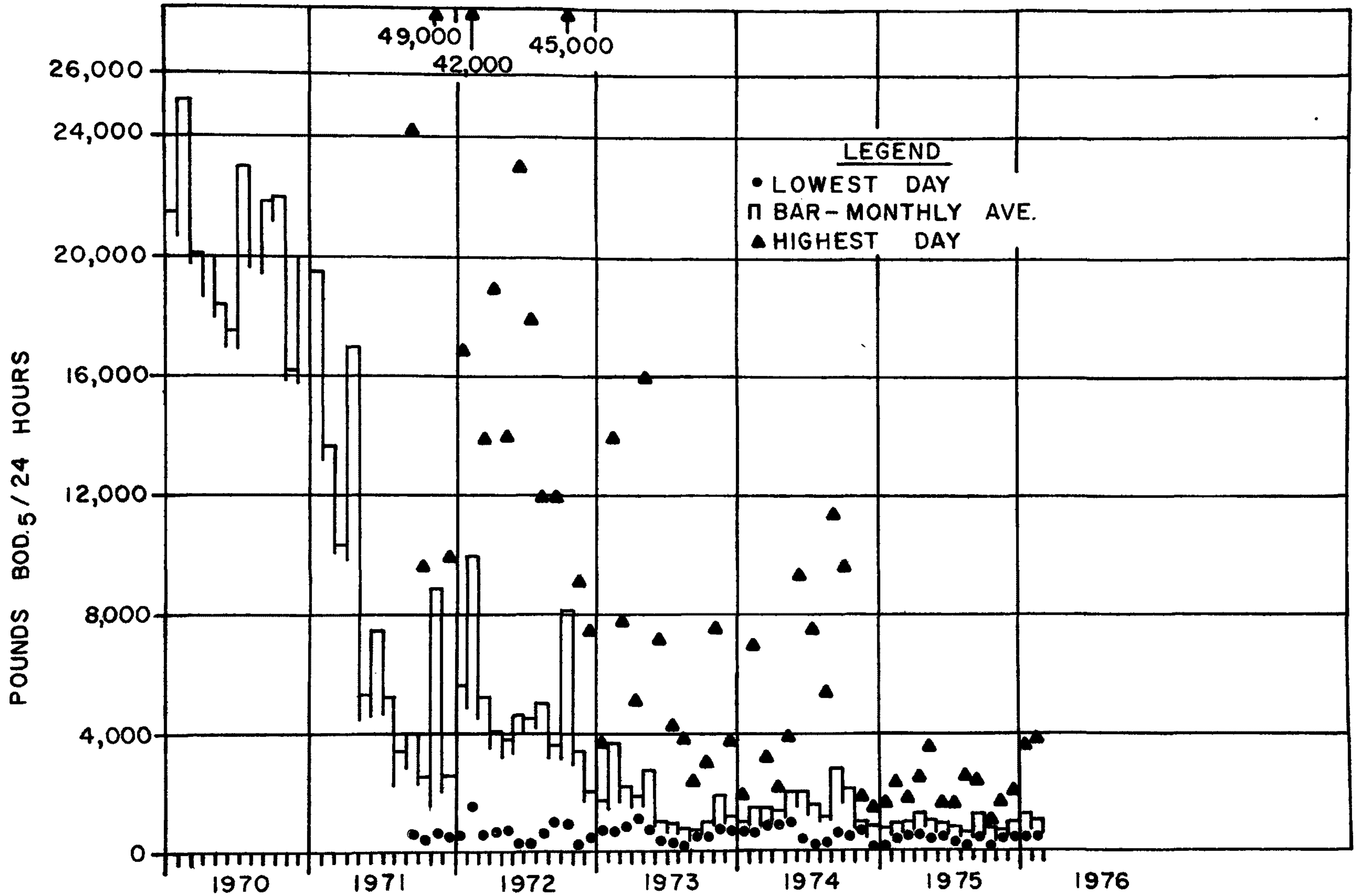

Figure 3. Historical mill discharge performance.

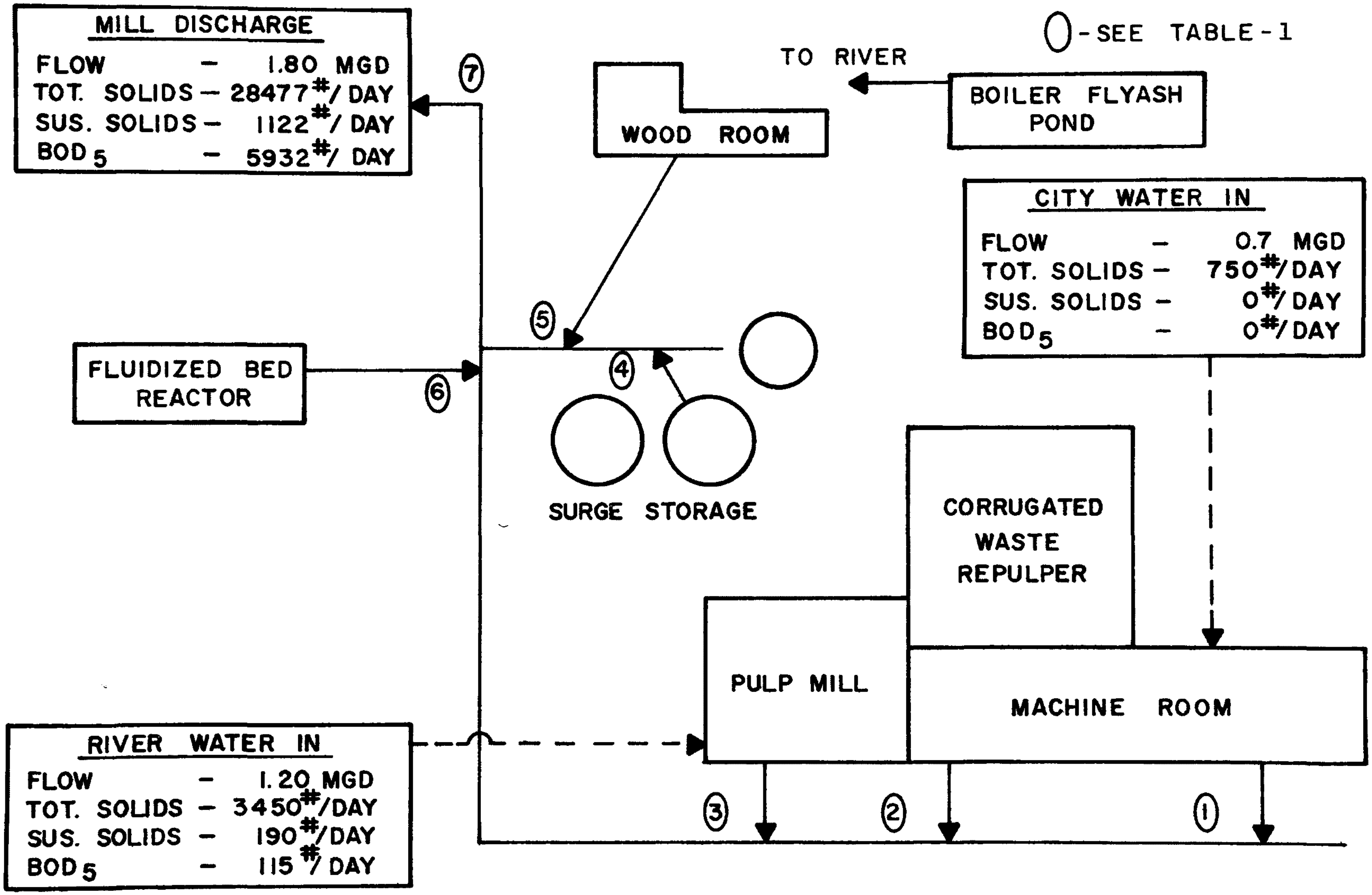

Figure 4. Mill discharge stream--1971.

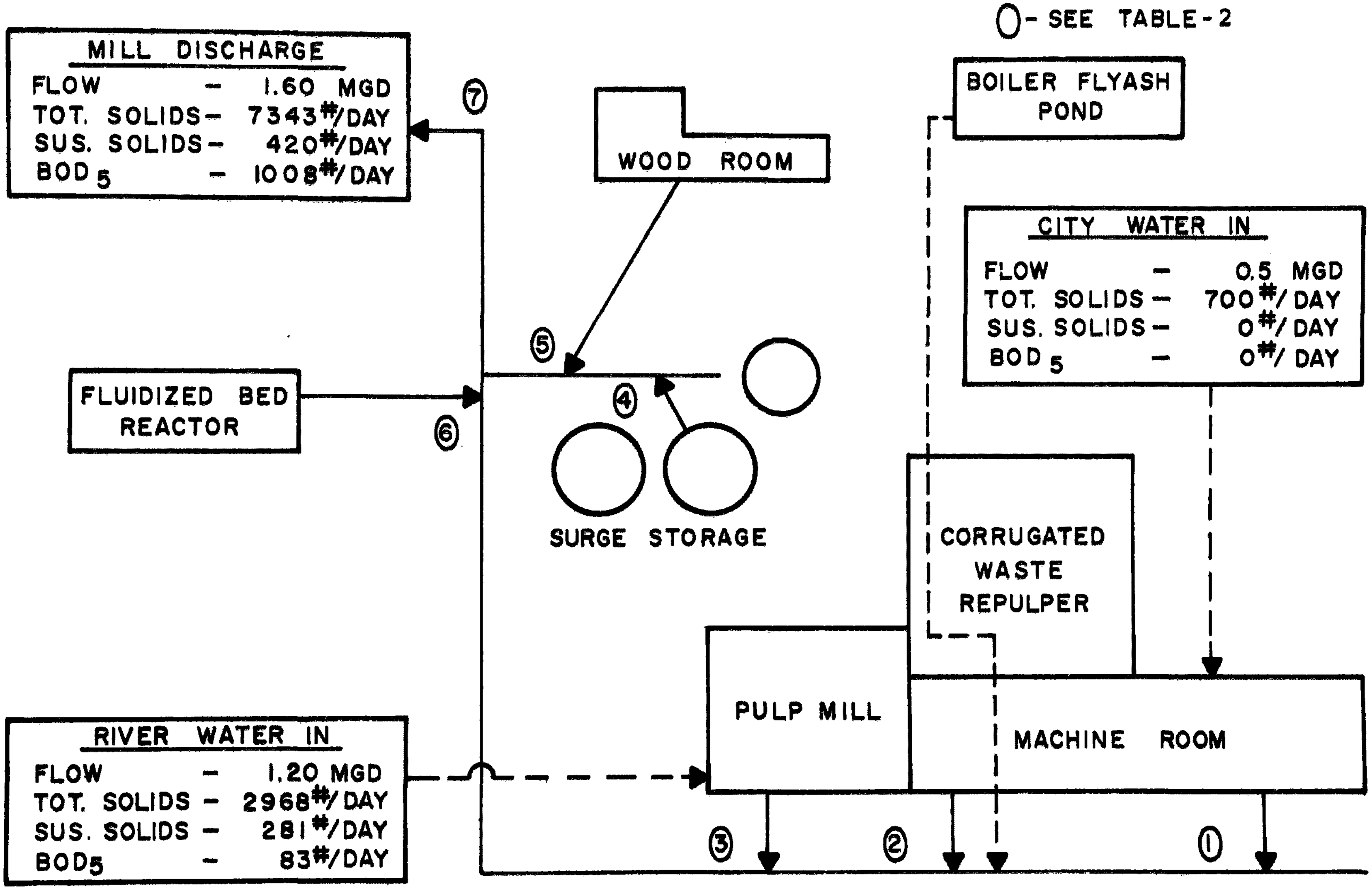

Figure 5. Mill discharge stream--1975.

TABLE 1. MILL DISCHARGE STREAMS--1971
(Key for Figure 4)

Stream	Flow (MGD)	Total solids (#/day)	Total suspended solids (#/day)	BOD5 (#/day)
1. East machine room	1.070	11,887	377	2,350
2. West machine room	0.029	2,100	137	490
3. Pulp mill	0.287	2,100	184	327
4. Tanks	0.047	9,929	329	2,400
5. Wood room	0.040	393	45	0
6. Fluidized bed reactor	0.327	2,031	50	365
7. Total mill discharge	1.800	28,477	1,122	5,932

TABLE 2. MILL DISCHARGE STREAMS--1975
(Key for Figure 5)

Stream	Flow (MGD)	Total solids (#/day)	Total suspended solids (#/day)	BOD5 (#/day)
1. East machine room	1.140	5,637	125	832
2. West machine room	(Discontinued)			
3. Pulp mill	0.250	610	281	19
4. Tanks	0.001	430	14	107
5. Wood room	0.040	108	0	0
6. Fluidized bed reactor	0.170	558	0	50
7. Total mill discharge	1.600	7,343	420	1,008

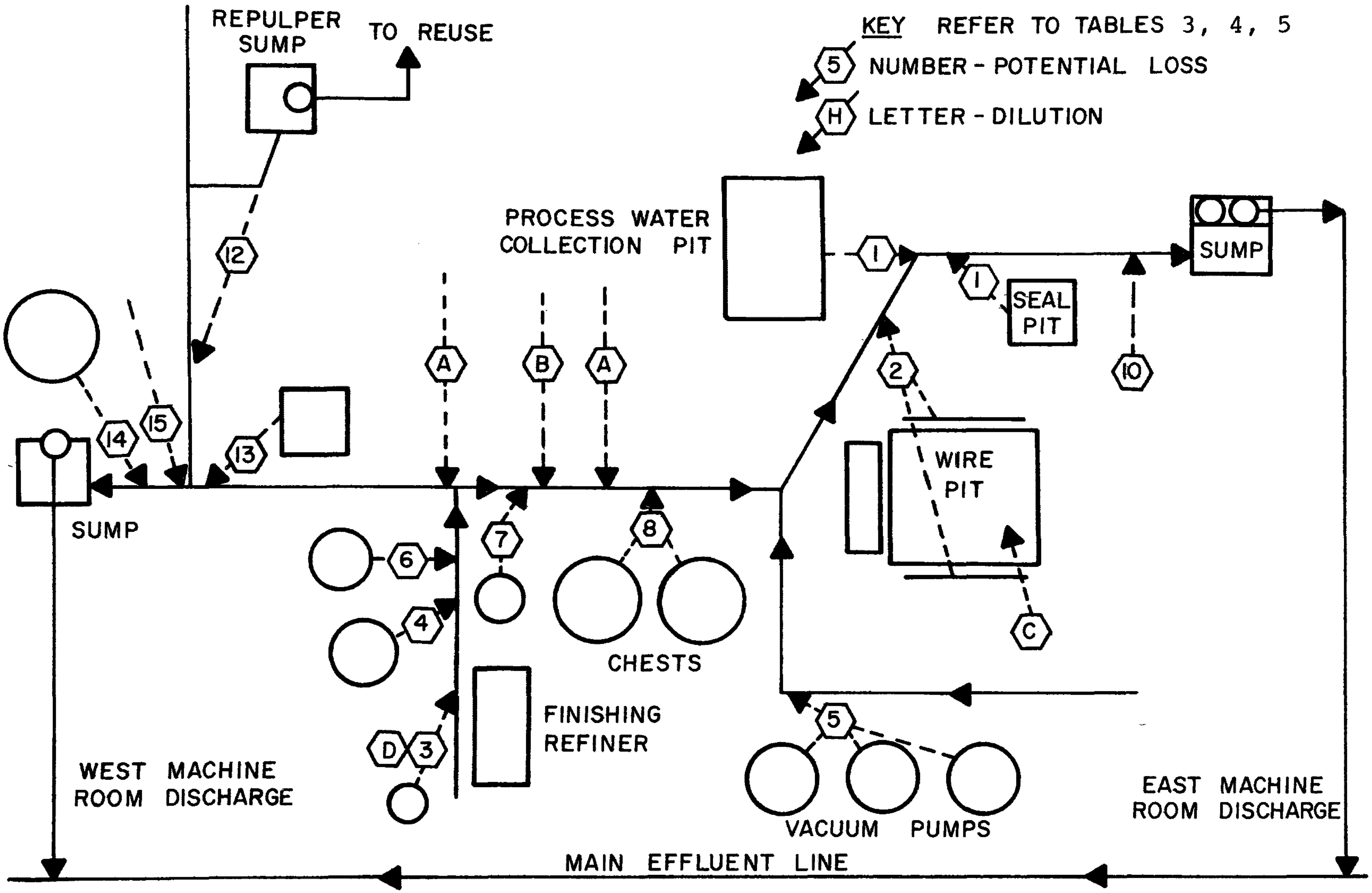

Figure 6. Paper machine floor collection system--1971.

TABLE 3. INVENTORY OF POTENTIAL PROBLEMS AS OF 1971 AND DISPOSITION AS OF 1975--EAST MACHINE ROOM DISCHARGE (In Order of Priority)

(Code for Machine Room Discharges, See Figures 6 and 7)

1971 - Problem	1975 - Status
Number 1 Priority: Urgent--elimination necessary to meet 1973 limits	
1) Seal pit and paper machine process water collection pit overflow; shutdown and startup surges or pump failure Amount: 3000 gal Frequency: once/day	Combined pits; installed larger pumps; installed spare pump; installed high level alarm
2) Losses from paper machine gutters and floor drains from normal seepage and washup Amount: 2-5 gal/min	All losses directed to process water pit by new piping
3) Periodic entrainment of process water in Centri-Cleaner vacuum pump seal water Amount: 5 gal/min Frequency: 30 min/wk	Installed conductivity alarm and manual vacuum breaker; modified vacuum pump seal water system
Number 2 Priority: Needed to ensure stable operation and better closure	
None in this category	
Number 3 Priority: May be postponed until after 1973--more information is required	
4) Overflow of Centri-Cleaner reject tank; shutdowns and failure of pump Amount: 50 gal Frequency: each shutdown, 2-3 times/wk	Discharges to enclosed sewer and is recycled with sump pump
5) Couch and wet press vacuum pump carryover Amount: 3-5 gal process water/min	Unresolved
6) Trap dumping Magna Cleaner finishing refiner Amount: 20 gal process water Frequency: once each 8 hr	Now dumps to closed sewer and is recycled by sump pump
7) Trap dumping Magna Cleaner secondary Centri-Cleaner system Amount: 20 gal process water Frequency: once each hr	Now dumps to closed sewer and is recycled by sump pump
8) Overflow from overfilling paper machine stock storage chests Amount: 600-1000 gal process water and fiber Frequency: once/mo	Now is in closed sewer area; stock is manually washed back to sump pump for recycle
Number 4 Priority: Insignificant or poorly defined	
9) Paper machine area pumps and side agitator seal leaks Amount: small but continuous	Most leaks are located in area of enclosed sewer and are recycled with sump pump
10) Seepage from area under paper machine wet presses Amount: small but continuous, some fiber loss	Unresolved

TABLE 4. INVENTORY OF POTENTIAL PROBLEMS AS OF 1971 AND DISPOSITION AS OF 1975--WEST MACHINE ROOM DISCHARGE (In Order of Priority)

(Code for Machine Room Discharges, See Figures 6 and 7)

1971 - Problem	1975 - Status
West sump pump is not used presently.	
Number 1 Priority: Urgent--elimination necessary to meet 1973 limits	
12) Kraft clippings repulper sump pump failure; mechanical or plugged with large junk Amount: 5000 gal Frequency: once/two mo	Installed bar screen for large junk; can now be diverted to process water pit for complete pump failure
13) Losses of process water and fiber from pilot DSM screen for reverse osmosis pilot work; coarse fraction only Amount: 5 gal/min	Eliminated at end of pilot work
14) DSM screen supply tank overflow Amount: 2000-3000 gal Frequency: twice/mo	Installed interlock system high level; installed larger pump to DSM screen; added one screen section to DSM screen
Number 2 Priority: Needed to ensure stable operation and better closure	
None in this category	
Number 3 Priority: May be postponed until after 1973--more information is required	
None in this category	
Number 4 Priority: Insignificant or poorly defined	
15) DSM supply tank area; pumps and agitator seal leaks Amount: small but continuous	Added new sewer trench to discharge to recycle system

TABLE 5. INVENTORY OF POTENTIAL PROBLEMS AS OF 1971 AND DISPOSITION AS OF 1975

Inventory of Dilution Streams Entering Process

East Machine Room

(Code for East Machine Room Dilution Streams)
(See Figures 6 and 7)

1971 - Problem	1975 - Status
A) Air conditioner cooling water, three units Amount: 25 gal/min	Piped out of closed system
B) Oil coolers and air compressor cooling water Amount: 17 gal/min	Piped out of closed system
C) Washup hoses, used on paper breaks Amount: 1000 gal/day	Two hoses connected to clarified process water; city water hose used only for final washing Amount: 300 gal/day
D) Centri-Cleaner vacuum pump seal water Amount: 9 gal/min	Piped out of closed system but alarmed for process water entrainment; see Item 3--East Machine Room Discharge

West Machine Room

None in this category

Pulp Mill

(Code for Pulp Mill Dilution Streams, See Figures 8 and 9)

1971 - Problem	1975 - Status
A) Oil coolers Amount: 10 gal/min	Rerouted directly to main effluent line
B) Digester blow line sample condenser Amount: 8 gal/min	Rerouted directly to main effluent line
C) Pulp mill testing station sinks Amount: 2 gal/min	Rerouted to sanitary sewer

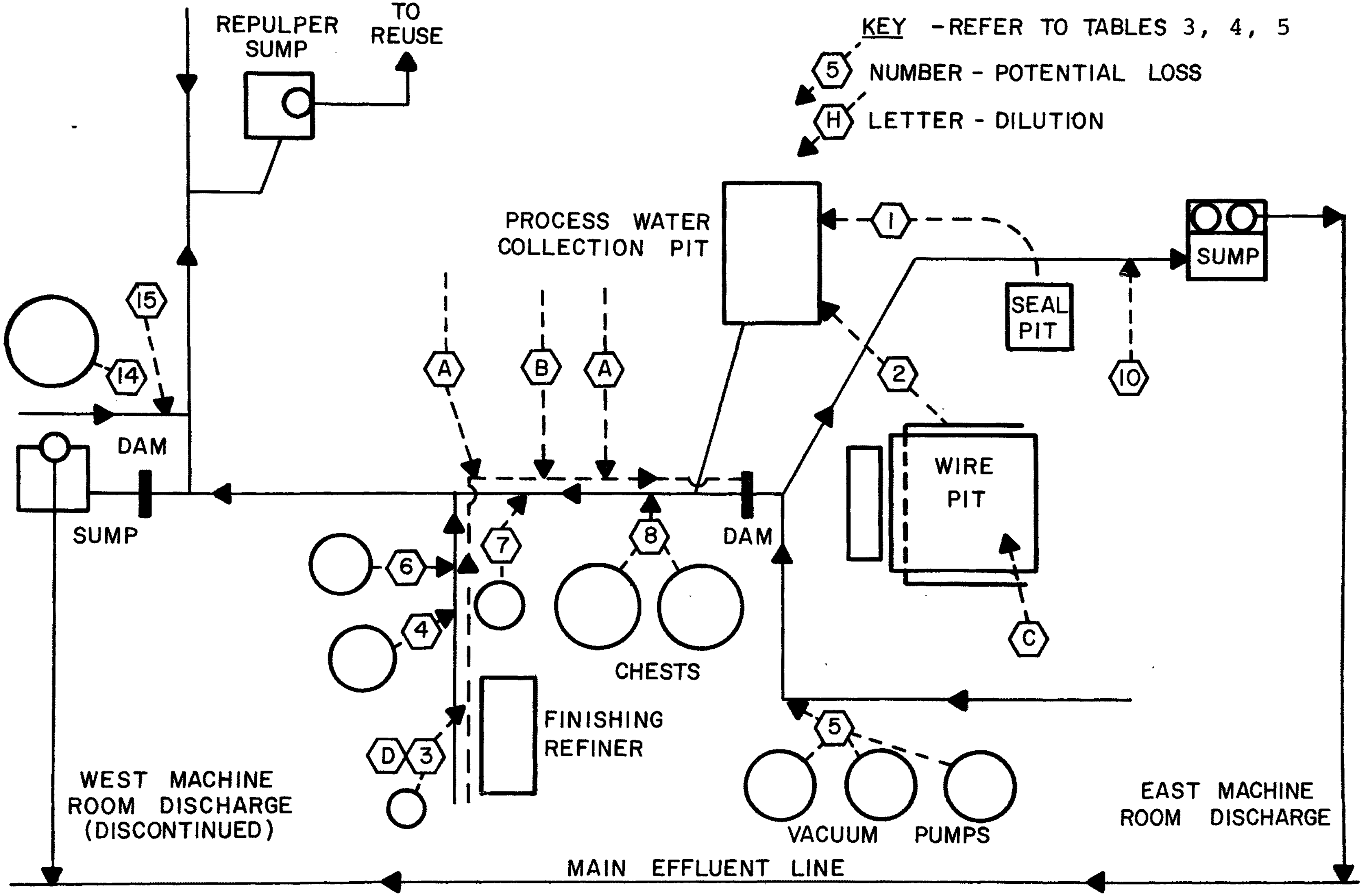

Figure 7. Paper machine floor collection system--1975.

in washup. City water, in small amounts, is still used on the cut squirts due to their tiny nozzles and at other critical points, such as the breast roll shower and suction roll box seals.

The same type of approach was used in the other operating areas of the mill. Figures 8 and 9 and Tables 5 and 6 are the result of a similar study made for the pulp mill. Tables 7, 8, and 9 indicate the problems and changes made in the reactor area, wood room, and tank storage area, respectively. No diagrams are included, but most items are self-explanatory.

In a lower priority category were steps that were needed to ensure stable operation and better closure. These included such steps as collection of evaporator cleanout streams and steam tracing and insulating of storage tank transfer lines formerly dumped to avoid freezing.

In a third priority category were items which could be deferred until after 1973 or which required more information. Some of these are now being evaluated, for example, a cyclonic mist separator on the couch vacuum pump. Others are unresolved at this time. Some have been taken care of more recently, including collection and recycling of both the acid scale removal waste stream from the bimonthly cleaning of recovery plant piping and the caustic from the evaporator demister pad wash. An unresolved problem is the acid condensate from the evaporator, adding 22.7 kilograms per day (50 lb/day) of BOD to the effluent. Another continuing problem is leaking of strong liquor from pump and agitator packing in the storage tank area.

The list of problems and solutions may not be complete, and will not apply directly to other mills, but should convey that reaching complete closure is an evolutionary process consisting of a great many separate steps, requiring diligence in seeking out and identifying even the minor contributions. Figure 10 summarizes the mill effluent sources as they now exist.

Although the total flow was reduced by only 11% since 1971, the total suspended solids and BOD loads were reduced by 63% and 83%, respectively. Most of the mill discharge is made up of river water which receives no treatment other than coarse screening. It is used, without recirculation, as seal water on vacuum pumps, for evaporator cooling, and for wood slab washing. The remainder of the effluent is uncontaminated city water used for cooling of air conditioners, air compressors, and oil coolers.

Present losses are characterized either as routine during stable operation or as upset losses. The largest routine loss is the mist of process water carried into the vacuum pump seal water. The upset losses arise during nonroutine conditions, such

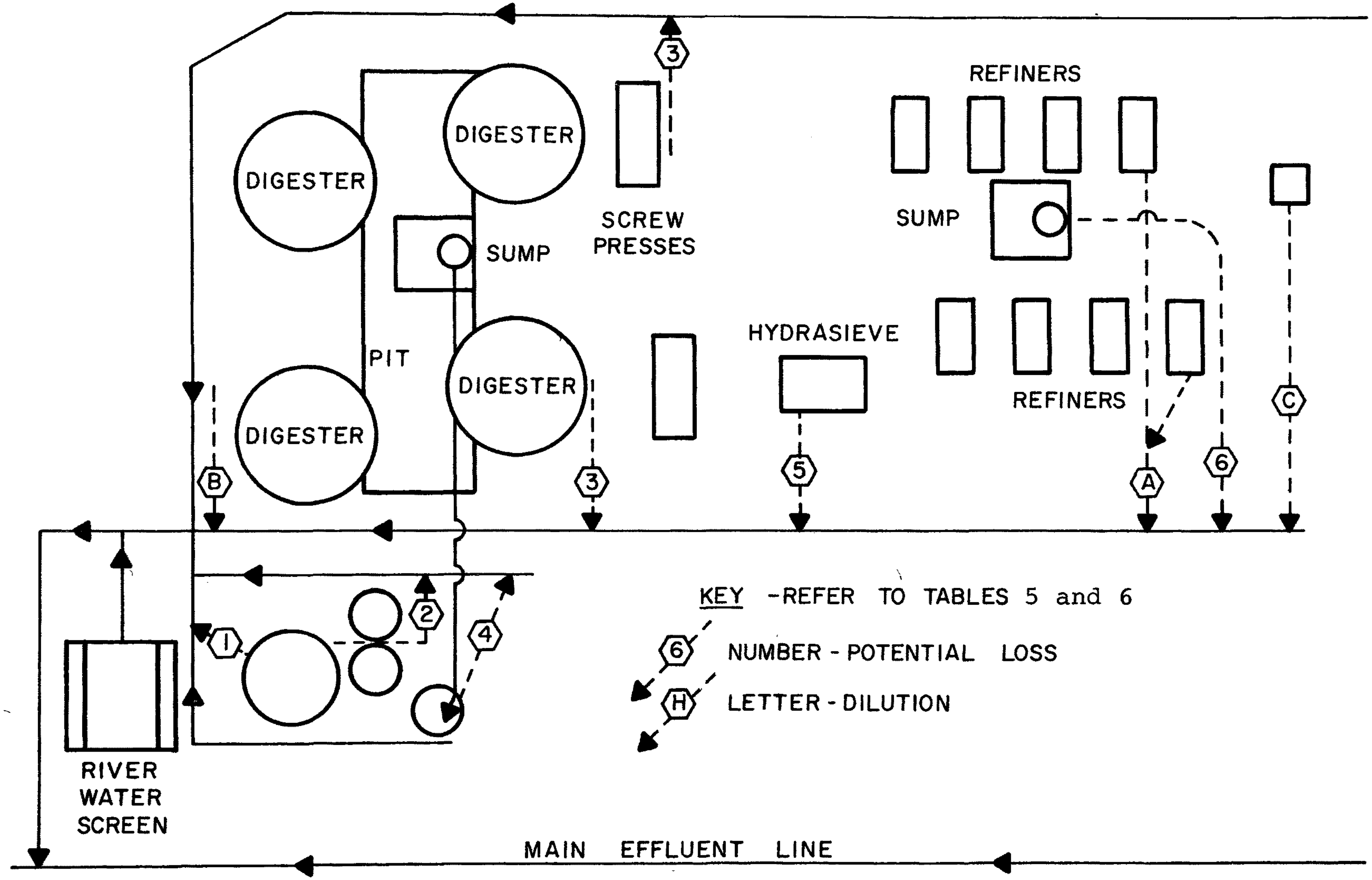

Figure 8. Pulp mill floor collection system--1971.

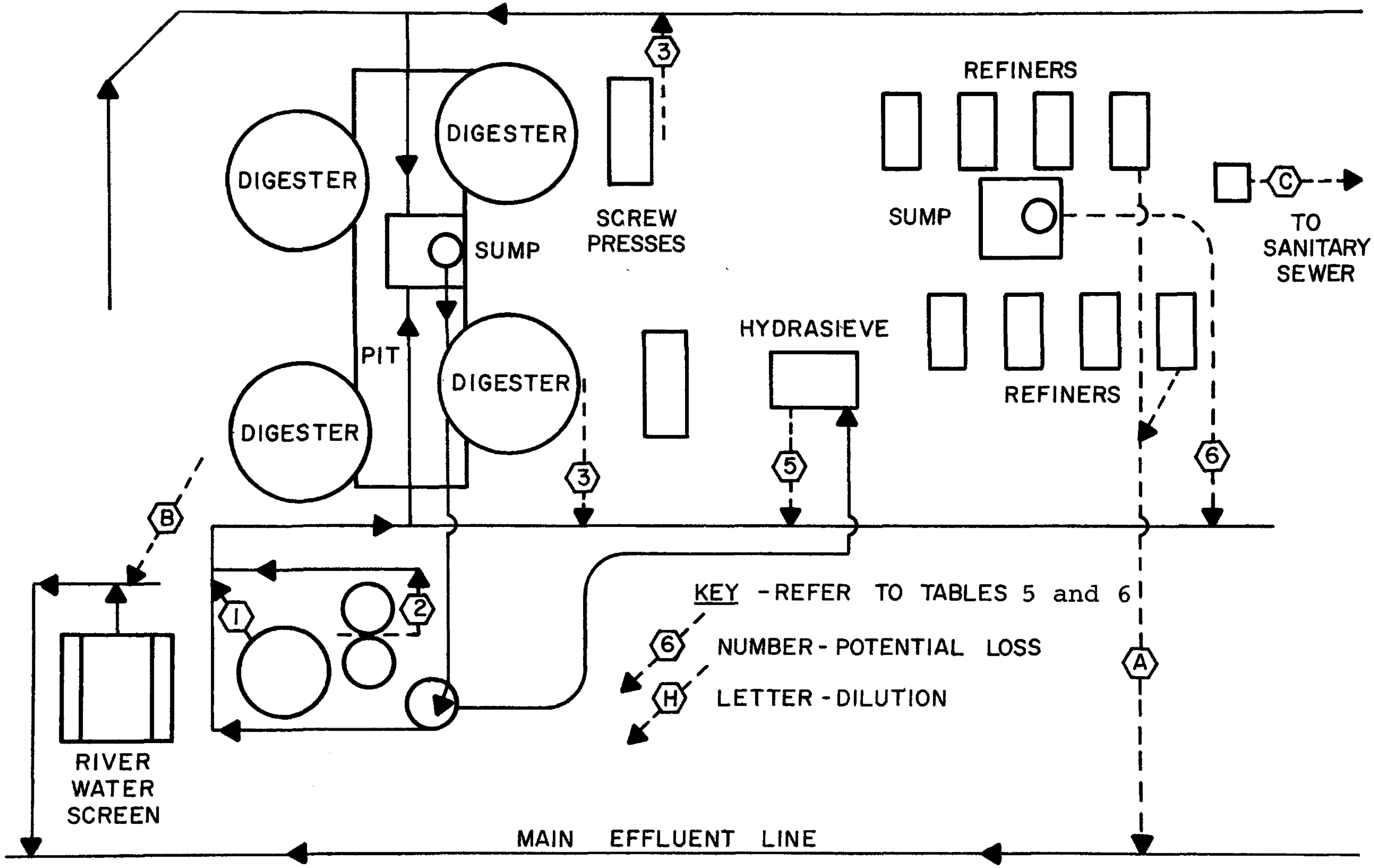

Figure 9. Pulp mill floor collection system--1975.

TABLE 6. INVENTORY OF POTENTIAL PROBLEMS AS OF 1971 AND DISPOSITION AS OF 1975--PULP MILL DISCHARGE (In Order of Priority)

(Code for Pulp Mill Discharge, See Figures 8 and 9)

1971 - Problem	1975 - Status
Number 1 Priority: Urgent--elimination necessary to meet 1973 limits	
1) Periodic overflow of press and digester process water wash tank Amount: 100-200 gpm Frequency: 5 min/wk	Control of makeup to tank improved; overflow to closed pulp mill liquor sump
2) Weak liquor seepage in screen area from splashes and leaks; concentrated liquor Amount: 1/4 gpm, continuous	Directed to closed pulp mill liquor sump
3) Screw press tank overflow from plugging with fiber and chips Amount: 25 gpm Frequency: 5 min, twice/day	Directed to closed pulp mill liquor sump
4) Overflow from pulp mill tank for fiber recovered from waste liquor Amount: 150 gal Frequency: each mill shutdown, 2-3 times/wk	Directed to closed pulp mill liquor sump
Number 2 Priority: Needed to ensure stable operation and better closure	
5) Dump of Hydrasieve effluent tank to clean out sand Amount: 100 gal/wk	Directed to closed pulp mill liquor sump; installed continuous sand removal system
6) Stock pump pit seepage Amount: small but continuous, stock and process water	Directed to closed pulp mill liquor sump

TABLE 7. INVENTORY OF POTENTIAL PROBLEMS AS OF 1971 AND DISPOSITION AS OF 1975--RECOVERY PLANT AREA (In Order of Priority)

(Not Diagramed)

1971 - Problem	1975 - Status
Number 2 Priority: Needed to ensure stable operation and better closure	
1) Dumping of Merco motor driven filter sludge Amount: 2 gal 40% liquor Frequency: once/hr	Installed small collection tank and pump to divert to unclarified process water surge tank
2) Flushing of gorator pump for repairs Amount: 100 gal Frequency: once/120 days	Flushes to recovery plant collection tank
3) Evaporator cleaning with water and NaOH Amount: 300-500 gal Frequency: once/wk	Pump directly to unclarified process water surge tank or weak liquor tank
Number 3 Priority: May be postponed until after 1973--more information is required	
4) Acid used to remove scale from liquor feeding lines Amount: 400 gal Frequency: once/2 mo	Pumped to recovery plant collection tank
5) Caustic wash for evaporator demister pads Amount: 250 gal Frequency: once/wk	Pumped to recovery plant collection tank
6) Acid condensate from evaporators Amount: 20 gpm Frequency: 150-200# BOD/day	Unresolved; evaporator usage is about 1/3 of what it was in 1971--50# BOD/day

TABLE 8. INVENTORY OF POTENTIAL PROBLEMS AS OF 1971 AND DISPOSITION AS OF 1975--WOOD ROOM DISCHARGE (In Order of Priority)

(Not Diagramed)

1971 - Problem	1975 - Status
Number 3 Priority: May be postponed until after 1973--more information is required	
1) Losses of fiber, bark, and small chips	Sweco screen and sump added to remove debris

TABLE 9. INVENTORY OF POTENTIAL PROBLEMS AS OF 1971 AND DISPOSITION AS OF 1975--TANK STORAGE AREA (In Order of Priority)

(Not Diagramed)

1971 - Problem	1975 - Status
Number 1 Priority: Urgent--elimination necessary to meet 1973 limits	
1) Seal pit and paper machine process water collection pit overflow; shutdown and startup surges or pump failure Amount: 3000 gal Frequency: once/day	Combined pits; installed larger pumps; installed spare pump; installed high level alarm
2) Losses from paper machine gutters and floor drains from normal seepage and washup Amount: 2-5 gal/min	All losses directed to process water pit by new piping
3) Periodic entrainment of process water in Centri-Cleaner vacuum pump seal water Amount: 5 gal/min Frequency: 30 min/wk	Installed conductivity alarm and manual vacuum breaker; modified vacuum pump seal water system
Number 2 Priority: Needed to ensure stable operation and better closure	
None in this category	
Number 3 Priority: May be postponed until after 1973--more information is required	
4) Overflow of Centri-Cleaner reject tank; shutdowns and failure of pump Amount: 50 gal Frequency: each shutdown, 2-3 times/wk	Discharges to enclosed sewer and is recycled with sump pump
5) Couch and wet press vacuum pump carryover Amount: 3-5 gal process water/min	Unresolved
6) Trap dumping Magna Cleaner finishing refiner Amount: 20 gal process water Frequency: once each 8 hr	Now dumps to closed sewer and is recycled by sump pump
7) Trap dumping Magna Cleaner secondary Centri-Cleaner system Amount: 20 gal process water Frequency: once each hr	Now dumps to closed sewer and is recycled by sump pump
8) Overflow from overfilling paper machine stock storage chests Amount: 600-1000 gal process water and fiber Frequency: once/mo	Now is in closed sewer area; stock is manually washed back to sump pump for recycle
Number 4 Priority: Insignificant or poorly defined	
9) Paper machine area pumps and side agitator seal leaks Amount: small but continuous	Most leaks are located in area of enclosed sewer and are recycled with sump pump
10) Seepage from area under paper machine wet presses Amount: small but continuous, some fiber loss	Unresolved

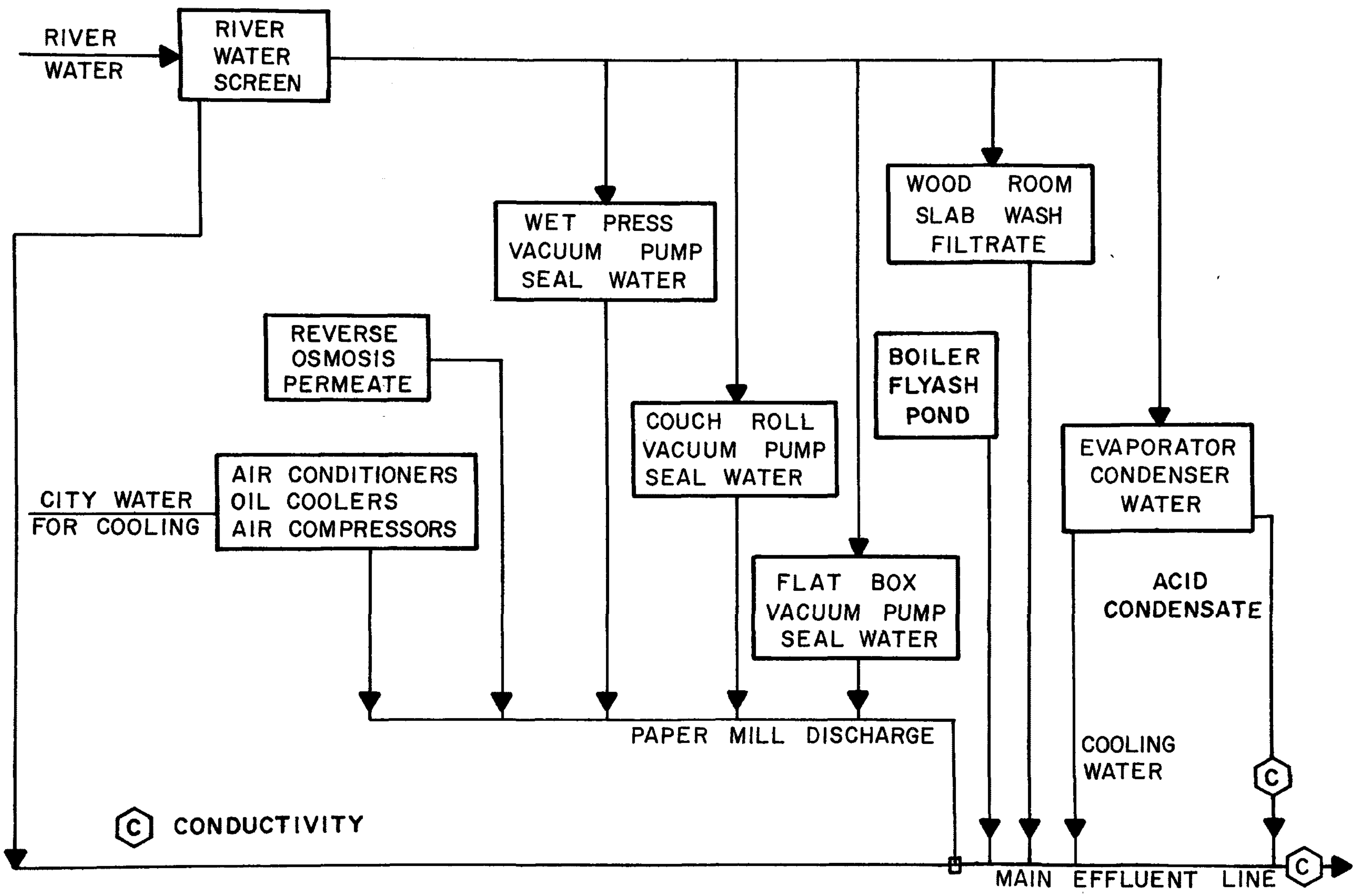

Figure 10. Mill effluent sources.

as shutdowns for machine clothing changes or failures in controls, equipment, and/or human judgment.

MILL SYSTEM WATER RECYCLING

The fresh water input to the process system was reduced from 3.21 cubic meters per minute (850 gpm) a few years ago to 0.491 cubic meters per minute (130 gpm) today. The 0.491 cubic meters per minute of water that does enter the process water system is either carried with the raw chips or is from certain small fourdrinier showers and many pump shaft seals.

All the excess water produced at the paper machine is directed to the main collecting point, which is the process water collection pit (Figure 11). This pit also receives the water from the paper machine floor washup drains and the floor gutters along the fourdrinier and wet presses. The collected water from the process water collection pit, containing about 2.16 grams of suspended solids per liter (18 lb/1000 gal), is pumped to our unclarified process water surge tank and is then supplied for direct reuse to the areas insensitive to suspended solids. These uses are waste paper repulping, machine broke repulping, all stock dilution, and cooking liquor makeup.

The excess unclarified process water not needed for the above operations is metered, based on unclarified process water surge tank level, into a large stream being used for corrugated waste repulping. This dilute stock is processed over a vacuumless thickener. Due to the gentle driving force removing water on the thickener, the thick mat containing long kraft fibers acts as an excellent filter medium for the retention of fiber, and the filtrate contains only 0.66 grams of suspended solids per liter (5.5 lb/1000 gal) with very little long fiber. The excess portion of this clarified filtrate is then pumped at a constant nozzle pressure of 2.81 kilograms per square centimeter (40 psi) over a four-bank, 150-micron DSM slotted screen for removal of any remaining long fiber down to 0.0096 grams per liter (0.08 lb/1000 gal). The treated water will still contain from 0.24 to 0.60 grams per liter (2 to 5 lb/1000 gal) of extremely fine suspended solids. The clarified water is stored in our clarified process water tank and is reused on all paper machine showers except cut squirts, the breast roll shower, and the seal water showers on the suction roll boxes.

Process water showers were selected after extensive testing of a variety of designs. The Bird Aqua-Purge shower was selected for its simplicity and absence of parts subject to deterioration. A key element in the successful operation of these process water showers is the completely closed design of tanks and other elements following the DSM screen cleaning step. This assures the absence of debris that might otherwise cause plugging.

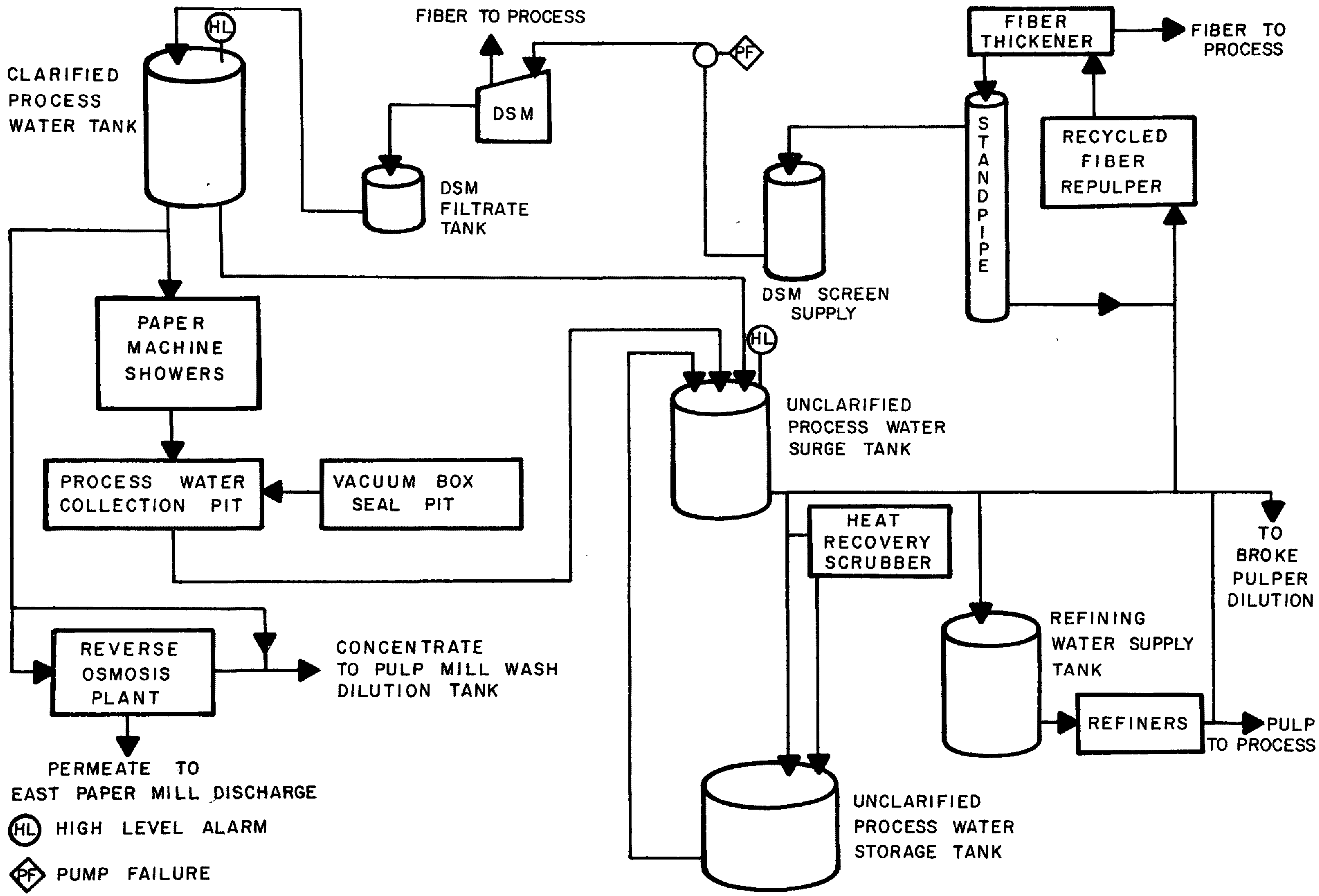

Figure 11. Process water reuse system.

A third very large tank--946.2 cubic meters (250,000 gal)--serves as long-term storage. This tank, designated as the unclarified process water storage tank, is held at a constant level by water flowing in a loop from the unclarified process water surge tank and back to the same tank at equal rates.

Two precautions are necessary in a closed water system. The first is to keep the process water hot; the second, to have no dead storage areas where cooling can take place and sludge can form. An area that is cool and/or dead will promote aerobic or anaerobic bacteria growth.

If in the course of operating an excess of water occurs either in the unclarified process water surge tank or clarified process water tank, the flow in the loop from the unclarified process water storage tank is lessened or stopped until the excess is removed from the system and stored in the unclarified process water storage tank. Then the normal equal flow in and out of this tank will resume. Likewise, a deficiency in either the clarified process water tank or unclarified process water surge tank will cause an increase in the returning flow rate from the unclarified process water storage tank until the need is satisfied.

Although there has been a substantial increase in wire pit suspended solids (from 0.2% to 0.3% as a result of closure), there has not been a loss of machine speed. Higher process water temperature--71^{o}C (160^{o}F)--and higher average sheet moisture (computer control) have undoubtedly been compensating factors. Furthermore, the increase in water extractables in the final sheet--increased from 20 to 41 kilograms per metric ton (40 to 180 lb/ton) due to closure--has been accompanied by a reduction in fiber content at the same basis weight and, presumably, a corresponding reduction in drainage resistance. No stiffness-related strength loss is associated with this change in composition.

INTERNAL WATER MONITORING AND ALARM SYSTEM

An important aspect of running a tightly closed mill is knowing when and where process problems occur, as system upsets and resulting spills remain a potential source of excessive discharge from a normally tight system. A good monitoring system is necessary to know as quickly as possible the location and degree of BOD and suspended solids losses.

The monitoring system put into use at Green Bay Packaging contains generally two types of sensors: storage level alarms and effluent concentration measurement by conductivity.

The monitoring and alarm system provides the following information at a central location:

(1) A continuous record of the total mill effluent dissolved solids level.

(2) A continuous monitoring of potentially high pollutant discharges at selected locations throughout the mill. Mill personnel are informed by an annunciating alarm panel of the upset conditions.

(3) A continuous record of each upset occurrence and its duration; also, "on time" event and duration of standby equipment, such as backup pumps.

(4) A continuous record of the dissolved solids concentration measured by each of the conductivity sensors.

In addition, this system is flexible to revision and is a source of dependable information which can be relied upon for overall supervision of a closed mill water balance.

It is worth noting that much work was done to determine the relationship between conductivity and dissolved solids concentration of the mill process water. This was necessary as conductivity measurement was to be the tool for the system monitoring. Once conductivity was selected as the means of system monitoring, the number and locations of the sensors were determined.

Four locations have been selected for the conductivity sensors. The sensors are presented in sequential order as they occur in the mill effluent system. The first sensor is on the vacuum pump discharge from the centrifugal cleaners. Although this discharge is normally fresh water, the vacuum seal can break, allowing process water with 5% dissolved solids to be discharged to the main clear water sewer in the mill. The next conductivity sensor is in the trench receiving the paper machine vacuum pump discharge. This flow is primarily river water; however, the main sewer trench also directs its flow past this sensor so that upsets occurring in the mill basement can be detected (see Figure 12). Another sensor is in the recovery plant discharge leading to the main effluent line. Ordinarily, this stream consists of cooling water from the evaporator condensers; however, an occasional strong liquor spill in the recovery plant can reach this stream (see Figure 10, page 25). Finally (on the same diagram), a conductivity sensor is at the flume. Its purpose is to monitor total mill effluent concentration. This sensor provides information on the relative strength of the effluent reaching the river.

In addition to relative strengths of streams within the mill system, liquid levels are monitored on five tanks and two sumps. High level alarms using conductance probes alert mill personnel of impending problems prior to overflow. Enough advance notice

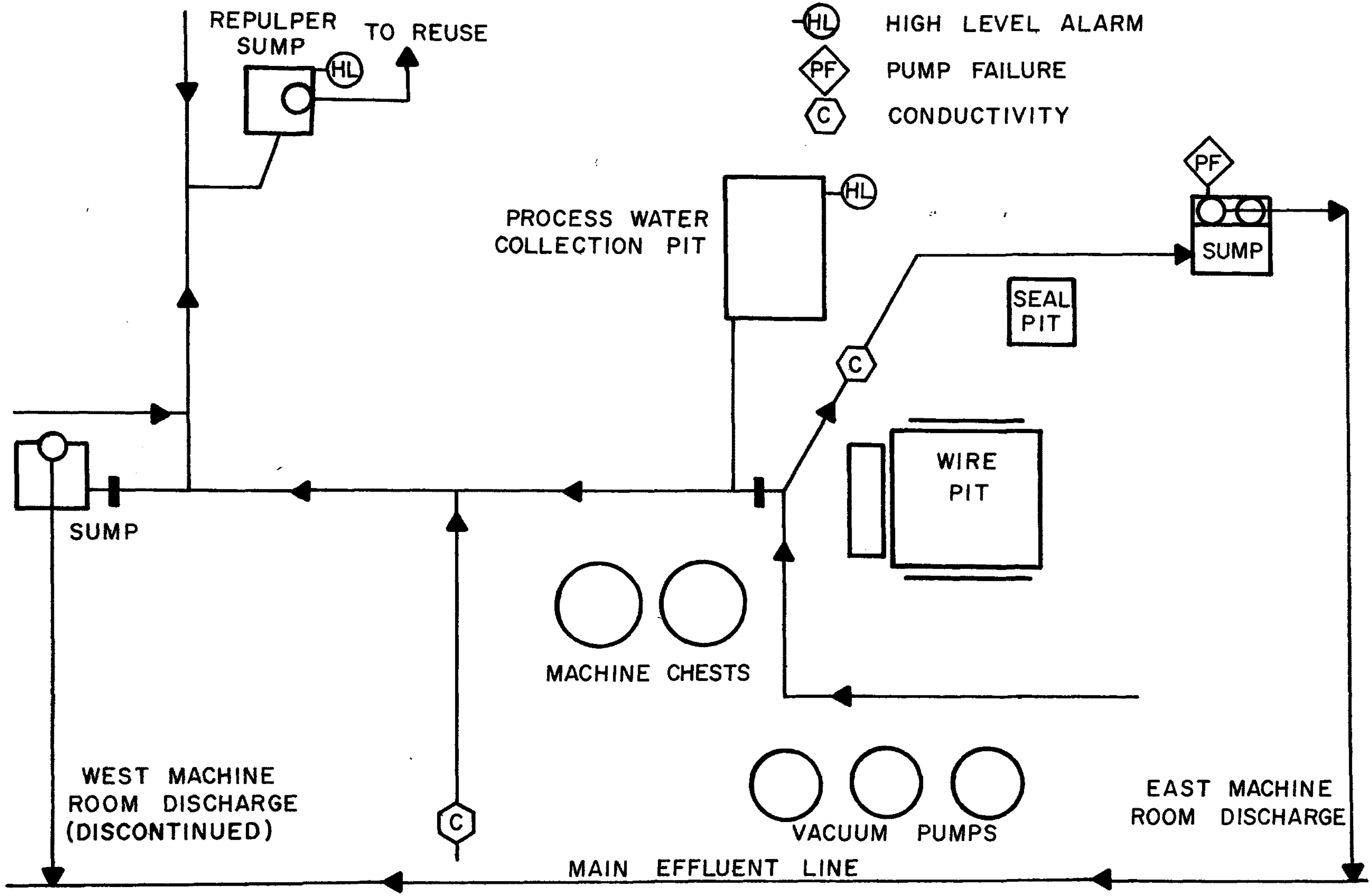

Figure 12. Paper machine effluent system--alarm points.

is given to allow for corrective action to be taken; thus, if the spill can not be averted, its impact will certainly be diminished. The seven items monitored are:

(1) Chemical mixing tank.

(2) Clarified process water tank.

(3) Unclarified process water surge tank.

(4) Refining water supply tank.

(5) Pulp mill wash dilution tank.

(6) Process water collection pit.

(7) Repulper sump.

Two pumps are also included in this monitoring system. The first is a pump supplying process water to the DSM screen for clarification. Should this pump fail, an alarm will be triggered by a pressure switch indicating low discharge pressure.

The second is the backup pump for the main sewer effluent pump. This pump is monitored for "on-time" only, an indication of primary pump failure or excessive flow to the flume.

Figure 11 (page 27) and Figure 2 (page 8) indicate the location of alarms and sensors schematically.

As with any complex mechanical-electrical system, a period of operational development must be endured. As an example, polyshrink tubing and time delays had to be installed on the tank high level probes to keep them from reporting falsely high readings caused by splashing.

Although the monitoring system has not, and will not, eliminate upsets, it is safe to say that the adverse impact of many potentially severe upsets has been either averted or greatly minimized by this system.

REVERSE OSMOSIS SYSTEM

By the spring of 1973, the revision of sewers and surge controls had stabilized the mill process water system to the degree that the losses caused by variable water inputs taxing the volume limit of the system became evident. Over a period of months of analyzing loss data, it was determined that during these times when excess volume was entering the system the normal rate of buildup was from one to a maximum of 56.7 liters per minute (15 gpm). It was subsequently decided that, with the surge storage available for sudden shifts of inventory, a reverse osmosis plant capable of 75.7 liters per minute (20 gpm) of product water would be suitable to keep the long-term system volume under control. The plant feed flow of 340.6 liters per minute (90 gpm) of clarified process water was then set by the Fluid Sciences Division of Universal Oil Products Company, based on striking an optimum between feed pumping power requirements and limiting solids increase through the plant, because the higher the solids the less driving force for water production.

Plant Feed Characteristics

The feed stream to the reverse osmosis plant is clarified process water taken from the line supplying the paper machine showers. Chemically, it is a solution of 4-6% dissolved solids containing wood extractives and sodium lignosulfonates characteristic of high yield NSSC hardwood pulping. The stream also contains an average of 300 ppm of suspended solids, which are by nature a mixture of semicolloidal solids and small fiber debris. The feed is supplied to the reverse osmosis plant from the mill process at a temperature of 60-65°C (140-150°F), a pressure of 7.03 kilograms per square centimeter (100 psi), and a pH ranging from 5.6 to 6.0.

Reverse Osmosis Theory

Osmosis is defined as the tendency of a fluid (water) to pass through a semipermeable membrane (cellulose acetate) into a solution of higher concentration, so as to equalize concentrations on both sides of the membrane. If a pressure is exerted on the more concentrated solution side, the flow will be decreased. As the pressure on the concentrated solution is increased, a point will be reached at which the osmotic flow has stopped entirely. This pressure is called the osmotic pressure of the solution and is a property of the solution. The osmotic pressure is a function of not only the type of solution but also the soluble solids concentration and temperature. For example, our process water has an osmotic pressure at 35°C (95°F) of about 12.3 kilograms per square centimeter (175 psi) at 5% soluble solids and 24.6 kilograms per square centimeter (350 psi) at 10%, whereas a sodium chloride solution at the same temperature has an osmotic pressure of 42.4 kilograms per square centimeter (603 psi) at 5% and 94.2 kilograms per square centimeter (1340 psi) at 10% soluble solids.

Increasing the pressure beyond the osmotic pressure at a given solution condition of temperature and percent solute causes a reversal in osmotic flow of the solvent and is the basis of the reverse osmosis process.

The peculiarities of the osmotic passage of a solvent through a membrane is the most important difference between the filtration and reverse osmosis processes. Osmosis depends on the selective property of a membrane, that is, solvent can pass through the membrane, while one or more of the soluble components can not do so. Therefore, in the reverse osmosis process, removal of the solvent increases the concentration; and, therefore, the osmotic pressure of the concentrating solution increases with a subsequent decrease of the flow of the solvent under a fixed pressure.

In a plant where the goal is to remove water and not to gain concentration, it can easily be seen why a maximum plant feed flow is necessary to minimize this concentration effect. This also is the basis for a lower limit on velocity passing the membrane surface so that a concentration gradient is not created by laminar flow. Velocity effects will be discussed further under fouling problems.

Reverse Osmosis Plant Interface

The role of the reverse osmosis plant in the general mill scheme has been previously described. Figure 13 illustrates the interface of this operation to other mill processes. As the temperature of the module membrane is limited to 40°C (105°F), the plant feed is cooled to 38°C (100°F) in a plate-style heat exchanger; boiler makeup water is used as the cooling medium. There are two product streams from the reverse osmosis plant permeate (product water) and a concentrate. Initially, the permeate was to substitute for a portion of the city water used for pump and agitator seals. In order to avoid corrosion, this was not done as all small pipelines in this system are steel or copper; and although low in BOD, the permeate has a pH of 4.5 due to a trace of acetic acid.

The concentrate, or the second stream, can be routed back, when necessary, to the process water collection pit; but it normally flows to the pulp mill wash dilution tank to be used in the countercurrent liquor washing operation. This use helps increase final liquor solids and promotes minimum evaporator usage.

Reverse Osmosis Hardware

The equipment received from Universal Oil Products (Figure 14) consisted of three separate packages: the pump assembly (right side), control center (center), and six module racks (left side). The pump rack consists of eight Goulds multi-stage booster centrifugal diffuser-type pumps of which two are 25 Hp 47-stage feed pumps and six are 10 Hp 23-stage recycle pumps. Also included in the pump package are the magnetic flow meters, valves, and sensors (Figure 15).

The control center is primarily electronic. The right panel consists of amp meters, pump controls, and electrical switches

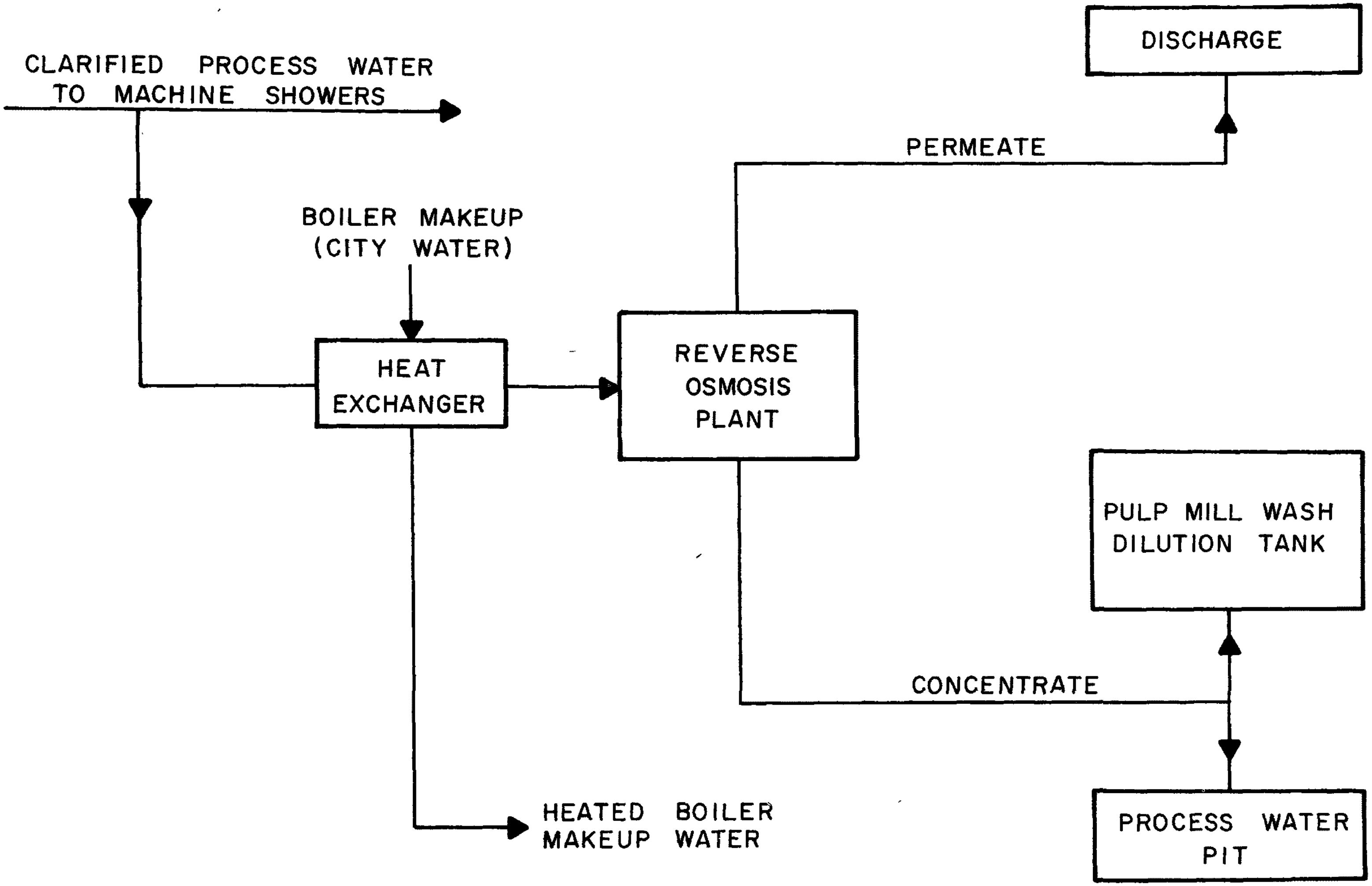

Figure 13. Reverse osmosis plant interface.

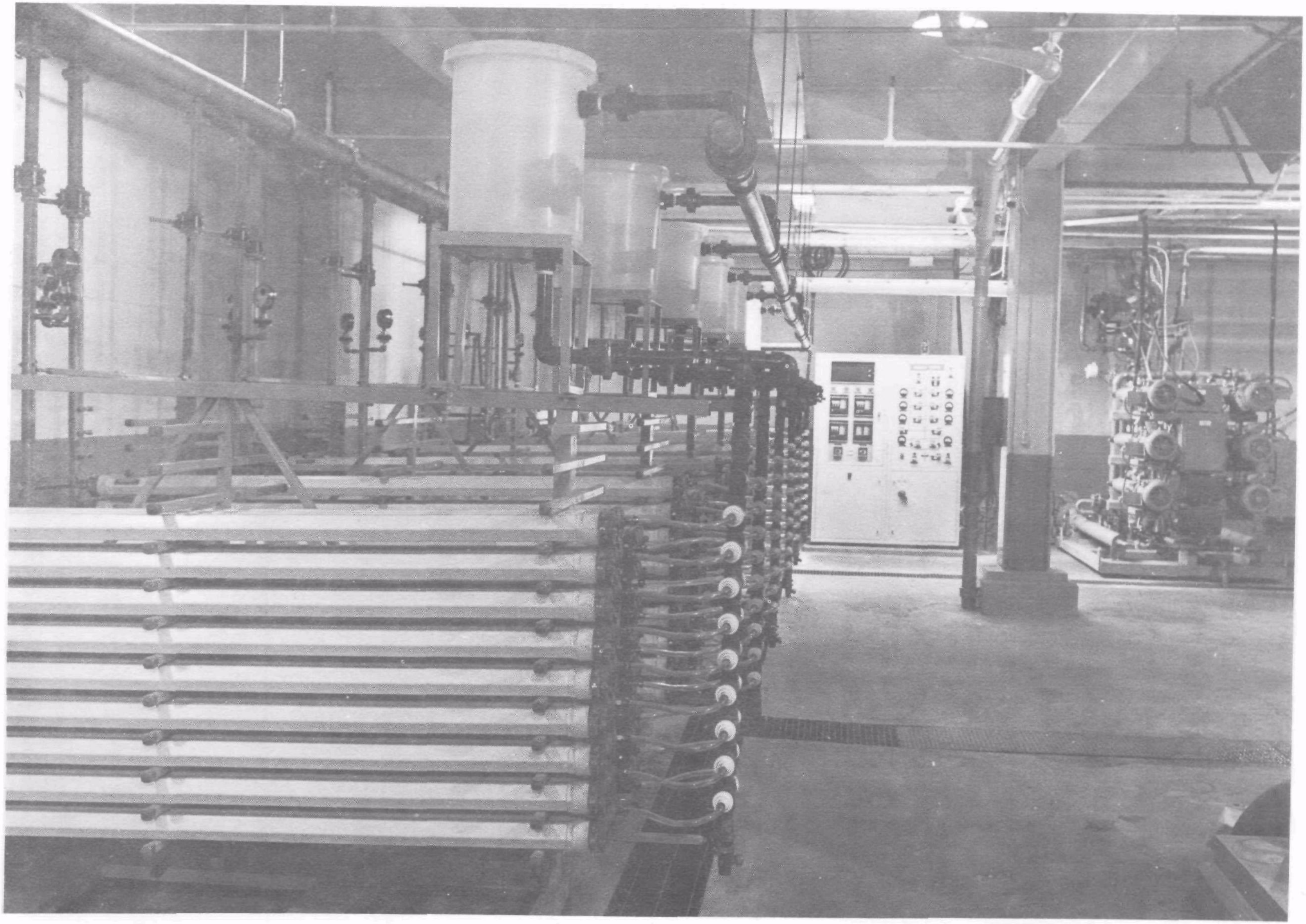

Figure 14. Reverse osmosis plant.

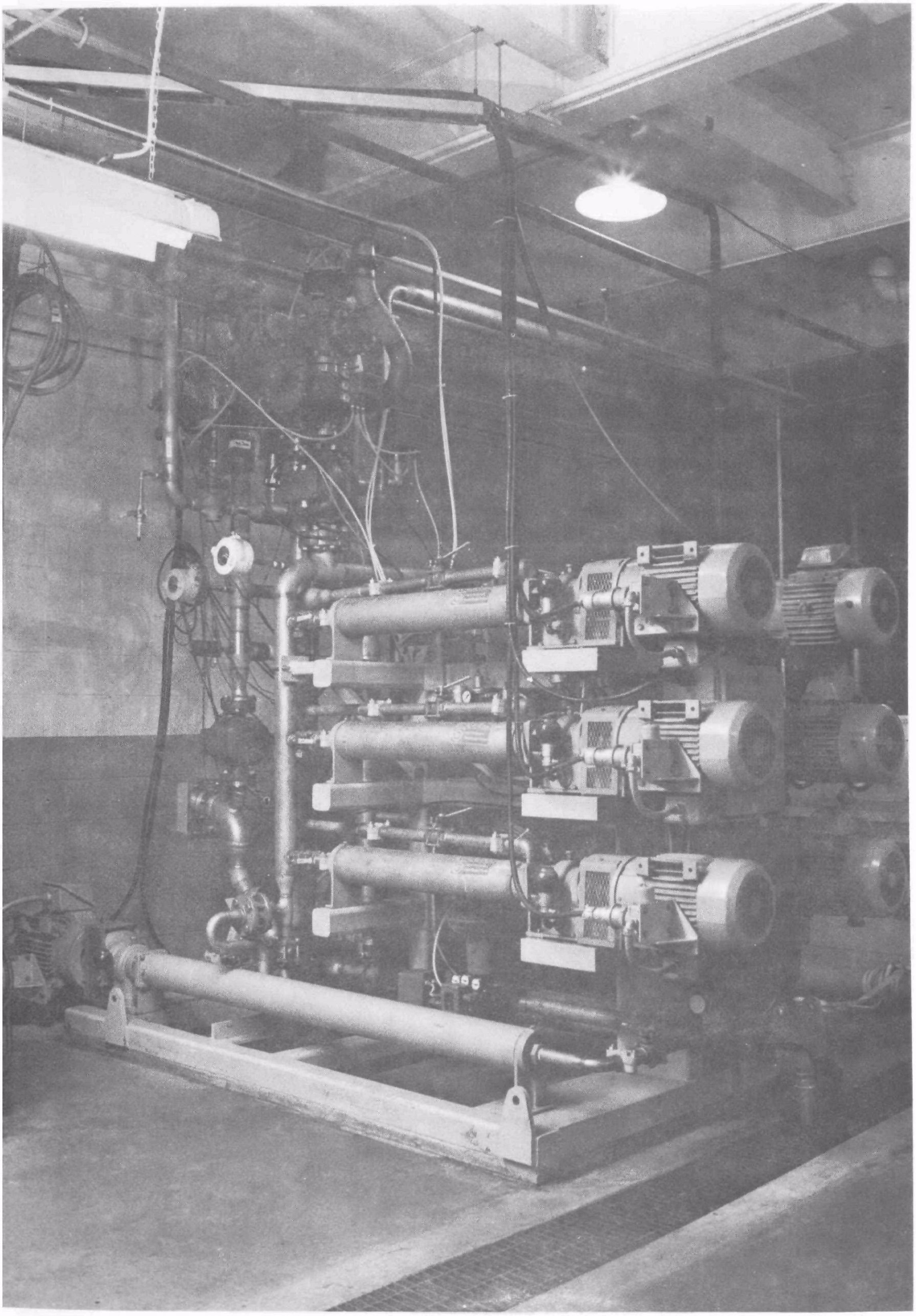

Figure 15. Pump assembly rack.

for starting and stopping the reverse osmosis unit. The left panel has the alarm annunciator panel; power, flow, and operational hour totalizers; adjustable timers; recording charts; and necessary controllers.

The 288 modules are incorporated equally on the six racks with 16 rows on each rack and three modules in each row. Each module contains 18 porous tubes which are fiberglass, filament wound, and resin bonded. The membrane, formed from cellulose acetate, is on the inner surface of the fiberglass tubes and provides 1.55 square meters (16.7 ft^2) of membrane surface per 18-tube module. These tubes, approximately 2.23 meters long (88 in), are contained within a hexagonal shroud and connected internally in series by means of two molded heads.

Feed is piped into either of the two ports at the high pressure end; and after nine complete round trips (18 tube lengths), it exits at the same end as it entered. The other port in the feed end becomes the concentrate exit (near the wall, Figure 16). Water molecules permeate outward from the 18 pressurized tubes through the semipermeable membrane and the porous tube wall into the shroud. Permeate is collected inside the shroud and exits from the outlets at the opposite end under low pressure.

Reverse Osmosis Process Plant Flows

The clarified process water feed flow, under conditions of full plant operation (Figure 17), is 340.6 liters per minute (90 gpm). The two feed pumps pressurize this literage to 31.6 kilograms per square centimeter (450 psi) before it combines with the recycled concentrate; the combined flows--946 liters per minute (250 gpm)--are boosted by the six recycle pumps to 42.2 kilograms per square centimeter (600 psi). This module feed is supplied to the six identical module rack assemblies arranged in parallel. After passage through the 96 module rows, the individual rack concentrate flows are recombined in the return header; a portion, the concentrate discharge--255 liters per minute (67.5 gpm)--is returned to the pulp mill, and the remainder, still under pressure, is recombined with fresh feed to maintain the high velocities necessary to minimize fouling.

The permeate is collected in small tanks above the six module racks before combining as the total permeate flow. The tanks are necessary to return permeate to the modules during the pause or rest cycle, during which osmotic backflow removes accumulated material (fiber debris) from the membrane surface. The modules are sloped to ensure that the individual tubes are surrounded by permeate (Figure 16).

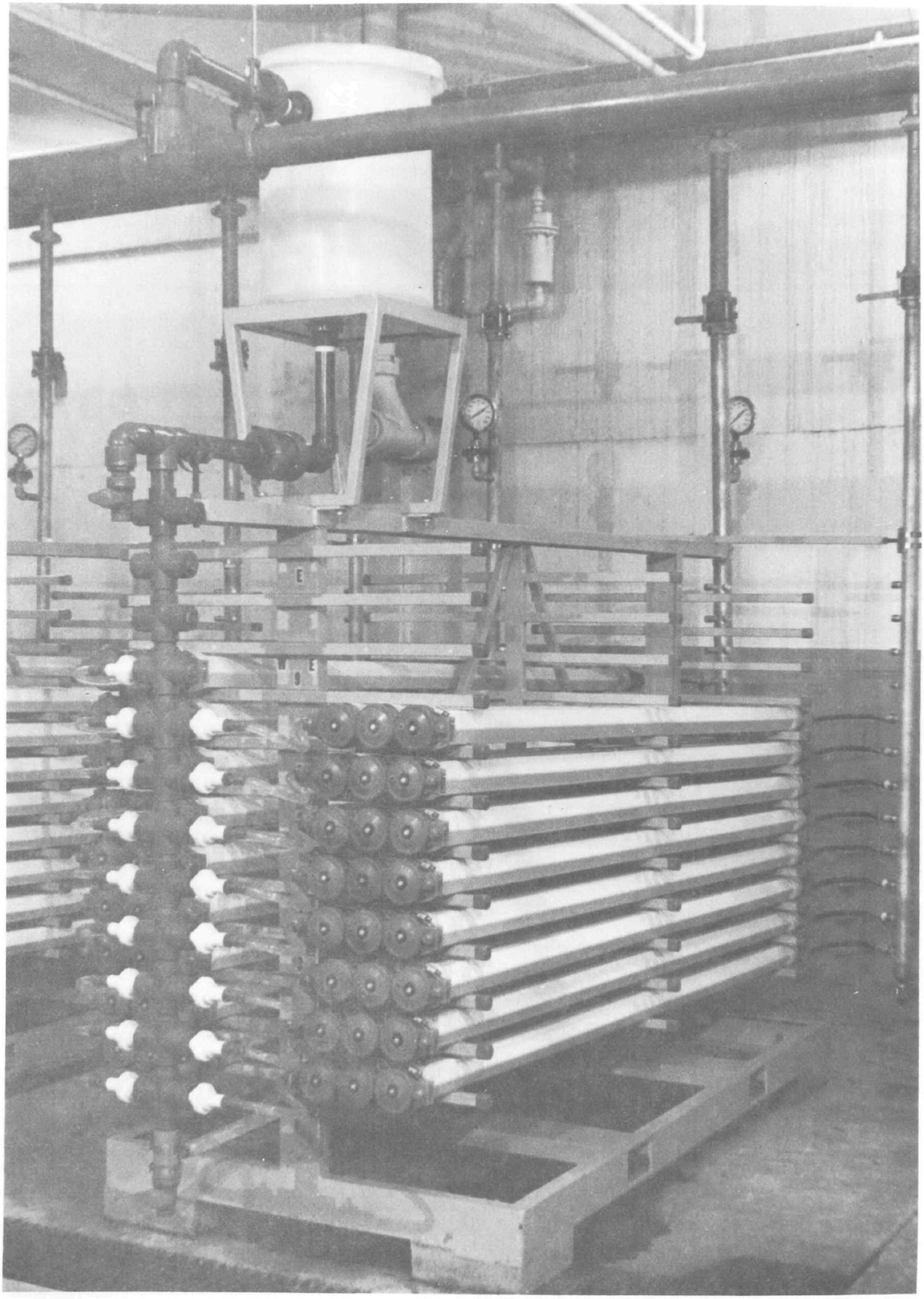

Figure 16. Module rack.

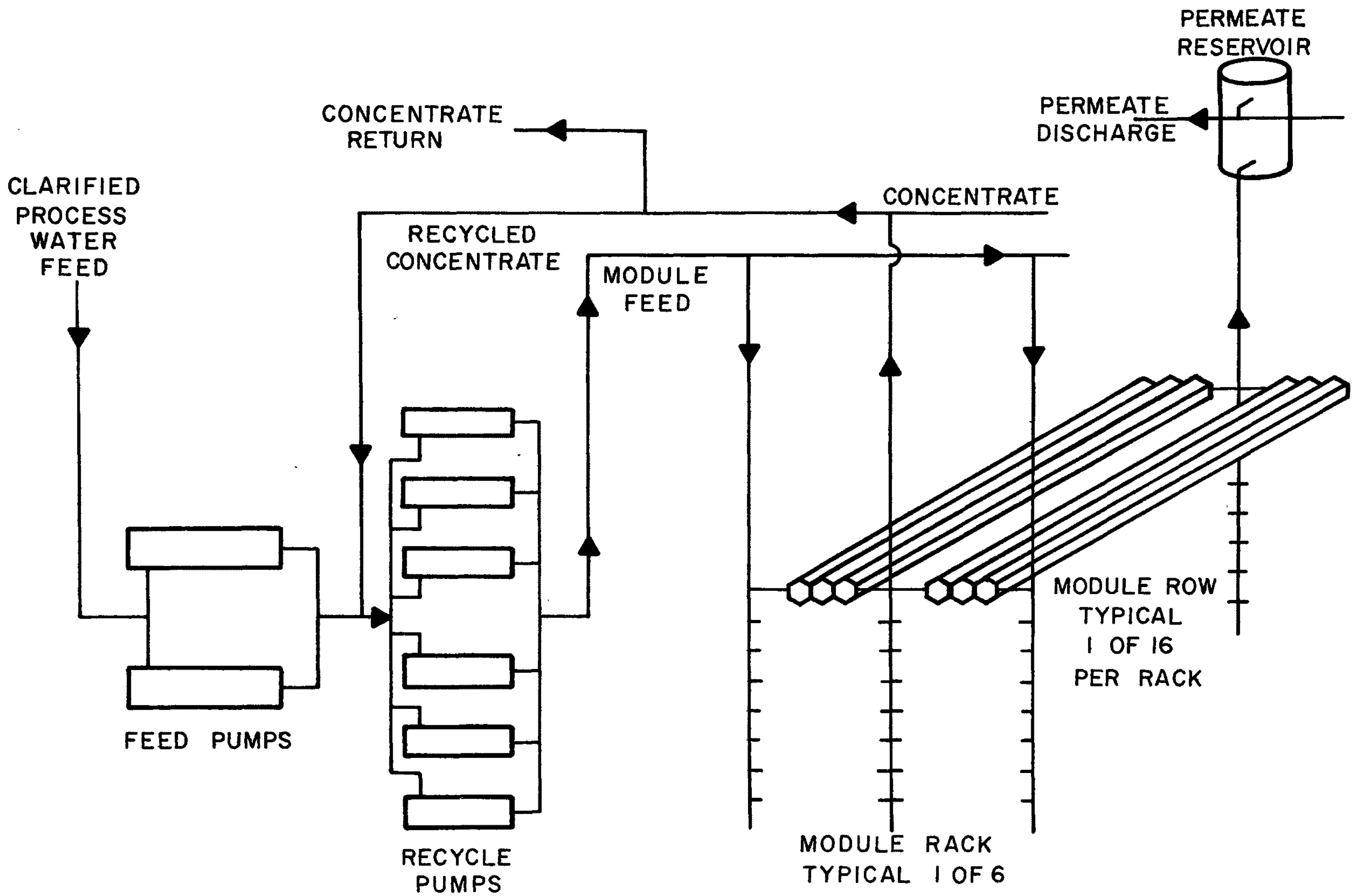

Figure 17. Reverse osmosis flow diagram.

Reverse Osmosis Plant Controls

The control and monitoring instruments for the plant are relatively straightforward (Figure 18). The feed flow and total module feed are measured, controlled, and totalized. The permeate is measured and totalized. Pressure on the modules is maintained by controlling concentrate flow. Other necessary variables are measured and recorded--electrical power consumption, pH, temperature, conductivity of the permeate, etc. All the indicating and recording devices were provided to ensure ample data for reporting the performance of this demonstration plant. Also, adjustable timers controlling the pause and operating cycle times are included.

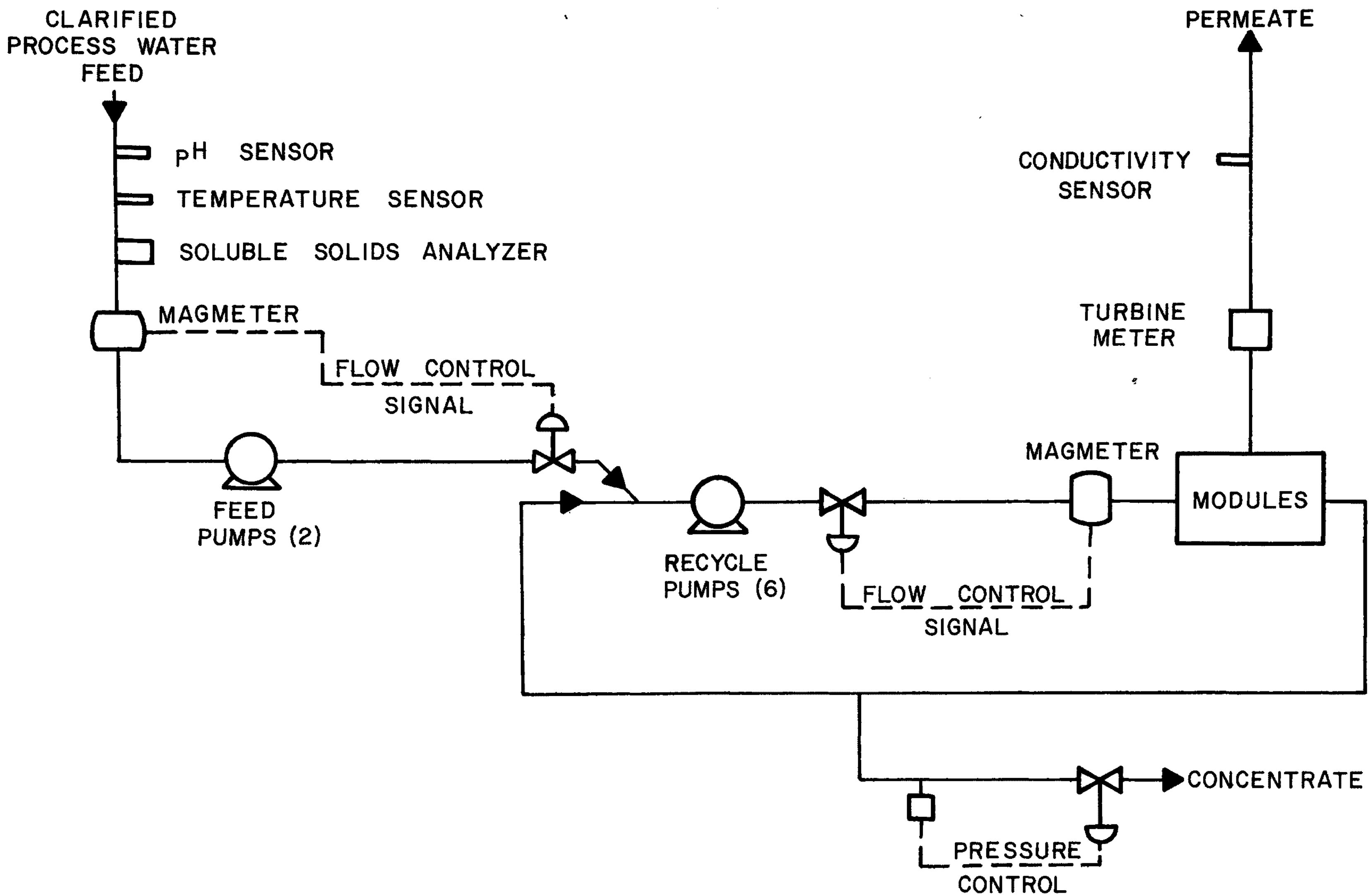

Figure 18. Reverse osmosis plant control.

SECTION 5

OPERATING EXPERIENCE

IN-PLANT ENVIRONMENTAL EFFECTS OF MILL WATER SYSTEM CLOSURE

From 1968 to 1973, the total dissolved solids in the mill process water rose from 0.7% to 5.2%. This was a consequence of intensive process water reuse.

Several effects from the increased dissolved solids were noticed. First, the buildup of dried liquor solids on paper machine surfaces increased. This was particularly true on the underside of the machine above the wire pit. A first approach to correcting this problem was to install under-machine, side entry, atomizing steam showers to increase the humidity and thus prevent the drying of soluble solids. Because of adverse mist outside the machine, this eventually gave way to installing vinyl side curtains on the machine and abandoning the atomizing steam showers. The side curtains appear to avoid air circulation and trap the necessary humidity under the fourdrinier.

By reusing process water, the system temperature also increased. The rise was approximately from 60°C (140°F) to 71°C (160°F). This temperature rise made necessary the reconstruction of the machine room ventilating system. A canopy had to be placed above the fourdrinier to keep condensed water vapor from falling onto the paper machine wire. More air was needed to reduce the room air temperature as well as remove excess humidity. An additional 30 Hp was required to bring in fresh air and properly distribute it, and another 30 Hp was required for a second roof fan above the fourdrinier paper machine to expel warm, humid air. In addition to the above changes, the machine tender aisle ventilation system was reworked, with another 25-Hp fan capacity added to this system.

These changes have not only improved employee comfort but they have also reduced the in-house fallout of process water solids. These modifications were made over a period of several years at a cost of approximately $115,000.

PROCESS WATER SYSTEM ADDITIVES

Slimicides

The potential for slime growth is significantly enhanced by closing the process water loop. This is mainly due to the increased nutrient concentration in the system. Bacteriological slime, a gelatinous secretion of undetermined type bacteria, under certain conditions can detach from vessels and pipe walls to create runnability problems for the paper machine.

The general level of slime growth can be controlled by the use of slimicides and by maintaining a sufficiently high system temperature. In the early weeks of system closure, little increase in slime growth was noted. However, the first time the mill's recovery plant had a lengthy shutdown after closure, the process water system temperature dropped due to lack of makeup heat from the recovery plant. With the cooling of the now enriched process water, the bacterial growth mushroomed. The resultant increase in loosened slime globules caused numerous breaks of the wet web leaving the couch roll on the paper machine. The immediate remedy was to return to fresh water on the paper machine showers, followed by a thorough cleaning of the entire process water system.

Slimicide was then used to suppress new growths of slime-forming bacteria. The level of slimicide addition was then adjusted to the minimum amount while just maintaining control of bacterial growth.

Currently, two types of slimicide are used, an organic dibrominate and methylene-bis-thiocyanate. These materials are alternated from drum to drum. The slimicide addition occurs every four hours with 22.7 to 45.4 kilograms per day (50 to 100 lb/day) being added to the DSM screen supply tank.

Samples of process water are taken at four locations: the inlet to the headbox, the clarified process water storage tank, the process water collection pit, and the reverse osmosis plant. Normally, the desired level for total colony count is 100,000 or less at the headbox and 500,000 or less in the rest of the system. Although these are desired levels, actual counts may vary from 1000 to several million for short periods without any visible indication of slime.

The daily process water samples are cultured in 100 x 15 millimeter Petri dishes using tryptone glucose extract agar as the culture medium. The cultures are incubated at 37°C (100°F) for 48 hours.

Defoamers

The closing of the process water loop caused the temperature to rise to a high of 71°C (160°F) at the paper machine headbox and a low of 62.8°C (145°F) at the surge capacity storage tanks. The defoamer used prior to the closed system was a combination of oils (steric fats and fatty acids) and isopropyl alcohol. The defoamers had to be heated to affect solution and were water emulsifiable. The combination of higher temperatures and dissolved solids made this type of defoamer ineffective.

After an extensive investigation, a defoamer was found which met all the necessary pH range and temperature requirements of a closed system. Basically, the defoamer was a mineral oil carrier with a silicone coated silica suspension. The defoamer was surface active and immiscible with water. The application was on and around the paper machine with a daily rate of usage at approximately 13.6 to 59.1 kilograms per day (30 to 130 lb/day), depending on machine conditions. The system for addition of the defoamer is completely automated and will respond according to existing conditions.

A different defoamer was used in the secondary fiber repulping system, specifically on the water dropleg on the Impco thickener. Foam develops here due to the cascading of process water into the standpipe. This defoamer is similar to the one on the paper machine but has some esters added. The machine defoamer can be used in this area also, but doesn't have the same efficiencies. Use at this point amounts to approximately 90.9 kilograms per day (200 lb/day).

PROCESS WATER SYSTEM ASH BUILDUP

Although ash buildup in a closed paper mill water system is not easily observed or measured as is slime or soluble solids buildup, it is real and can be a problem due to increased refiner plate wear. Following the same pattern as that of soluble solids with system close-up, ash continued to increase until 1975 when a means was found to remove the normally recirculated ash from the system in a concentrated, reasonably dry form. Approximately one-third of the ash percent is normally silica, and the remainder is calcium oxalate.

Figure 19 is a diagram of the complete centrifugal cleaning and reject refining system. Abrasive material is removed at two points. The first is relatively coarse sand, gravel, and metal removed by a MagnaCleaner just before the second stage of centrifugal cleaners. The second is the reject stream from a 13-centimeter (5-in) centrifugal cleaner operating on the effluent from a Hydrasieve. The fine recirculated ash in this loop is at its greatest concentration of any point in the system. After

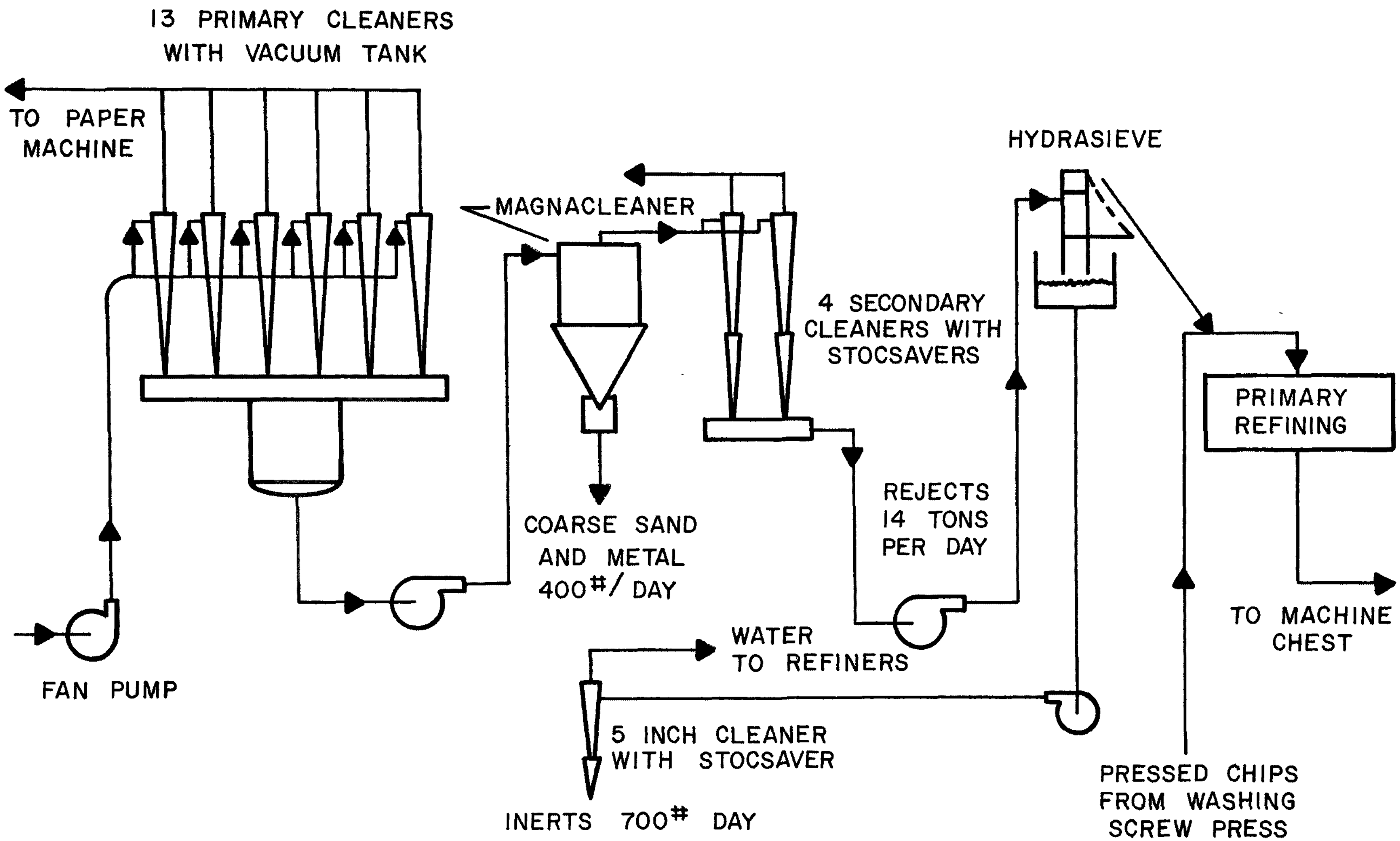

Figure 19. Grit removal system.

being rejected from the small centrifugal cleaner, the separated ash is dewatered in a grit chamber and removed by a lift screw to be hauled away to landfill.

REVERSE OSMOSIS PLANT OPERATING PHILOSOPHY

The reverse osmosis plant has operated 60% of the mill operating time during the two years since it was installed. The excess inventory of process water required its use only about 15% of the mill operating time. The plant was run as continuously as possible because of the project goal to determine membrane life and rejection efficiency over an extended period of time.

The 40% downtime was the result of a number of problems--plant control system and piping revisions, pump maintenance, module replacement, and plant descaling.

Reverse Osmosis Plant Performance

After a few initial revisions in the instrument control scheme and hardware, the plant control has been very complete and maintenance has been minimal. The automatic features of the plant have resulted in reliable unattended operation.

The pumps have operated well to produce the intermittent high pressures necessary for plant operation but have required a high degree of maintenance to keep them efficient. This aspect is more completely described in the section entitled "Reverse Osmosis Pump and Pump Seal Problems."

The third component of the plant, the modules, constituted the main research and development area of the project. This part of the project was slowed considerably by problems relative to the porous fiberglass support tubes for which details are also described under "Reverse Osmosis Module Fiberglass Membrane Support Tube Failure."

The module membrane used in this plant is of a medium permeability grade. The quality of the permeate from this membrane has been better than specified in the listing of plant bid requirements. This property, as well as the other normal operating parameters, are listed in Table 10.

Power consumption of 82.0 kilowatt-hours per 3785 liters (1000 gal) of permeate has been less than other alternate evaporative methods of pure water removal. Comparative costs are described in the report section "Economic Evaluation of Reverse Osmosis vs. Evaporation."

The only disappointment has been in the area of reduced productivity brought about by membrane aging.

TABLE 10. TOTAL REVERSE OSMOSIS PLANT AVERAGE OPERATING PARAMETERS

(See Appendix A for Test Procedures and Calculations)

Item	Feed (ppm)	Concentrate (ppm)
Soluble solids	54,400	66,900
Sodium	6,500	8,000
BOD_5	13,900	17,600
Color	112,500	146,800
pH	5.8	5.8

Item	Permeate (ppm)	% Rejection Specified	% Rejection Actual
Soluble solids	372	98.0	99.86
Sodium	62	none	99.86
BOD5	1,005	96.0	98.56
Color	65	99.0	99.94
pH	4.1	--	--

Item	Design	Actual
Flux gallons (per day per sq ft) at 5% feed solids, 600 psi (41.4 bar) module feed pressure, and 100°F (37°C)	6.65	5.13*

Power consumption per 1000 gallons permeate = 82.0 kwh*

*average for two years

Figure 20 is a comparison of the flux at 5% dissolved solids obtained on two different plant complements of modules over a period of approximately 2000 hours of exposure. This figure is limited to the operational time data we have available on a full plant basis as of this date. The original modules supplied with the plant were replaced due to a material defect, allowing the evaluation of a second set. In both cases, the flux decreased gradually over the 2000 hours as the modules aged. The difference observed in the flux levels shown by the two groups has not been determined but is believed to be related to the original membrane characteristics. All attempts to return to starting or even design flux--11.29 liters per square meter-hr (6.65 GFD) at 5% dissolved solids--have been futile. This rate of drop in flux does not continue indefinitely but tends to level out after approximately 2500 hours. This can be observed by the longer term flux exposure times on the individual module (replacement) racks installed over the last 14 months (Figure 21). Evidence of the long-term flux stability after the initial drop can be seen up to the longest rack exposure time of 7000 hours. The initial drop in flux which occurs within a 24-hour period after the membrane is installed is recognized in the industry and is known to be caused by initial compaction of the membrane. Whether the drop after this is continued slow compaction or some other phenomenon is not known at this time. There has been no deterioration in membrane rejection of soluble solids or color during this period of 7000 hours.

REVERSE OSMOSIS MODULE FIBERGLASS MEMBRANE SUPPORT TUBE FAILURE

The first six months after plant acceptance saw module failure, due to tube structural strength loss, reaching an untenable number, as high as 21 modules per 100 hours of exposure. Initial failures, generally occurring close to the ends of the tubes, were thought to be caused by questionable manufacturing processes or lack of employee care in positioning the tubes for the delicate tube cut-off operation. When further ruptures occurred randomly spaced along the entire length of tubes, it was realized that these new failures were a result of some mysterious and unknown cause.

An analysis of tube processing and qualification data showed no correlation of the rupture phenomenon with various manufacturing variables. The location of failed tubes within the module appeared to have no correlation with failure incidence. The one ominous feature that did correlate was the length of exposure to the process water feed stream. The history of 4000+ hours of successful piloting with several modules was of little benefit in the light of this new reality in which tubes were rupturing in less than 300 hours.

Tube burst strengths had dropped during exposure from 276 bars (4000 psi), as originally manufactured, to as low as

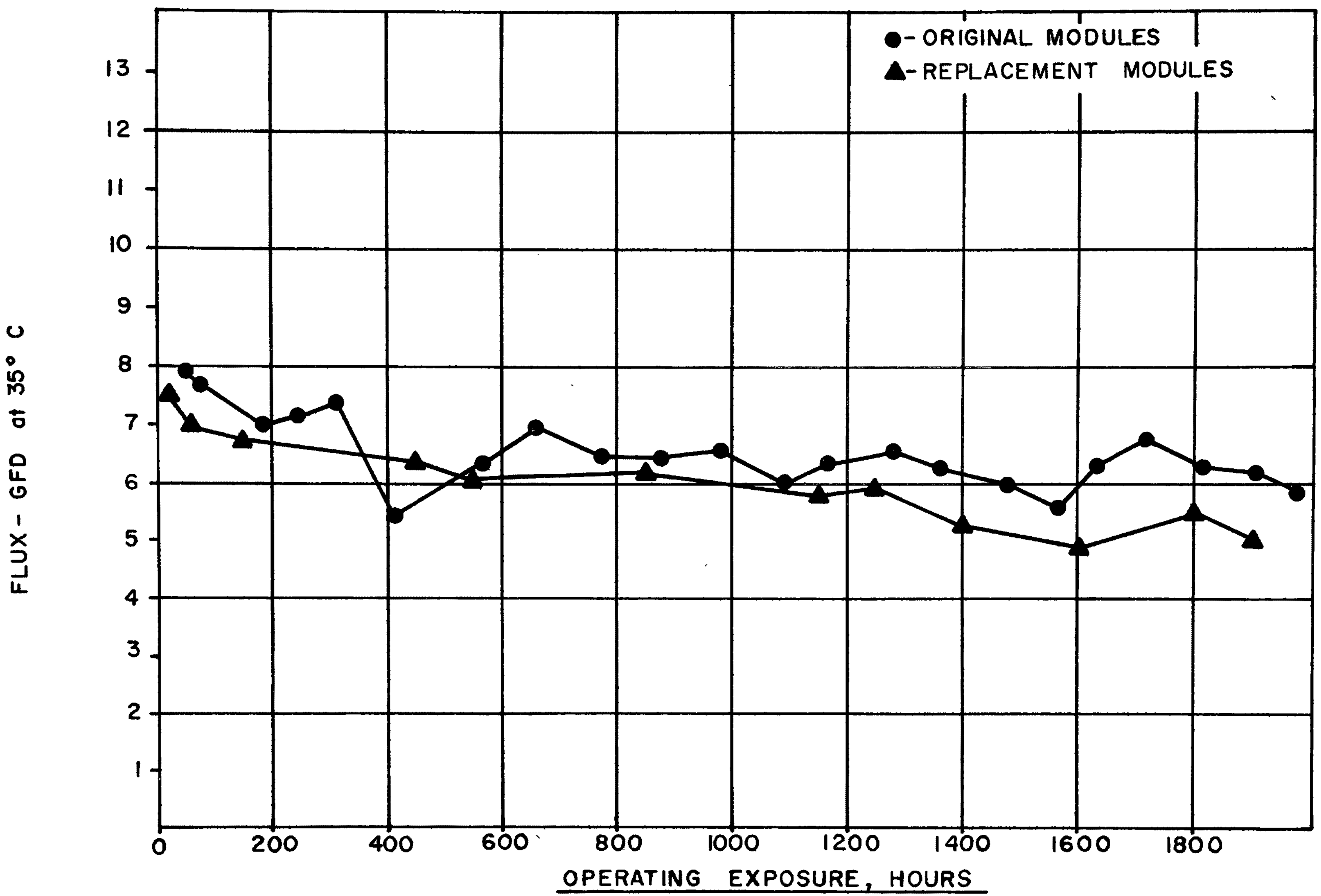

Figure 20. Flux performance comparison.

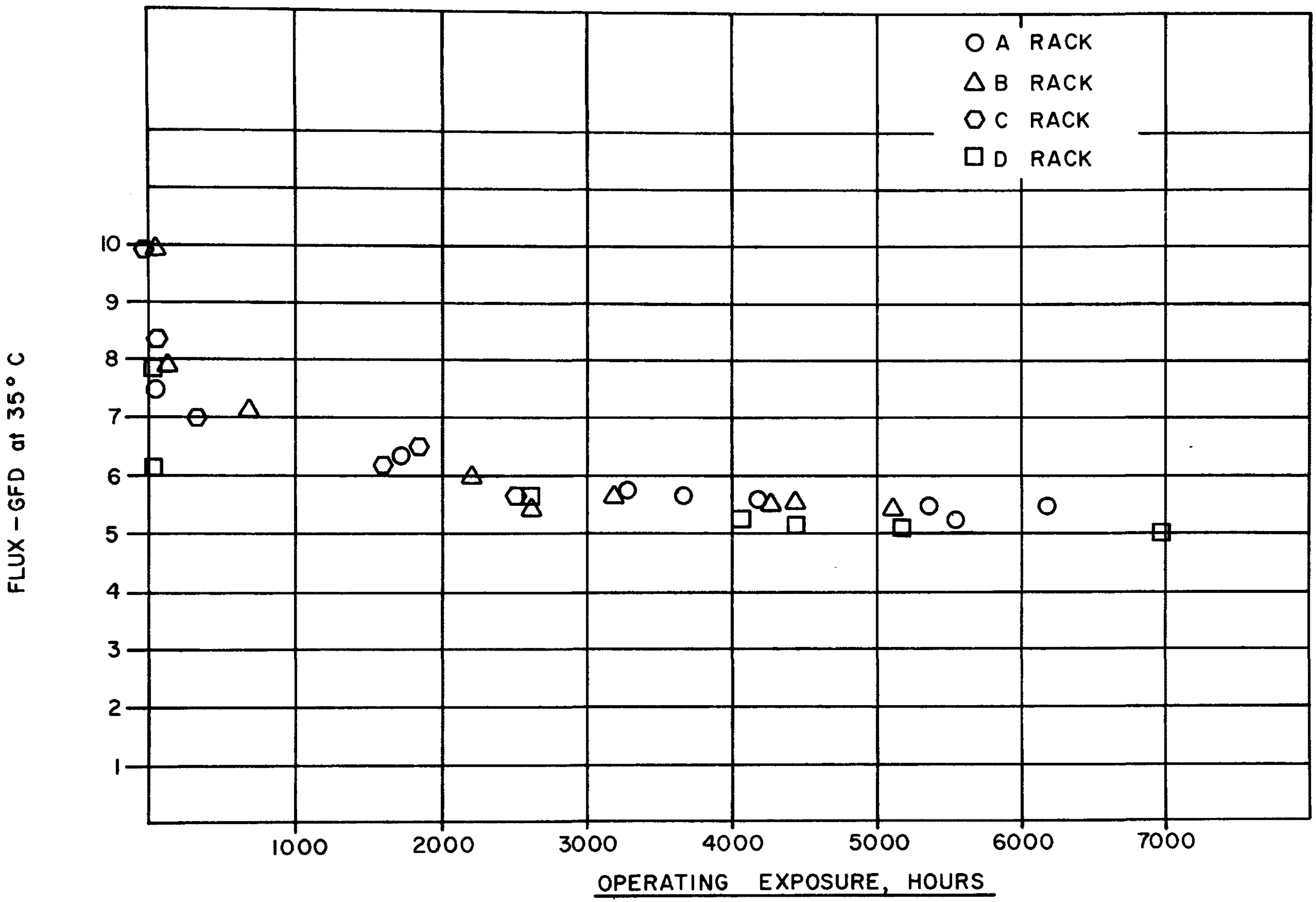

Figure 21. Cleaned module flux data.

166 bars (2400 psi) and even 124 bars (1800 psi). With all manufacturing processes and quality control procedures tightened to eliminate any possible causes from the manufacturing end, it was recognized these premature ruptures could only be caused by the chemistry of the feed stream as it related to and affected the mechanical integrity of the tube structure itself. Samples of raw and aged tubes plus samples of feed and permeate liquids were submitted to Universal Oil Products' Corporate Research Group for analytical investigation.

Analyses of permeate and feed showed acetic acid present in both, demonstrating the tube was being exposed to an acidic environment continuously, albeit in low concentrations. Elemental analysis of the tubes' resin system showed no leaching of the components. Ash contents of raw and aged tubes were also similar. Submitting the tube samples to Scanning Electron Microscopy showed the glass fibers had been corroded and etched severely, giving them the appearance of "swiss cheese" rather than a long, smooth, and round filament. Xray analysis indicated a loss of Mg and a higher ratio of calcium-to-silica content in the aged fiber. The glass then being used contained basic glass elements in a certain ratio. It was determined that the acetic acid of the feed stream and the permeate altered the chemical composition of the glass itself, allowing the acidic water to etch the more soluble elemental portions.

The photographs obtained with the Scanning Electron Microscope are presented in Figure 22. An unexposed fiberglass tube is shown in the top two photos at different magnifications. The lower two frames are duplicate magnifications of a tube exposed to acid permeate.

The conclusion was drawn that failure of the tubes at Green Bay was due to corrosion degradation of glass fibers by the acidic permeate. Continued exposure time caused a sudden drop of strength from 124 bars (1800 psi) to the 41 bars (600 psi) operating pressure due to the failure of microcracks, introduced by the leaching process, and the growth of these cracks by flexure during startup and shutdown cycling.

<u>Action Taken to Correct the Problem</u>

In addition to their Corporate Research's efforts, Universal Oil Products' Norplex Division, with experience in the production of composite laminates using resinous glass fiber-filled technology, Owens Corning Fiberglas' Technical Center personnel, and a consultant, experienced in resin/glass fiber structures, were all engaged to assist in finding a solution. The search was begun to find a glass and resin combination that would stand up to Green Bay's feed stream and operating conditions.

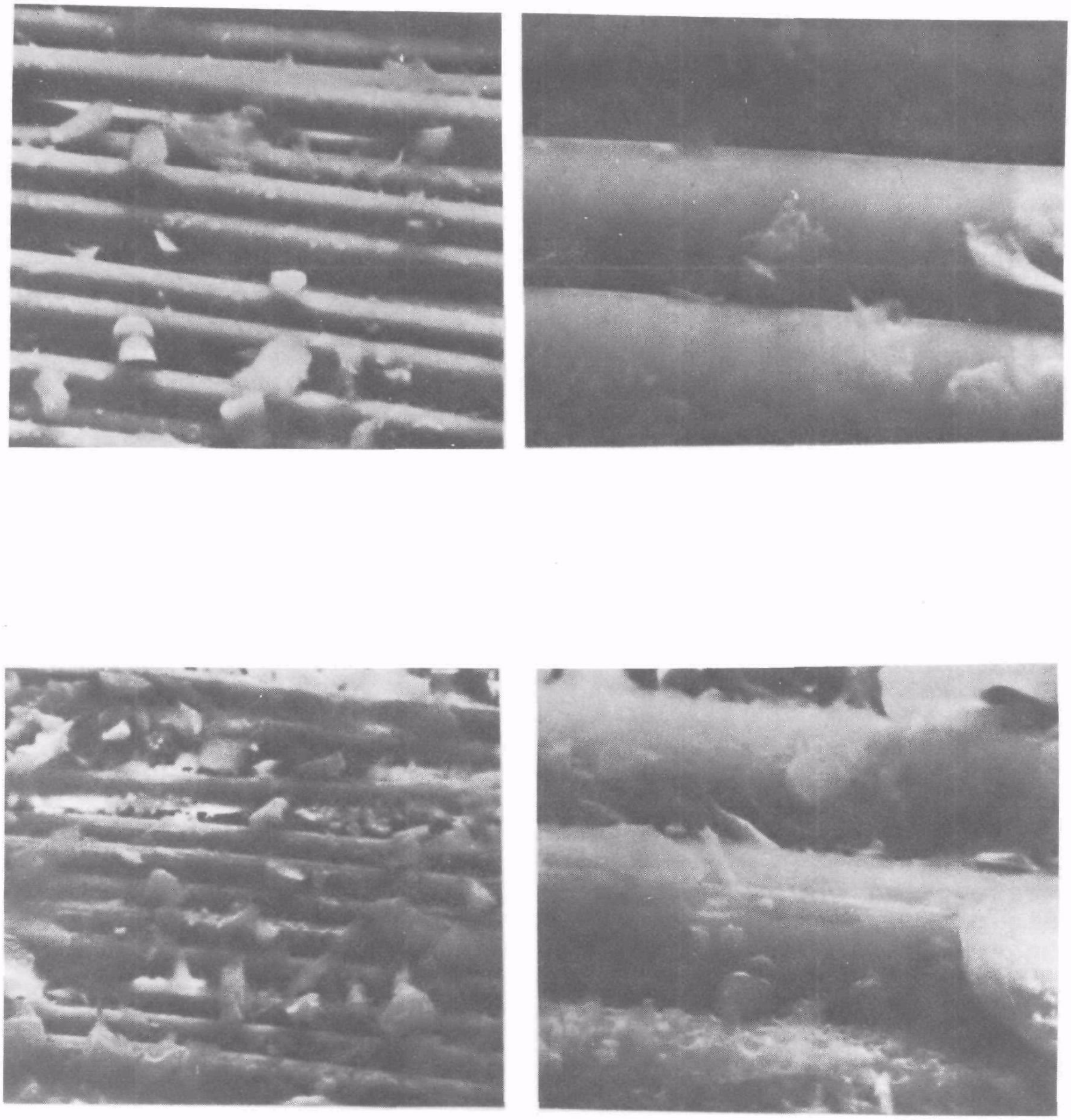

Figure 22. Photomicrographs--new (top) and aged tubes (bottom) (furnished through the courtesy of Universal Oil Products, Corporate Research).

A major problem in developing an improved tube structure centered about finding tests that would provide accelerated data which could quickly and reliably correlate to long-term exposure in the commercial application. Selection was finally made of a water boil test over predetermined time periods from two to as long as 1200 hours. Additionally, a rapid cycle life test was developed in which tubes were subjected to an acidic water solution at 49°C (120°F) while full modules were pressurized to 41 bars (600 psi), held for 60 seconds at pressure, and then depressurized to atmospheric pressure for 30 seconds to complete one cycle. This cycle was repeated, usually many thousand of times, until failure occurred.

The ultimate test, of course, in order to check the effectiveness of any improved tube structure, was in their being placed in actual operation on the Green Bay unit. Each tube improvement showing significant results in both static water boil and dynamic life cycle tests was duplicated to get the required number of tubes to assemble into a module for placement in service. Ultimately, 17 tube improvements were placed in service after prescreening (by the accelerated tests at Fluid Systems) suggested their ultimate success in the field.

Eventually, one tube's resin/glass composition emerged as superior to all others. It consisted of a more chemically inert glass fiber and new resin combination that overcame an encountered, secondary problem of loss of old resin to new glass adhesion. The final new resin/new glass combination provided an adequate matrix for glass bonding, glass distribution, and tube porosity.

With on-board accelerated testing continuing to show good results, and units at Green Bay with several hundred hours exposure to the process water feed, it was decided to retube the entire plant with the new version. The rebuild of the Green Bay plant commenced January, 1975, and has continued through the present date with the final 75 modules, including 26 spares, scheduled for installation in February, 1976. A tremendous improvement in support tube life was achieved with the new resin/glass composition. This improved life is shown graphically in Figure 23. The originally supplied modules are compared with the new modules based on cumulative percent failures with exposure hours. Unfortunately, we have only an exposure time of 6000 hours on the new tubes and cannot predict what the maximum effective module life will be. To date there have been fewer than two dozen module failures which have been ascribed to tube ruptures, and these few have been determined to have been caused by manufacturing variances rather than structural deficiencies. When a failure is caused by a flaw, correction requires only the replacement of one tube of the 18, and the module can be placed back in service. This was not the case previously with the original modules, as commonly all the tubes were structurally weakened by

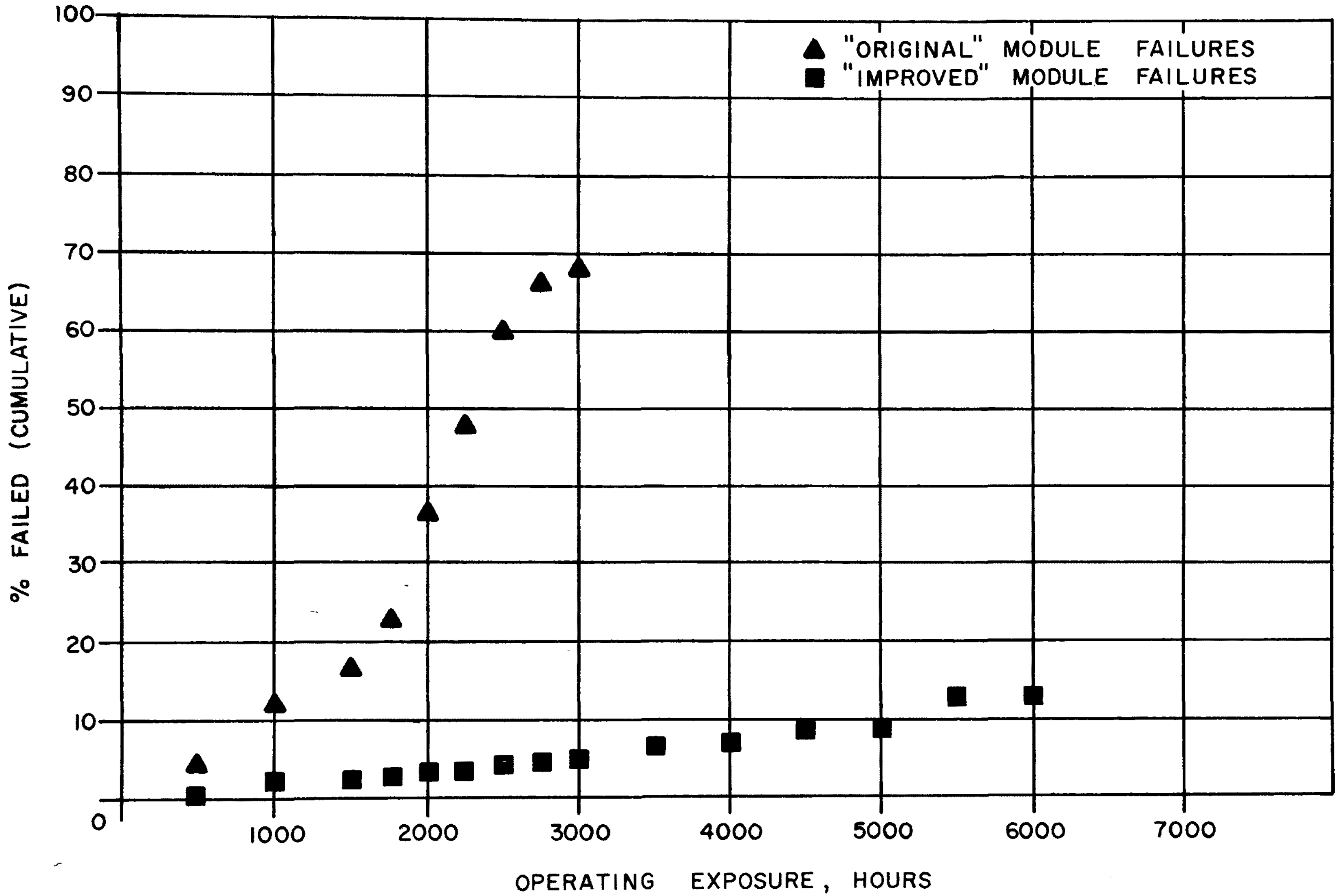

Figure 23. "Original" vs. "improved" module failure experience.

etching when the first failure occurred. The oldest tubes of improved structure have over 8000 hours exposure and show signs of lasting well into the second year of operation, considerably beyond the warranty period.

As a result of the problem experienced at Green Bay and its ultimate solution, Fluid Systems has incorporated the new improved tube as its standard product for all high pressure reverse osmosis applications, a technical development which has already paid bonus benefits in providing the answer to another application where the older tube version showed shortened life in the field.

REVERSE OSMOSIS MEMBRANE FOULING

Membrane fouling continues to be an area warranting further research and development. For a more definitive explanation of membrane fouling, reference is made to the work done by the Institute of Paper Chemistry, entitled Reverse Osmosis Concentration of Dilute Pulp and Paper Effluents, USEPA, 12040 EEL, 02/72.(2)

Observed Nature of Membrane Fouling

Membrane fouling by mill process water takes place by seemingly multiple, complicated, and not well understood mechanisms; however, the fouling observed in the Havens-type tubular module can be classified into two distinct types.

The first type of fouling is caused by fiber debris and wood fines. Although the process water passing the membrane contains only a small amount of filterable fines, after prolonged exposure, debris collecting on the membrane will significantly reduce the membrane permeability. This debris is always present. It is that passing the two-step filtering process to make the water suitable for use on paper machine showers.

The second type of observed fouling is scale buildup. After an operating exposure of 750 to 1000 hours, a tough scale can form on the membrane surface, reducing the membrane flux from 1.7 to 5.1 liters per square meter-hr (1 to 3 gal/ft^2-day). Analysis indicates that the process water system is normally saturated with respect to calcium; therefore, the propensity to form insoluble calcium salts is extremely great. Calcium oxalate has been identified as the major foulant material in module scale examined by Scanning Electron Microscopy. The oxalate anion is a naturally occurring constituent found in varying amounts in hardwood bark. Red oak contains a relatively high concentration of oxalate. Red oak chips are regularly received as a component of the mixed hardwood wood supply to the mill. Calcium oxalate will salt out of solution upon cooling to form an extremely insoluble scale. As the process water feed to the reverse osmosis plant must be cooled from 65°C (150°F) to 38°C (100°F), the reaction takes place quite readily on heat exchanger, pump, and piping, as well as membrane surfaces.

In addition to the observed long-term fouling, data analysis indicates short-term effects can be experienced as well. As an example, the startup of the fluidized bed reactor requires bed material (granular Na_2SO_4 and Na_2CO_3) to be transferred into the reactor. Dust carryover of fines is scrubbed out in the reactor's Venturi evaporator/scrubber. Normally, this dust carryover is not a problem as liquor is used as the scrubbing agent; but during startup, process water and not liquor is pumped to the Venturi evaporator/scrubber. This process water, too dilute for combustion, is brought back to the mill, saturated with soluble sodium sulfate and carbonate. The formation and deposition of relatively insoluble sulfate, carbonate, and bicarbonate salts accounts for the blinding of the membrane in a matter of hours. To avoid this rapid flux drop, the precaution has been taken not to run the reverse osmosis plant during or immediately following a reactor startup. The observed coincidence of reactor startup and drastic membrane flux loss has ceased since this change was made.

Countermeasures Currently in Use to Remove Fouling

It was determined in the pilot plant work that an osmotic backflush would be necessary for 12 minutes in every 120 minutes of operation. This osmotic backflush allows for a lifting of deposited material that has not become physiochemically attached to the membrane surface. For further information regarding the development of this technique, consult the previously mentioned reference and Recycle of Papermill Waste Waters and Application of Reverse Osmosis, USEPA, 12040 FUB, 01/72.(3)

In addition to maintaining a turbulent flow velocity of 1.2 to 1.5 meters per second (4 to 5 ft/sec) and using the osmotic backflush, it was determined that a daily high velocity flush with process feed water was necessary to further prevent the deposition of fiber debris. This technique involves flushing one-half the modules at a time for 10 minutes per day using the full pumping capacity of the plant, directing the discharge back to the process water recycle system.

Although these practices are valuable in preventing the buildup of inordinate amounts of fiber debris, they are not effective in eliminating the fouling due to insoluble precipitated salts. It became evident that a cleaning procedure would be necessary; thus, recommendations were sought from Universal Oil Products on chemical cleaning techniques that would remove the foulants without harming the membrane or its support tubes.

The cleaning procedure recommended involves flushing all of the process water from the modules as a first step. Next, a 2% solution of E.D.T.A. Na_4 prepared with tap water and pH adjusted to 7.0 with HCl is recycled through the modules for two to four hours at a flow rate of at least 13.2 liters per minute (3.5 gpm) per module row. A previously recommended 45-hour quiescent soak period was eventually deleted as no improvement in flux was observed after the initial 4-hour dynamic treatment. After the E.D.T.A. treatment, the plant is purged with tap water and flux checks are made prior to returning the plant to process water. All discharges of flushing and cleaning waters are returned to the process water recycle system.

The flux rate of a given group of modules can be improved from 1.7 to 5.1 liters per square meter-hr (1 to 3 gal/ft^2-day), depending on the condition of the modules prior to the time of cleaning. In general, this cleaning will return the plant flux to a level of 8.5 to 10.2 liters per square meter-hr (5 to 6 gal/ft^2-day), close to the design capacity.

Because of the cost of E.D.T.A. treatment, other types of cleaning agents have been investigated. One that appears to show promise is a combination of sodium tripolyphosphate and enzymatic cleaning agents. It is commercially available as BIZ, a home laundry product. The procedure used to date requires purging the plant of process water, introducing a 1% solution of BIZ, pH adjusted to 7.0 with HCl, and allowing this solution to dynamically wash the modules for three to four hours. The plant is then allowed to soak for 12 to 18 hours prior to being flushed and put back on line. Limited experience with BIZ indicates the same type of flux recovery as provided by E.D.T.A., but at considerably less cost.

Areas of Anomalous Behavior Requiring Further Study

Four years of pilot study and two and one-half years of full-scale operation have not provided all of the information needed to understand some of the anomalous behavior observed in membrane fouling.

Knowing the many chemical and physical constituents present in the mill's process water, it is not possible at this time to explain why on some occasions a flux drop of 3.4 to 5.1 liters per square meter-hr (2 to 3 gal/ft^2-day) will recover without having changed any operating factors and without cleaning. It appears that, on some occasions, factors causing the fouling are countered by other unidentified changes occurring in the process water system.

Six modules have been set apart in a pilot plant receiving the same feed, at feed conditions, as the main plant. However, the means are available on the pilot unit to test various techniques of foulant inhibitors and cleaning agents.

The work to be done in the ensuing year will be aimed at identifying the nature and mechanisms of fouling and developing a better understanding of mill operation as it affects reverse osmosis plant function.

REVERSE OSMOSIS PUMP AND PUMP SEAL PROBLEMS

The pump assembly for the reverse osmosis plant came as a completely piped unit consisting of six pumps, valving, and interconnecting piping. There are two feed pumps and four recycle pumps of multistage centrifugal design. The feed pumps are Goulds, Type 3933, with 47 stages; and the recycle pumps are Goulds, Type 3933, with 23 stages.

The first eight months of operation for the pumps seemed to indicate acceptable performance. Then, in the ninth month, a critical problem appeared which has been partially resolved at this time. A dramatic drop in pump amperage indicated a loss of capacity. Upon disassembling the affected pumps, it was found that a severe degradation of the plastic impellers had occurred. The impellers are constructed in two pieces by injection molding and then assembled using a solvent bond. The nature of the damage to the impellers indicated that the components had separated and then had begun to disintegrate. Because of the multistaging, the damage was extensive as broken pieces of impeller were forced through the successive units causing further damage. Chemical analysis of the process water indicated the presence of constituents which could adversely affect the life of the bond between the two impeller components.

To overcome the problem of impeller disintegration, an impeller of more substantial construction was substituted for the original type. This has significantly reduced the disintegration; however, the bond separation continues to be a problem at the time of this writing.

To further complicate the resolution of the pump problems, it became evident that the main support bearings for the impeller drive shaft were deteriorating with use. The feed pumps have five such bearings and the recycle pumps three each. The problem appeared to be caused by the swelling of the Buna-N bearing. The impeller shaft has a stainless steel sleeve which was abraded away by the swollen bearing. Once there was sufficient reduction of the sleeve cross section, the shaft was no longer firmly held in place. As the drive shaft began to travel eccentrically, this caused the plastic impellers to contact the sides of the stainless steel bowls. The result was debonding of the impeller components and some physical wear to the bowls themselves.

In attempting to overcome the bearing problem, new ceramic-coated stainless sleeves were used to replace the original sleeve type. This did not completely eliminate the problem; therefore, the remaining corrective measure appears to be replacing the Buna-N bearing material. A composition bearing has been substituted for the Buna-N type on one of the pumps. The bearing material is a bronze impregnated fluorocarbon polymer that has a steel backing. The bearings have functioned for three months in which time the pump has shown no amp loss or increase in vibration. An actual operating exposure of a year or more will be needed to demonstrate any superiority over the original bearing type.

The motor end pump rotary mechanical seals have also required attention. Leakage around these seals causes considerable housekeeping duty as the spray of process water from the leaking pumps can be extensive. A new supplier's seal is being substituted for the original with some success to date. In addition, the shaft sleeve at this location on the drive shaft has been affixed with cementing agents to reduce leakage between the shaft and the seal shaft sleeve.

For two years, total plant maintenance cost for parts and labor (excluding modules) was $22,330.26. Of this cost, $15,877.00 was for pump repairs. It is hoped the pump repair costs will be reduced in future years with changes that are presently being evaluated.

SECTION 6

RESULTS AND DISCUSSION

RESUME OF MILL OPERATING EXPERIENCE

The use of intensive recycling has created some new requirements and costs, such as replacement of traditional materials with more expensive resistant materials; but in many ways, recycling has resulted in cost reductions, as well. Production cost comparisons (see pages 61, 62, and 64) illustrate some of these cost reductions. This experience contrasts with increases in operating costs required by end of the pipe biological treatment methods and thus illustrates the cost advantages of in-plant reuse, where possible.

In obtaining the present point of equilibrium, the process water soluble solids content rose from 2.5% in 1970 to as high as 5.4% in 1974 (Figure 24). The peak concentration during this six-year period was 7.5%. The system temperature also increased from the 54-60°C range (130-140°F) to the 65-71°C range (150-160°F). Both factors affect the corrosive properties of the process water. Also, as has been previously described under "Process Water System Ash Buildup," the circulated ash followed the same pattern as the soluble solids until a method was found to remove it in a concentrated form from the system. How much of the increase in cost of refiner plates (Figure 24) and wires (Figure 25) can be attributed to wear as a result of ash circulation is open to conjecture, but it is certainly a major factor. The other factors of increased temperature and solubles were unchanged in 1975 when costs for both were decreased as ash decreased. In an effort to make a valid comparison, all costs related in these graphs are adjusted for inflation at 9% per year. It is still difficult to make good comparisons for wire and felt cost because of the changes in materials made during these years. During the base year, 1971, bronze wires were used; but from 1972 through 1975, most wires were stainless steel.

A normal stainless wire will run on the machine about 40 to 50 days, as compared to seven to ten days for a bronze wire. We have tried a few plastic wires with mixed success initially but with good results so far in 1976. Paper machine wet felt costs

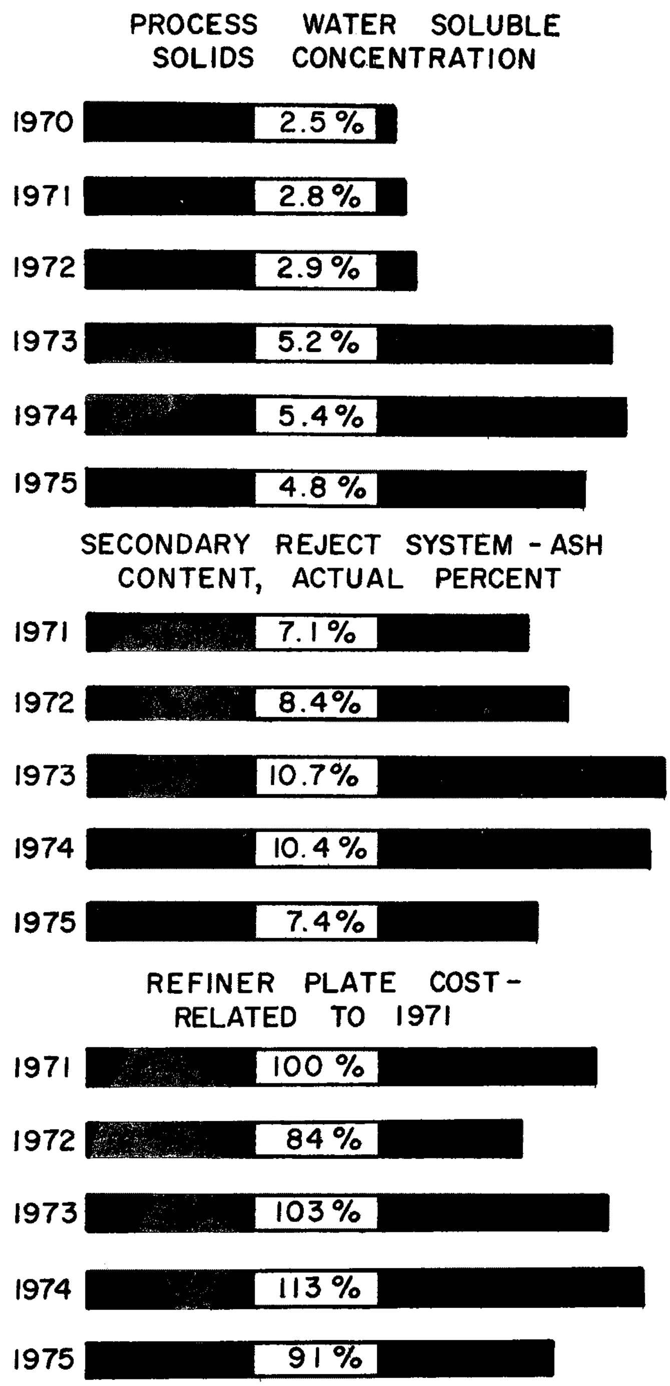

Figure 24. Relationship of percent dissolved solids, secondary reject system percent ash, and refiner plate cost per short ton product, as percent of 1971 costs.

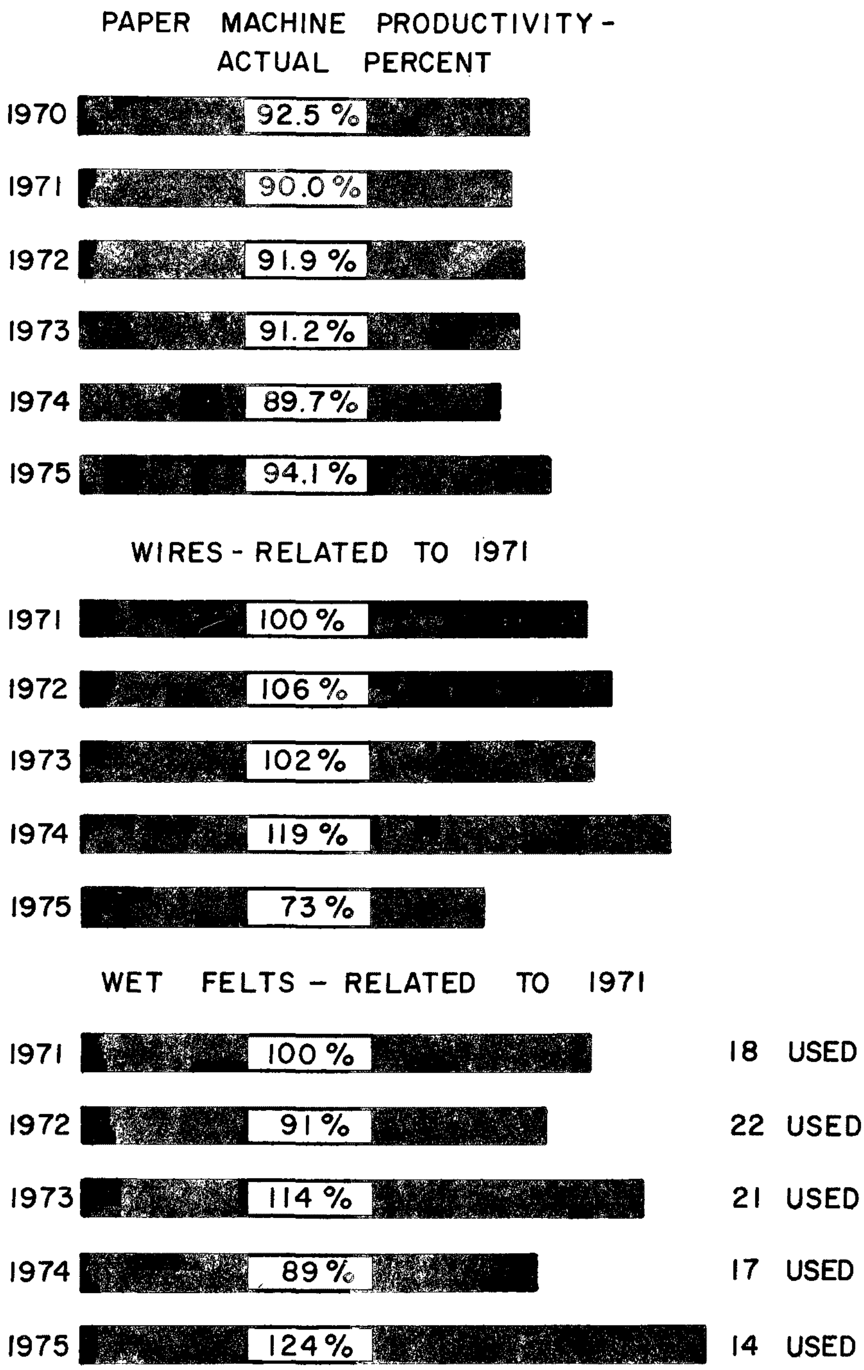

Figure 25. Paper machine productivity and clothing costs per short ton product, as percent of 1971 costs.

are not any easier to compare. In 1971, the construction was mostly wool; but increasing amounts of synthetics have been used since then so that presently they are 100% synthetic. As can be seen, the number of felts used did decrease even though the cost per ton was slightly higher.

The last factor, and most important, is paper machine productivity. This is the ratio of the maximum tonnage the paper machine could produce with no downtime or paper breaks to the actual tonnage produced. As can be observed, this aspect was essentially unchanged by recycling. Also, although there has been a substantial increase in wire pit suspended solids (from 0.2% to 0.3% as a result of closure), there has not been a loss of machine speed. Higher process water temperature and higher average sheet moisture (computer control) have undoubtedly been compensating factors. Furthermore, the increase in water-extractables in the final sheet--increased from 20 to 41 kilograms per metric ton (40 to 180 lb/ton) due to closure--has been accompanied by a reduction in fiber content at the same basis weight and, presumably, a corresponding reduction in drainage resistance.

A number of other important cost factors are graphed in Figure 26. In all cases adjusted for inflation, improvements were made on the base year of 1971.

The cost reduction for water and steam are easily reconcilable as a result of closing the water system. Some portion of the cost of electricity may also be related to water recycle, but most of this reduction is due to a conscious effort to conserve power instituted as a management program.

The last item, maintenance, is the one that might be anticipated to rise dramatically; but this was not the case. Fortunately, most of the mill system in 1971 was stainless steel. The two principal non-stainless areas were parts of the fourdrinier and many of the process pumps. Pump cases in cast iron construction that had previously lasted two to three years corroded in as little as five months. As gradual replacement was necessary, it was made in all stainless pump construction.

Also, some changes and modifications had to be made at the fourdrinier. Grills, catwalks, and general machine components required more frequent cleaning. Corrosion of cast iron bearing housings on wire return rolls was accelerated and required more frequent replacement until these were replaced in stainless. Higher temperature greases were required for wire return roll bearings. The wire return roll doctor blades had to be changed from micarta to polyethylene because the life had decreased from six months to one week. Corrosion of the fourdrinier main frame and soleplate is a problem. There have been recent attempts to apply an epoxy coating (Trowelon) similar to that used

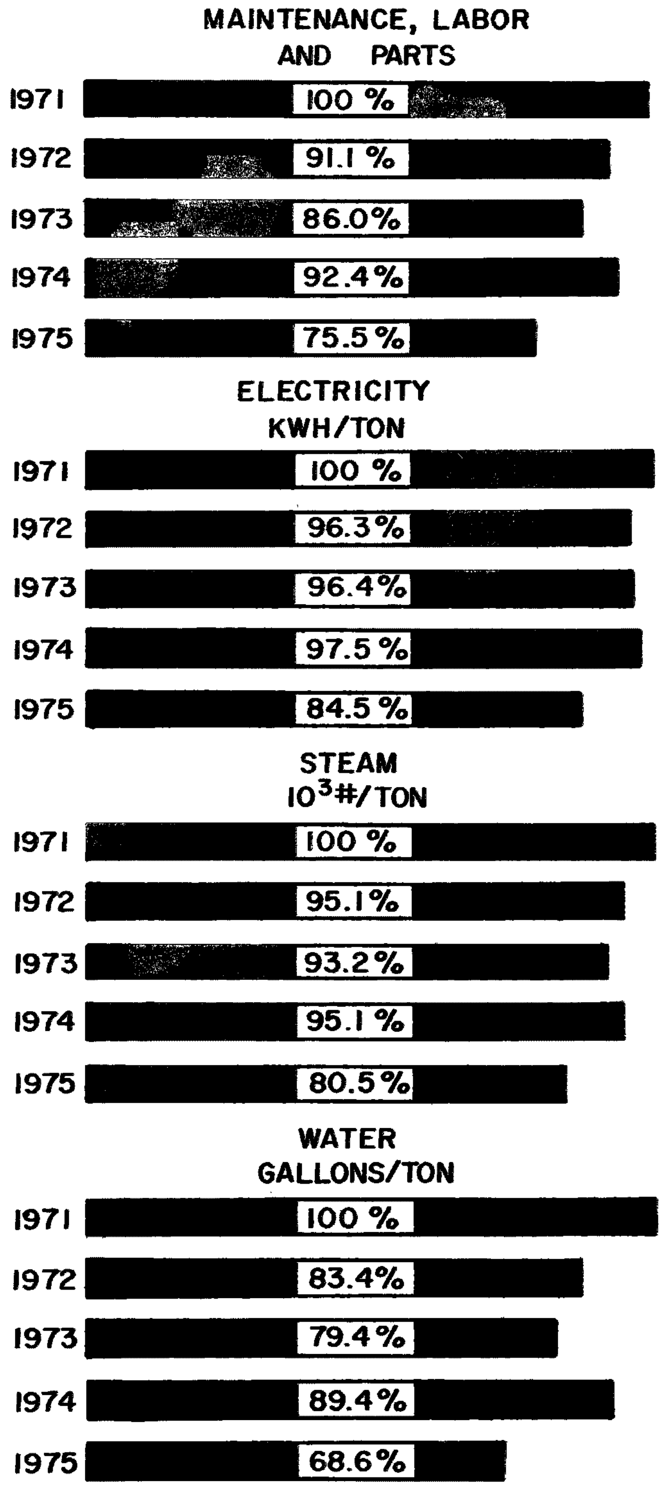

Figure 26. Total mill cost factors per short ton product expressed as percent of 1971 requirements.

successfully on concrete in the wire and seal pits. Only time will indicate how successful this approach is for long-term protection of these vulnerable components. With all the problems, it is a testimonial to the people involved that maintenance costs have actually decreased during this period of ever-increasing recycling. This decrease, in most part, is due to the proper selection of materials and good management by the maintenance staff.

There have been some process changes relative to recycling that are continuing problems. Chemical requirements for sizing can be increased from two to three times over that required for washed stock; but as these are not costly chemicals, this can be tolerated. We did find it uneconomical to produce wet strength grades because chemical requirements for equal wet strength are three to four times greater than those required for washed NSSC stock, and this additive is an expensive chemical.

Contaminants from waste paper sources (such as latex, hot melts, and asphalt) accumulate in the process water and have a greater chance of being deposited on paper machine wires and press rolls. We have found ways to minimize the problem but not to eliminate it.

Any additive to the process water system in a closed loop becomes a potential hazard in that it may react with other chemicals or with itself at some concentration to produce a chemical slime. Therefore, it is necessary to have an overall deposit-control program, and its control merits the sustained attention of operating mill management. Any new additive or change in rate of an established additive must be carefully scrutinized before implementation and watched closely for problems after a change is made.

Mill shutdowns and subsequent startups can be problems, particularly if the downtime is of long duration. The large volume of process water--1134 to 1512 cubic meters (300,000 to 400,000 gal) in our system--becomes increasingly susceptible to bacterial growth as it cools. Increased dosage of the same slimicides used for control under operating conditions can deter microbiological activity up to two days in stagnant storage. If a shutdown is to be for three days or longer, provision must be made to add additional amounts of slimicide at two-day intervals and to mix the stored water by good agitation or by circulation with pumps.

For long shutdowns (up to two weeks), we have run out our inventory of paper stock completely, even if the last reels are not salable. The machine system is completely emptied and washed. All process water is stored in three large tanks, which can be circulated for slimicide addition. Insulation of these tanks is helpful to retain temperature as long as possible. In our cold climate, exposed pipelines must be steam traced and insulated to avoid freezing.

Another mill may choose different options to avoid biological deterioration of stored water, as each mill has its own unique system and problems.

MEDIUM STRENGTH CHARACTERISTICS AND CONVERSION BEHAVIOR

One of the concerns during the progressive closure of the mill process system was the effect on strength and runnability as the retained soluble matter in the sheet increased. A number of approaches were used to try to evaluate the consequences of process water closure:

(1) Physical testing at the paper machine.

(2) A thorough investigation of all customer complaints, even minor ones.

(3) Continuous monitoring of our own largest corrugating plant for changes in strength or runnability.

(4) A study was sponsored under the U. S. Environmental Protection Agency project to try to determine the effects of degree of closure on medium properties by testing it under laboratory conditions at the Institute of Paper Chemistry.

The changes at the paper machine were so gradual that is was impossible to show any immediate, clear-cut effects. After an extended period of observation, it has been concluded that the soluble solids retained in the sheet do have some effect on fiber bonding. The change is small up to our normal maximum solubles level of 6% and affects mullen, tear, and tensile strength but shows little effect in tests related to stiffness, such as concora and ring crush. The measured reduction in mullen brought about by increasing solubles in the process water from 1% to 5% was a drop from 17.7 to 15.9 kilograms (39 to 35 lb), or approximately 10%.

Reductions in tensile strength would appear to be of the same magnitude; and tear may be just slightly greater, but our data are not complete enough to give precise numbers. Mullen is run on each set off the paper machine as a routine test, so good, continuous data are available. Tear and tensile are not normal tests. Based on laboratory testing, there is also some indication of a reduction in wet web strength with increasing sheet soluble levels, again of about the same 10% magnitude.

The complaints from our customers were not very indicative of problems related to mill closure. There were some intermittent problems involving two corrugators using archaic tension systems, but these problems had existed before closure.

Our Green Bay Corrugated Division is a very modern operation with an extensive quality control program. This continuous quality program was well established before 1971, so comparison figures were readily available for strength. Also, our corrugators are run on an incentive program, as are most in this industry, so that any interference with normal operations would be indicated immediately. Again, no trends were observed during closure that could be attributed to the increased solubles level in the medium. Table 11 is a comparison of medium and corrugated board strength for 1970 and 1975, representing open system and almost completely closed system, respectively.

TABLE 11. STRENGTH COMPARISON--OPEN SYSTEM, 1970, TO CLOSED SYSTEM, 1975

Item	Year 1970	Year 1975
Paper machine		
Basis weight (pounds/1000 sq ft)	26.3	26.1
Concora (pounds)	71.8	70.6
Mullen (pounds)	42.0	34.0
Corrugator		
Flat crush (pounds/sq in)		
A Flute	30.8	30.1
B Flute	48.1	55.0
C Flute	46.5	40.3
Standard box, top to bottom compression strength (percent of standard)	100.6	107.4

The summary of the work carried out at the Institute of Paper Chemistry is reported in Appendix B.

The slight reduction in bonding strength has not been a problem involving the paper machine or corrugator. The problem has been negated to some degree by the use of slightly more long fiber in the sheet in recent years. This is added to the system in the form of corrugator plant clippings and/or recycled corrugated boxes, depending on market conditions. The percentage has increased from less than 20% to approximately 30%. This change has helped wet web strength, and therefore minimized breaks occurring at the couch and press sections with no loss of concora strength.

ECONOMIC EVALUATION OF REVERSE OSMOSIS VS. EVAPORATION

An economic comparison is presented to show the relative costs of water removal by reverse osmosis and evaporation. Updated capital cost data are provided for Green Bay Packaging's reverse osmosis plant and the company's two effect evaporator. Energy cost and maintenance cost data are also provided.

To provide an effective evaluation, the capital and operating costs are also provided for a vapor compression evaporative system. However, maintenance cost data are based on limited field experience from other users of vapor compression evaporation.

For design comparison, it is assumed that the following conditions would hold true for each system:

(1) Daily water removal capacity--109 cubic meters per day (28,800 gal/day).

(2) Annual water removal--19,100 cubic meters (5.05×10^6 gal) for 60% annual operating time.

(3) Mill process water feed would be essentially free of suspended solids with a dissolved solids concentration of 5% average.

(4) Concentrated product will be approximately 7% dissolved solids.

(5) Product quality should be equally low in contaminants.

For such water removal capacity, the purchased reverse osmosis plant has 288 modules, or 445.9 square meters (4800 ft^2) of permeable membrane. It is powered by two 25-Hp feed pumps and six 10-Hp recycle pumps. There is also a 1½-Hp permeate pump for ultimate disposal of the permeate.

The comparable two effect evaporator would be essentially the same size as the existing liquor evaporator at the mill's recovery plant. As the existing evaporator is designed to produce 150 cubic meters per day (39,700 gal/day) of condensate, a somewhat smaller tube surface area would be required than actually is in use in the recovery plant evaporator. The two effect evaporator is designed to use 123 kilograms per square centimeter (175 psi) steam and up to 1.66 cubic meters per minute (440 gpm) condenser cooling water. A normal economy for this device is 0.68 kilograms (1.5 lb) condensate per 0.45 kilograms (1 lb) steam.

The vapor compression evaporator would consist of two units with combined capacity of 109 cubic meters (28,800 gal) daily. The necessary heat exchangers would be provided to transfer all available heat to the feed stream to raise the feed to boiling. Essentially all energy input is electrical with a small fraction as steam.

1976 Capital and Installed Costs

	Reverse Osmosis	Two Effect Evaporator	Comparable Vapor Compression Evaporator
Total installed cost	$324,572	$200,000	$250,000

1974-1975 Operating Cost Experience

Operating cost--$/3.785 cubic meters (1000 gal) purified water			
Energy consumption	$1.70	$8.60	$3.34
Depreciation	6.45	3.18	3.71
Maintenance and labor	2.58	.91	.99
Total cost--$/3.785 m^3	$10.73	$12.69	$8.04

The total installed costs for reverse osmosis and the two effect evaporation have been updated from the original costs by the use of CHEMICAL ENGINEERING plant cost indices. The vapor compression installed cost estimate was supplied by the manufacturer of such equipment.

Energy input costs are given based on electricity and steam costs at the mill for 1974 and 1975. The vapor compression energy cost is based on a conservative estimate of 118.8 kilogram-calorie per kilogram (66 Btu/lb) evaporation and is considered to be a cost of electrical energy. This energy consumption value is based on the experience of an existing evaporator used in a pulp mill application.

Depreciation charges are assumed to be for a 12-year useful life on all hardware. It should be noted that the expected useful module life in reverse osmosis is given at five years--this may be conservative.

Maintenance and labor costs for reverse osmosis and two effect evaporation are based on mill experience for 1974 and 1975. These costs for reverse osmosis may be excessive because of the developmental nature of the changes required in the pump-in system. The maintenance costs for vapor compression are based on limited field experience and the assumption that maintenance will cost 2% per year of the installed cost.

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APPENDIX A

ANALYTICAL AND TEST PROCEDURES AND EQUATIONS USED IN REVERSE OSMOSIS PLANT

The analytical samples were collected when the operating conditions of the units were stable. This required that the samples be taken at the middle of each pause-operate-pause cycle, as the conditions close to the depressurization (pause) period were not representative of the majority of the operating period. Operating data, e.g. pressures, were recorded at the time of taking samples.

Frequent measurements were made of the total solids in the feed and concentrate. The sample is weighed in an oven-dried tared beaker, dried overnight at 105°C, cooled in a desiccator, and reweighed.

Soluble solids and suspended solids were determined by standard filtration and oven drying. A sample is filtered through a glass fiber pad (Reeve Angel 934 AH, 11 cm), and the filtrate is collected. The pad is oven-dried, cooled in a desiccator, and reweighed for suspended solids. The filtrate is weighed in an oven-dried tared beaker, dried overnight at 105°C, cooled in a desiccator, and reweighed for soluble solids. Samples of product water from the reverse osmosis units required no filtering.

Sodium content was determined with a Model 303 Perkin-Elmer atomic absorption spectrophotometer. The sample is prepared to the proper working range using distilled water for dilution. The spectrophotometer is operated according to Perkin-Elmer's Analytical Methods Manual.

Analysis of incubated bottles for five-day biochemical oxygen demand (BOD_5) was measured according to procedures outlined by the Yellow Springs Instrument Company using their Model 54 Dissolved Oxygen Meter. Chemical requirements, sample preparation, apparatus, and calculations described in Standard Methods for the Examination of Water and Waste Water (APHA-AWWA-WPCF), 13th edition, 1971, page 489, Method 219, were used for the remainder of the analysis. Volumetric flasks and pipettes are utilized for measurement and dilution. A sample, two cubic centimeters or larger, is pipetted directly into the BOD bottle.

Color is determined by spectrophotometric comparison of the sample with known concentration of colored solutions. The procedure is described in NCASI Stream Improvement Technical Bulletin No. 253, December, 1971.

EQUATIONS

All flux data (unless indicated otherwise) are reported at standardized conditions of plant design of 38°C (100°F), a feed soluble solids of 5%, and a plant feed pressure of 41.4 bars (600 psi), and have either been obtained at these conditions or have been corrected to these conditions by the following formula. Correction is avoided when possible because of additional lab work and errors in measurement of average module soluble solids.

Permeate flux in gallons per day per sq ft of membrane

$$= \frac{\text{PPF} \times T_c \times 1440}{\text{No. of modules} \times 16.67\ \text{ft}^2 \text{ per module}} \times \frac{\text{AMFP} - 185}{\text{AMFP} - \pi_o}$$

where PPF = plant permeate flow in gallons per minute

AMFP = average module feed pressure in pounds per sq in

π_o = actual osmotic pressure
= 37* x percent average module soluble solids

T_c = temperature correction to 38°C (decrease by 2.3% above 38°C, or increase by 2.3% below 38°C)

185 = osmotic pressure at 5% soluble solids
= 37* x 5

1440 = minutes per day

*average measured osmotic pressure of process water at 1% soluble solids, as observed at Green Bay Packaging

Material balances and percent rejections for soluble solids, BOD, sodium, and color are obtained using plant measurements, laboratory data, and the following expressions.

Flow Balance:

$$V_f = V_c + V_p$$

where V = volume per unit time of plant flow for feed ($_f$), concentrate ($_c$), or permeate ($_p$). These are obtained from plant instrument measurement and checked by actual timed volume collection in a container of known volume.

Mass Balance:

$$W_f = W_c + W_p$$

where W = component weight per unit time in each stream of sodium, soluble solids, BOD, or color. These are obtained from analytical determination of concentration described previously, and the expression for each is as follows:

$$W_f = V_f \times \text{specific gravity} \times \text{concentration}$$

Percent rejection for each component is then calculated as follows:

$$\% \text{ Rejection} = (1 - W_p/W_f)100$$

Figure A-1. Typical routine reverse osmosis data sheet.

Entry No.	Date 1976	Clock Hrs.	Raw (Process Water) Feed					Module Feed			Permeate	
			Flow Rate (gpm)	Temp. (°F)	No. of Modules In Service	Dis. Sol. (%)	pH	Flow (gpm)	Feed Press. (psi)	Back Press. (psi)	Conductivity (μmhos)	Flow (gpm)
608	2/06	10378.9	79.5	98	261	5.15	5.6	240	600	460	410	17.4
609	2/10	10459.8	82.0	98	261	5.08	5.5	245	600	450	370	16.8
610	2/11	10480.0	81.5	98	258	4.17	5.4	244	600	460	280	19.8
611	2/12	10501.1	81.0	98	258	5.04	5.5	244	600	455	345	16.8
612	2/13	10521.8	81.5	100	261	5.12	5.5	246	600	451	335	17.5
613	2/24	10553.9	82.0	100	261	5.33	5.6	246	600	461	385	16.5
614	2/25	10570.3	82.0	100	261	5.46	5.6	240	600	490	330	16.5
615	2/26	10594.5	82.0	105	261	5.12	5.7	245	600	471	290	16.8
616	3/01	10676.0	81.5	99	258	4.29	6.0	245	600	452	260	17.1
617	3/05	10762.7	79.5	99	258	5.23	5.7	240	600	450	370	12.0
618	3/09	10848.0	80.0	101	255	5.64	5.8	220	600	450	450	11.4
619	3/10	10868.5	80.0	97	258	6.02	5.8	228	600	445	500	10.8
620	3/11	10889.5	80.0	98	258	6.29	5.9	237	600	446	570	9.6

APPENDIX B

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

EFFECT OF MILL WATER SYSTEM CLOSURE ON CORRUGATING MEDIUM QUALITY

SUMMARY

This study was carried out under the sponsorship of Green Bay Packaging Inc. with the objective of determining the effect of the degree of closure of their corrugating medium mill process water system on selected corrugating medium quality characteristics. For this purpose, three 30-centimeter (12-in) wide rolls of corrugating medium were obtained for each of the following degrees of mill water system closure:

1. "Partially" closed system--process water solubles, 2.9%.

2. "Fully" closed system--process water solubles, 5.6%.

It should be noted that it was originally planned to evaluate a third mill process water condition, namely, an "open" system, to serve as the reference condition; however, these samples could not be obtained for the study by the cooperator.

Each roll of medium was fabricated into single-faced board shortly after arrival at the Institute and after 60 days storage to determine its conversion quality. Conversion quality was evaluated in terms of (1) the maximum runnability conditions of corrugator speed and web tensions which could be employed without causing fractured flutes, (2) flute height, (3) average difference in flute height (related to high-low flute formation), and (4) draw factor. At each time of fabrication, samples of the corrugating medium were obtained and evaluated for selected physical characteristics.

The following results were obtained:

1. In general, the mediums representing both the "partial" and "fully" closed mill water system exhibited

satisfactory conversion behavior on the corrugator. The "partial" closure water system medium generally exhibited somewhat higher physical property levels than the "fully" closed system mediums. However, the differences in physical properties may not be of commercial importance in many cases. A more detailed summary of the results is as follows:

2. Conversion Behavior.

   a. Runnability.

      When evaluated on arrival, the maximum web tensions which could be employed without fracture at a corrugator speed of 183 meters per minute (600 fpm) ranged from 272 to 363 grams per centimeter (1.5 to 2.0 lb/in) and averaged 327 grams per centimeter (1.8 lb/in) for the "partially" closed system mediums. The corresponding results for the mediums representing the "fully" closed system ranged from 182 to 363 grams per centimeter (1.0 to 2.0 lb/in) and averaged 272 grams per centimeter (1.5 lb/in). The difference in average runnability is not considered to be significant in view of the variability from roll-to-roll and the levels appear to fall within the usual commercial range for good runnability. After the 60-day storage period, the maximum runnabilities of the "partial" system closure medium rolls decreased about 109 grams per centimeter (0.6 lb/in) on the average. A decrease of this magnitude due to aging is not uncommon. The medium rolls representing the "fully" closed system exhibited about the same maximum runnability tension after aging as was obtained on arrival.

   b. Flute height and high-low flute formation.

      The degree of system closure did not have any marked effect on the flute height of the single-faced boards or the tendency of the mediums to form high-low flutes.

3. Physical Characteristics of Medium.

   a. The Concora flat crush strengths of the "partially" closed system mediums averaged 2.7% higher than that of the "fully" closed system mediums in the "on arrival" tests but the difference was not statistically significant.

b. The degree of closure did not have a statistically significant effect on the cross-direction edgewise compression strength of the medium.

c. The "partially" closed system mediums exhibited a slightly higher water drop time on arrival which was statistically significant but the difference may not be of commercial importance.

d. The "partially" closed system mediums exhibited significantly higher tearing strengths and tensile properties than the fully closed system mediums in the "on arrival" tests, but the differences may not be of commercial importance in many applications.

APPENDIX C

PROJECT VISITORS

MAY, 1972, THROUGH DECEMBER, 1976

Number	Organization or Affiliation
	U. S. Industrial Companies
2	A & P, National Dairy Division
3	Aqua-Chem, Inc.
1	Butter Manufacturing
1	Chrysler Outboard Corporation
2	Clark & Vicario
2	Continental Can Co., Inc.
2	Dresser Industries, Inc.
2	Eastman Chemical International Co.
1	W. D. Ehrke Co.
4	Fabric Research Laboratories, Inc./Albany International Co.
2	Hammermill Paper Co.
2	Kenics Corporation
1	Kimberly Clark Corporation
1	McGark Strapp & Associates
2	McMaster-Carr
1	Milk Specialties Co.
5	Nicolet Paper Co.
5	Owens-Illinois
2	H. C. Prange Co.
2	Proctor & Gamble
1	Reed Paper Ltd.
1	Rex Chainbelt, Inc.
3	St. Regis Paper Co.
1	L. D. Schreiber Cheese Co., Ltd.
1	Scott Paper
5	Sonoco Products Co.
5	Stone Container
1	3M Co.
2	Universal Foods
1	Ward's Cheese
2	WesCor Corporation
1	Westinghouse
2	Weston Paper and Mfg. Co.
2	Whirlpool Corporation

Number	Organization or Affiliation
	Foreign Concerns
3	ASSI Development Laboratory (Sweden)
1	Australian Paper Manufacturers, Ltd.
2	B.D.M.R. Consultants (Canada)
2	T. W. Beak Consultants Ltd. (Canada)
3	Broby Industrier AB (Sweden)
3	Cellulose Attisholz AG (Switzerland)
3	Daicel, Ltd. (Japan)
7	Domtar, Ltd. (Canada)
2	Emsland Staerke (Germany)
5	Fiskeby AB (Sweden)
1	IVL Consulting Ltd. (Sweden)
1	IVL Swedish Pollution Control Co.
1	IVL Swedish Water and Air Pollution Research Laboratory
2	Kon. Scholten Honig. (Netherlands)
2	LaRochette-Venize Mill (France)
1	Mitsubishi Heavy Industries, Ltd. (Japan)
1	Mitsui & Co. (Japan)
4	MoDoCell (Sweden)
1	National Environmental Board (Sweden)
1	Örebro Pappersbruk AB (Sweden)
1	Osaka Municipal Technical Research Institute (Japan)
1	Papeteries de L'Epte (France)
2	Paterson Candy International, Ltd. (England)
3	Sanyo-Kokusaku Pulp Co., Ltd. (Japan)
3	Sasakura Engineering (Japan)
1	South African Pulp and Paper Industries, Ltd.
1	Tomoegawa Paper Mfg. Co., Ltd. (Japan)
1	Woodall-Duckham Pacific Ltd. (Australia)
	Government
4	Environmental Protection Service (Canada)
1	Federal Elected Official
1	Illinois State Water Survey Division, Department of Registration and Education
3	U. S. Environmental Protection Agency
4	Wisconsin Department of Natural Resources
	Tour Groups
9	American Society for Quality Control Sponsored Tour
5	Bay City Alternative School
35	CESA Environmental Education Trainees
27	East DePere High School

Number	Organization or Affiliation
	Tour Groups (continued)
12	Forest Industry Council Sponsored Tour of News Personnel
13	Green Bay Chamber of Commerce Environmental Committee
65	Institute of Paper Chemistry
6	Institute of Paper Chemistry Technical Advisory Committee
39	Instrument Society of America Sponsored Tour
22	International Fibre Box Association
75	Northeast Wisconsin TAPPI Sponsored Tour
19	Northeastern Wisconsin Dairy Technical Society
10	TAPPI Sulfite and SemiChemical Pulping Committee
19	Third SemiChemical Corrugating Medium Superintendents' Meeting Tour
108	University of Wisconsin-Green Bay
10	University of Wisconsin-Madison
12	University of Wisconsin-Stevens Point
	Educators
13	Institute of Paper Chemistry
1	Yokohama National University (Japan)
2	University of Wisconsin-Madison
	Miscellaneous
1	Chamber of Commerce
3	News Media (Press and TV)
1	Pulp and Paper Magazine

GLOSSARY

BOD_5: Biochemical oxygen demand based on oxygen requirements needed during a five-day period for stabilization of decomposing organic matter in an aerobic biochemical action.

CentriCleaner: Trade name. Free vortex cone type cleaner for centrifugal separation of shives, dirt, bark, etc., from normal wood fiber by density, size, and shape.

compaction: Decrease of water permeation rate through a membrane with time at a fixed pressure and temperature.

concentrate: The solution exiting from the reverse osmosis unit after removal of a portion of the water through the membrane.

consistency: The percentage, by weight, of air dry fibrous material in a stock suspension.

DSM screen: Trade name. Pressurized nozzle feed screen with a curved screen surface.

fluidized bed reactor: Fluid solids process of burning spent liquor to obtain a dry ash in the form of inorganic pellets.

flux rate: Rate of permeation or transport of water through the membrane.

Hydrasieve: Trade name. Stationary, three-slope, stainless steel, wedge bar screen.

NSSC: Neutral Sulfite SemiChemical pulping, usually with sodium bisulfite, but other bases such as ammonia are also used.

osmosis: Diffusion through a semipermeable membrane separating a solvent and a solution that tends to equalize their concentrations.

osmotic pressure: The hydrostatic pressure required to stop the diffusion across a semipermeable membrane between two solutions of dissimilar concentrations.

pause: Periodic reduction of the pressure from an operating level to atmospheric for the purpose of restoring the flux rate lost by the deposition of a fouling material on the membrane surface.

process water: A general term for all waters of a paper mill which have been separated from the stock or pulp suspension, either on the paper machine or accessory equipment, such as thickeners, washers, and savealls. In a closed system, the water which recirculates throughout the mill for pulp dilution and showers.

reverse osmosis: Osmosis in reverse flow through a semipermeable membrane when external pressure in excess of the osmotic pressure is applied.

spent liquor: Waste liquor separated from cooked chips and pulp containing the residual cooking chemicals and dissolved constituents from the chemical cooking of wood chips.

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

1. REPORT NO. EPA-600/2-77-241	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE CLOSED PROCESS WATER LOOP IN NSSC CORRUGATING MEDIUM MANUFACTURE		5. REPORT DATE December 1977 issuing date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Gerald O. Walraven, William R. Nelson, Peter E. DeRossi, Richard L. Wisneski		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Green Bay Packaging Incorporated P. O. Box 1107 Green Bay, WI 54305		10. PROGRAM ELEMENT NO. 1BB610 11. CONTRACT/GRANT NO. S-800520
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Lab. - Cin., OH Office of Research & Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/12
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Over the last 5 years, the Green Bay Packaging corrugating medium mill has converted to an essentially closed process water system. The mill is a net consumer of water. This is due to the greater amount of water carried out of the system with the sheet compared to the lower water content entering the process system in raw materials. Many small dilute water streams are accepted into the process without upsetting the water balance.

When extraneous water inputs do upset the system balance, the condition is correctable by thermal evaporation or reverse osmosis. The reverse osmosis plant design operating performance and economics are described. Although many reverse osmosis operating problems have been solved, flux rates are somewhat lower than had been predicted. Other system additions and revisions for process water entrapment, recycle, and surge protection are described.

When a spill cannot be prevented, a monitoring system is used by production personnel for early detection and correction. Included in key areas is redundant equipment to help correct failures quickly.

Levels of BOD loss have been reduced from the 20,000 pounds per day range (9072 kg/day)--1971-- to less than 1000 pounds per day (454 kg/day)--monthly average-- for 1975. The daily maxima of 4000 pounds per day (1814 kg/day) has not been exceeded in any mill operating day during 1975.

This report covers a period from July 19, 1972, through February 2, 1976.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Circulation, Water Pollution, Color, Biochemical Oxygen Demand	Pulping, Closed System, Reverse Osmosis Waste Concentration, Physical Separation, Product Quality, Waste Monitoring Total Suspended Solids, Waste Control	13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 94
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978— 757-140/6649