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Aircraft Industry Wastewater Recycling

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June 1978

AIRCRAFT INDUSTRY WASTEWATER RECYCLING

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 that new and increasingly more efficient pollution control methods be used. The Industrial Environmental 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 work undertaken to demonstrate the feasibility of recycling certain categories of water used in the manufacture of airplanes. The results of the work can be used by those involved in water conservation as a source of technical and cost data that will enable them to assess the relative merits of recycling compared with other water conservation methods.

David G. Stephan
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ABSTRACT

This research program was initiated with the objective of demonstrating the feasibility of recycling certain categories of water used in an airplane factory. These categories are: chemical process rinse water, dye-penetrant crack-detection rinse water, machine shop coolant, and cyanide-containing rinse water. Water used solely for cooling purposes, and sanitary water, are not included in the program.

The feasibility of recycling water in each of the four categories was demonstrated in 380-liter (100-gallon) treatment plants. For each plant, contaminated water was continuously purified, then recontaminated, in a closed demonstration "loop."

Based on the experiences of constructing and operating the pilot scale treatment plant, an estimate was developed for the cost of a full-scale water recycling plant. The plant was of a size suitable for a typical medium-sized airplane factory generating 1.5 Ml/day (0.4 x 10^6 gal/day). The estimate was: capital cost including installation, \$3.4 million; recycling costs—\$0.94/kl (\$3.57/1000 gal) for chemical process rinse water, \$1.65/kl (\$6.25/1000 gal) for dye penetrant rinse water, \$4.36/kl (\$16.50/1000 gal) for cyanide process rinse water, and \$12.18/kl (\$46.09/1000 gal) for machine shop coolant.

A color and sound movie, "Closing the Loop," was made that describes the research program. This 13½-minute movie is suitable for a wide range of audiences from nontechnical ecology groups to engineers and other specialists in the field.

This report was submitted in fulfillment of Grant Agreement No. S803073-01-1 by the Boeing Commercial Airplane Company under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from August 1, 1974 to August 31, 1976, and work was completed on October 31, 1976.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

Amortiz.	–amortization
ASTM	–American Society for Testing and Materials
evap.	–evaporator
ORP	–oxidation-reduction potential
Pa	–Pascal, Newton/meter^2
TDS	–total dissolved solids
UF	–ultrafiltration
uv	–ultraviolet
µmho/cm	–micromhos per centimeter (same as µS/cm)
µS/cm	–microSiemens per centimeter (same as µmho/cm)
µW/cm^2	–microwatts per square centimeter

SYMBOLS

A,Y,D,Z,X	–parameters used in math analysis
C_c	–concentration of concentrate
C_f	–concentration of feed
C_m	–mean concentration
C_p	–concentration of permeate
E	–recovery ratio
M^{2+}	–(divalent) heavy metal ion (Cu^{2+}, Cd^{2+}, etc.)
Q_c	–flow rate of concentration
Q_f	–flow rate of feed
Q_p	–flow rate of permeate
R	–rejection ratio

METRIC CONVERSIONS

To Convert	To	Multiply by
gal	l	3.785 412 E+00
gal/min	l/min	3.785 412 E+00
gal/hr	l/hr	3.785 412 E+00
gal/day	l/day	3.785 412 E+00
gal/mo	l/mo	3.785 412 E+00
inches	cm	2.540 000 E+00
lb/hr	kg/hr	4.535 924 E–01
lb/day	kg/day	4.535 924 E–01
ppm	mg/l	1.000 000 E+00

SECTION 1

INTRODUCTION

To meet the proposed goals of the Federal Water Pollution Control Act for "best available" technology by 1983, it was felt that a pilot-scale demonstration would be logical before committing funds for the very high capital and operating costs of a full-scale water recycling plant. Many of the techniques of water treatment suitable for use in water recycling were well known; some, however, would require proving tests. A pilot-scale demonstration would provide the opportunity to observe and test both established and new techniques in a controlled environment.

The water used in an airplane factory falls into three categories: water for sanitary use, water for cooling air compressors and other machinery, and water for chemical process rinsing and for making machine shop coolant. This report is concerned only with the third category. Category two, cooling water, is already recycled by well-known methods, mainly cooling towers, and category one, sanitary water, is outside the scope of this work.

The waste water with which this report is concerned originates in four ways in a medium-sized airplane manufacturing plant. Between 50 and 100 chemical process rinse tanks provide a slightly acid stream containing small amounts of dissolved chromium, copper, cadmium, zinc, and other metals. This stream is referred to in the report as the "chemical process rinse water." The second stream results from 10 to 20 tanks that are used to rinse a crack-detecting oil from the surface of airplane parts. (Virtually all structural airplane parts are crack tested and rinsed in this way.) This system is referred to as the "dye penetrant inspection rinse water." A third stream consists of water-based coolant used in machine shops to assist in the rapid cutting of metals in mills, lathes, etc. Between 150 and 300 machines contribute to this stream. The last stream consists of rinse water from electroplating rinse tanks using cyanides. Because of their toxic nature and their ability to release toxic HCN gas when acidified, these rinse waters require special handling. This stream is generated by five to ten cyanide rinse tanks. The volumes of each of these streams generated in a medium-sized plant would be roughly: 1.5 Ml/day (0.4 x 10^6 gal/day) chemical process rinse water, 0.12 Ml/day (30 x 10^3 gal/day) dye penetrant inspection rinse water, and 20 kl/day (6 x 10^3 gal/day) each of machine shop coolant and cyanide process rinse water.

The demonstration plant was intended to show the technical feasibility of recycling the water from each of the above waste streams. A cost analysis, also included in the study, examines the economic feasibility of this recycling.

SECTION 2

CONCLUSIONS

This pilot scale demonstration of aircraft factory water recycling has demonstrated the *technical feasibility* of recycling at least 85% of the water used for chemical process rinsing and machine shop coolant.

The *economic feasibility* of recycling depends on the cost of recycled water compared with the cost of fresh water used in a once-through system, i.e., the initial cost of the fresh water plus the cost of treating this water to the level required for discharge. As the cost of recycling is almost twice that of a once-through system in the most favorable case (chemical process rinse water) and almost five times in the least favorable case (machine shop coolant), the economic feasibility cannot be said to have been demonstrated.

The above economic feasibility conclusion depends on the assumption that the materials extracted from the waste have no economic value—which is presently the case.

The overall cost of installing a water-recycling plant in a typical airplane factory treating approximately 1.5 Ml/day (0.4 x 10^6 gal/day) is $3.387 million, and the average cost of treatment in such a plant is $1.21/kl ($4.57/1000 gal).

SECTION 3

RECOMMENDATIONS

To enable recycling to be economically achieved, improved methods of treatment of aircraft factory process water should be developed. In particular, methods for improving the rejection of nitrates by reverse osmosis membranes need to be developed. Alternative methods for the treatment of machine shop coolant are also needed to reduce the very high cost of treatment by ultrafiltration and reverse osmosis.

The development of methods for extracting useful materials from wastes presently trucked away should also be pursued, and efforts made to develop markets for the materials extracted.

SECTION 4

PILOT-SCALE DEMONSTRATION OF WATER RECYCLING

GENERAL DESCRIPTION

A demonstration laboratory was set up containing working pilot-scale treatment plants. Each plant took process solutions currently used at Boeing's Plant II facility, Seattle, Washington or at its Auburn, Washington facility, and diluted them to make simulated rinse water streams for use in the treatment plants. Each stream was then purified sufficiently to make the water reusable for its original purpose. The treatment plants were constructed as "loops," i.e., the water—after purification—was recontaminated to make more simulated used water which was then repurified and recontaminated, etc., in a continuously operating loop.

Five loops were set up:

- o Chemical process rinse water purified by ion-exchange resin
- o Chemical process rinse water purified by reverse osmosis
- o Dye penetrant rinse water purification
- o Machine shop coolant water purification
- o Cyanide process rinse water purification

The first two loops purified and recycled the same type of waste water but used two different methods of treatment. The reason for demonstrating two methods of treatment for chemical process rinse water was that this type of water forms 80% of the process water from a typical airplane factory.

Figure 1 shows a general view of the demonstration laboratory.

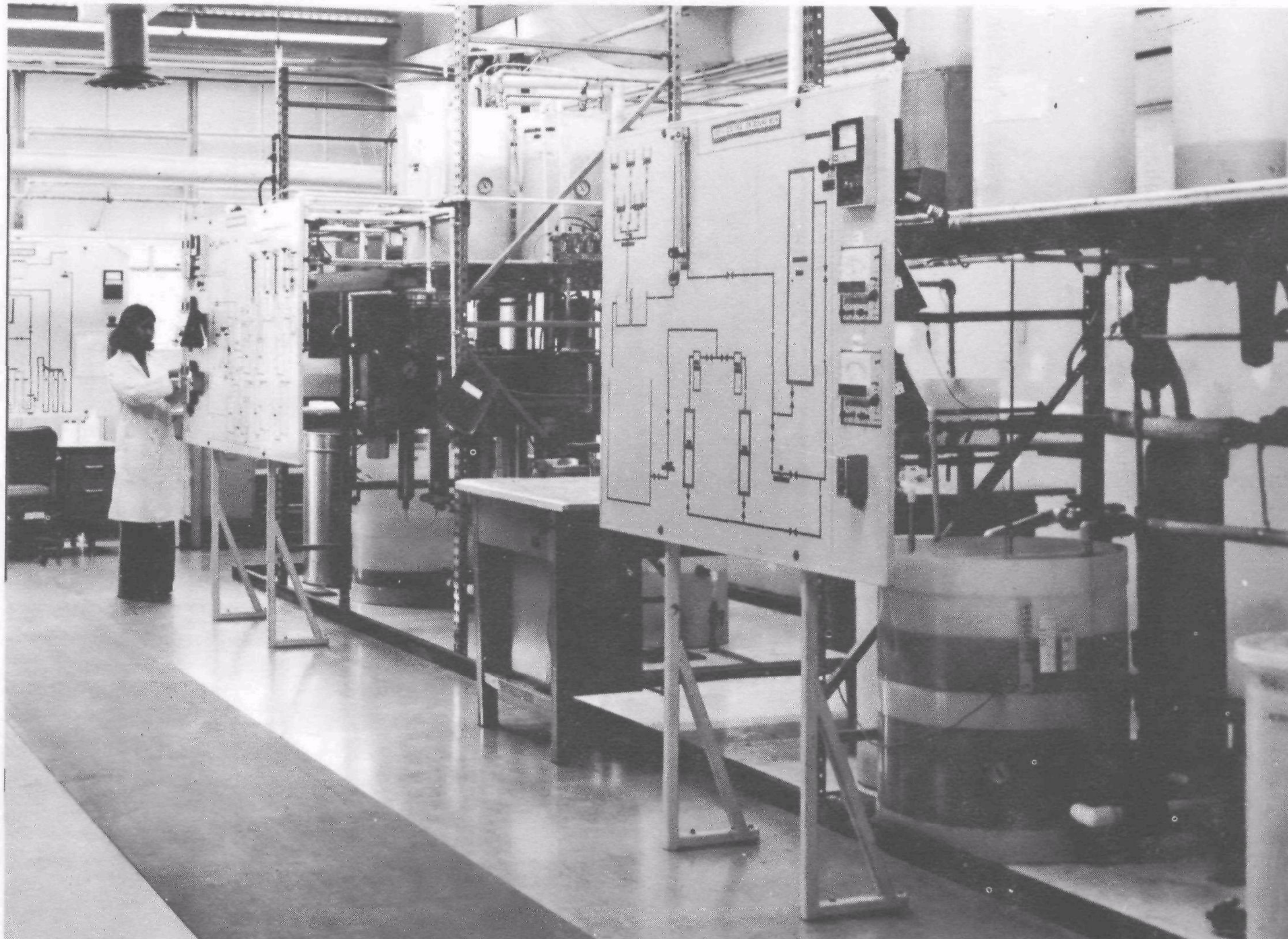


Figure 1.   General view of demonstration laboratory.

ION-EXCHANGE PURIFICATION OF CHEMICAL PROCESS RINSE WATER

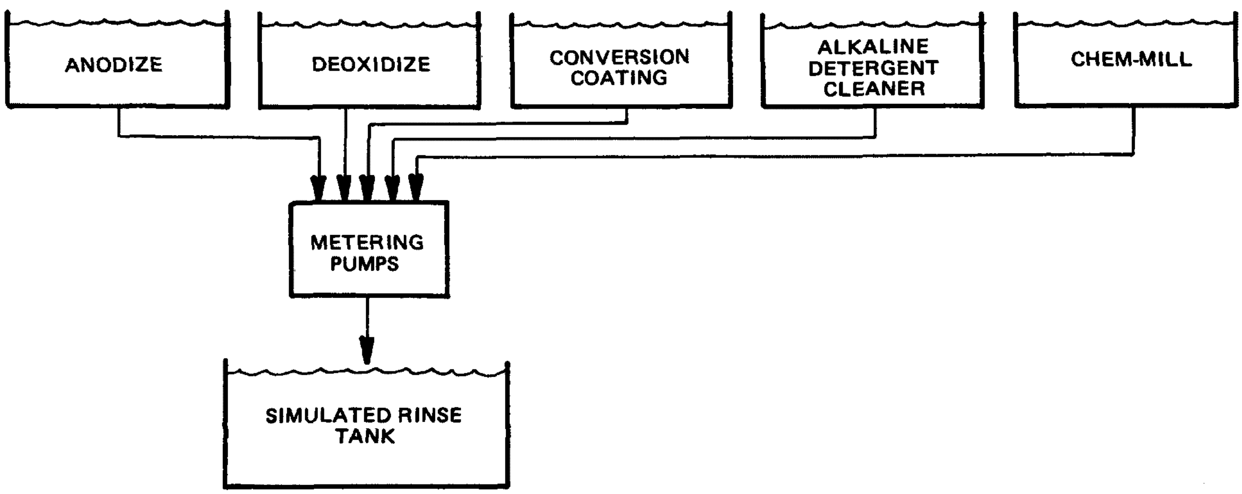
General

Figure 2 shows the demonstration equipment for this loop.

Treatment of simulated chemical process rinse water in this loop was comparatively simple, consisting of filtration (25 μm) to remove suspended matter, passage through activated carbon to remove organic matter (particularly traces of oil and surfactants from alkaline detergent cleaner tanks), and passage through a mixed bed ion-exchange column, to remove ionic contaminants.

Simulation of Rinse Water

Continuous addition of chemical process solutions to the purified recycled water, simulating the production of chemical process rinse water, was achieved by a steady drip feed via metering pumps.



Composition of the metered feed of contaminants was adjusted to the following percentages to conform to those obtained in a typical airplane manufacturing plant.

Chemical conversion coating (Alodine 1200)* solution	25.5%	by volume
Deoxidizer, nitric acid/Amchem 6/16*	22.5%	
Chromic acid anodize solution	20.0%	
Alkaline detergent cleaner	20.0%	
Deoxidizer, sulfuric-chromic acid	7.5%	
Aluminum chem-mill (caustic) solution	5.0%	

The dilution of this input by the incoming tap water varies in practice over a wide range. For this demonstration a dilution ratio of 1 in 500 was selected.

A flow diagram for ion-exchange purification of chemical process rinse water follows:

* Amchem Products Inc, Ambler, Pennsylvania, 19002.

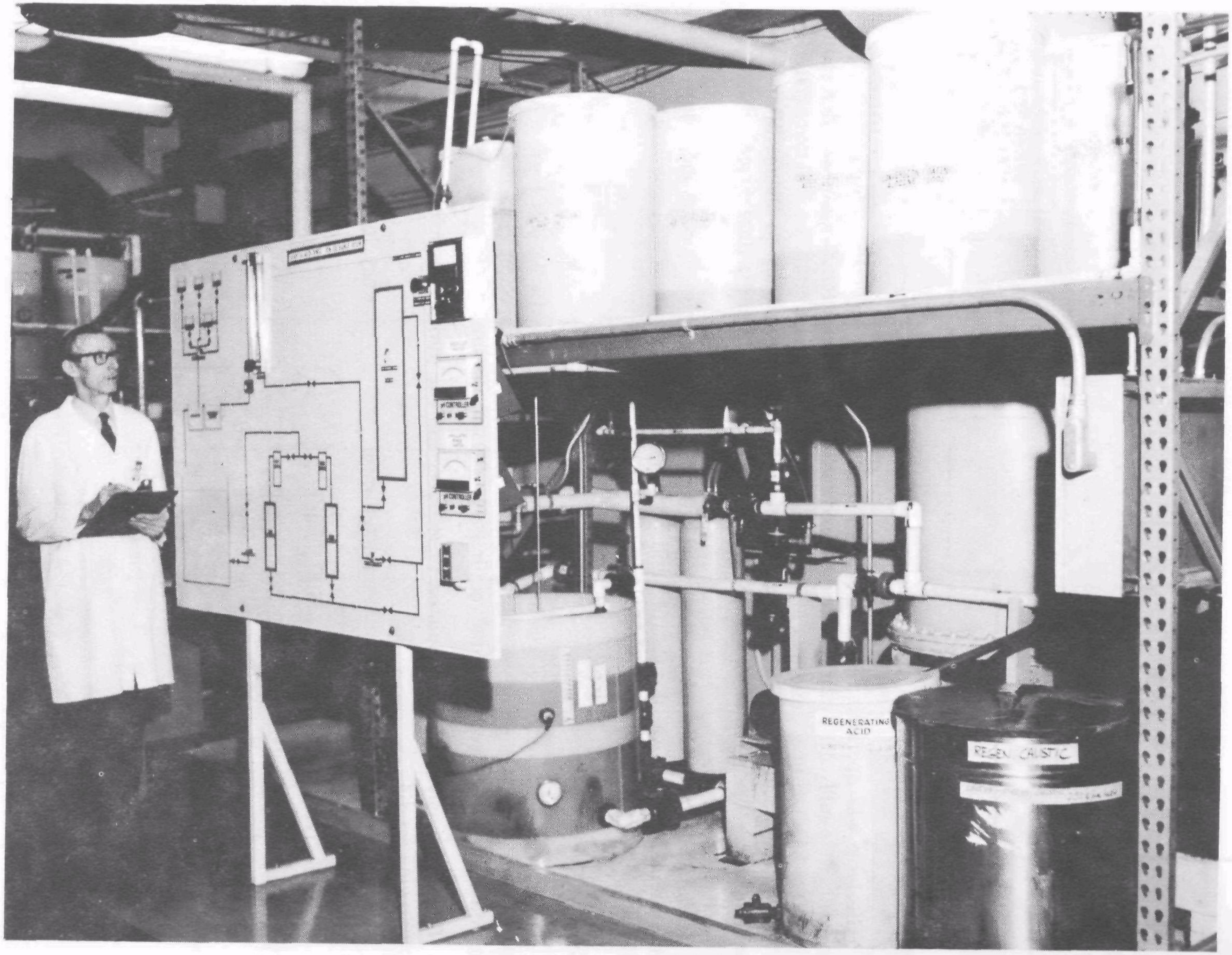
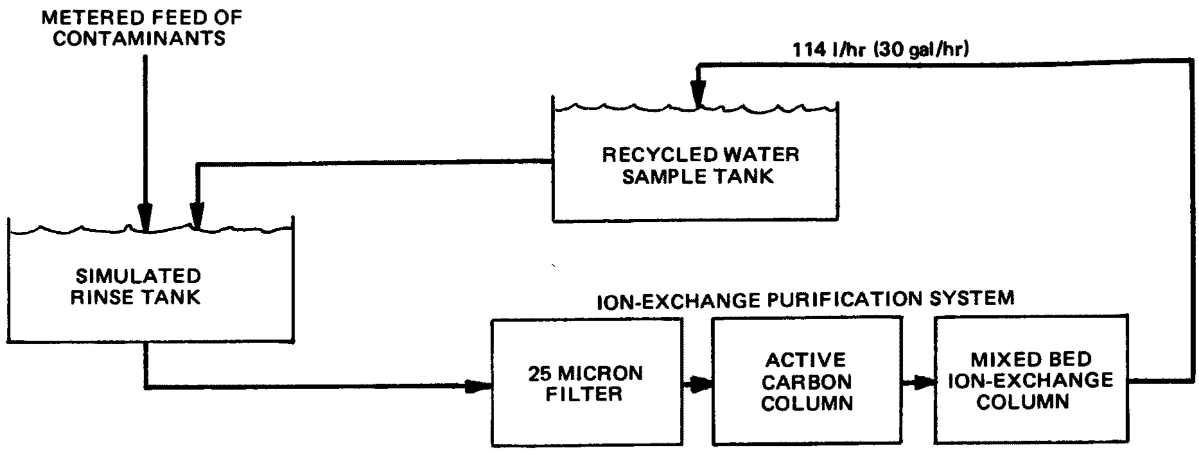


Figure 2. *Demonstration equipment for ion-exchange purification of chemical process rinse water.*



Deletion of Chem-Mill

The loop was operated as planned for the first 80 hours with all six inputs, including the aluminum chem-mill. However, the presence of sulfides in the chem-mill caused an odor and toxicity problem because small amounts of hydrogen sulfide were liberated in the acid rinse water. Also, the high aluminum content of the chem-mill solution made it necessary to change filters every 15 hours due to the formation of an aluminum hydroxide precipitate in the rinse water.

It was considered that the cost of modifying the system to remove odor and more efficiently handle chem-mill rinse was not justified and, accordingly, the chem-mill feed was turned off for the remainder of the demonstration period.

Quality of Recycled Water

Purification and recycling was accomplished without difficulty in this loop, a high quality "de-ionized" water being consistently obtained. Quality of the water (less than 0.5 mg/l total dissolved solids) far exceeded normal requirements for process rinse water.

Chemical analysis of the simulated rinse water and the purified recycled water typically gave the following results:

	Simulated rinse	Recycled
TDS	500 mg/l	
NO_3	300 mg/l	
SO_4	80 mg/l	
PO_4	0.3 mg/l	
Cl	12 mg/l	Less than 0.5 mg/l total dissolved solids
F	Less than 3 mg/l	
Na	150 mg/l	
Total Cr	40 mg/l	
Surfactant	0.8 mg/l	
Conductivity	630 μmho/cm	
pH	2.8	5.9

A practical test was made of the acceptability of the recycled water for rinsing chemical treatment solutions from the surfaces of an aluminum alloy. In this test (4), the rinsed surfaces were bonded together with a high strength aircraft structural adhesive, and the joint tested to failure in a crack extension test. The rinse water was found to be acceptable in this test.

Ion Exchange Resin Capacity

The mixed-bed ion-exchange column became exhausted after 719 hours of operation during which time it processed a total of 81,642 liters (21,570 gallons). This volume corresponds to a calculated resin capacity of 1.47 meq/ml for the anions, and 2.26 meq/ml for the cations. These values are in agreement with the expected values of 1.4 meq/ml for the strongly basic, highly crosslinked anion resin A-244D*, and 2.1 meq/ml for the strongly acidic, highly crosslinked cation resin C-361W*.

A graph showing the rapid rise in pH and conductivity as the bed became exhausted is shown in Figure 3.

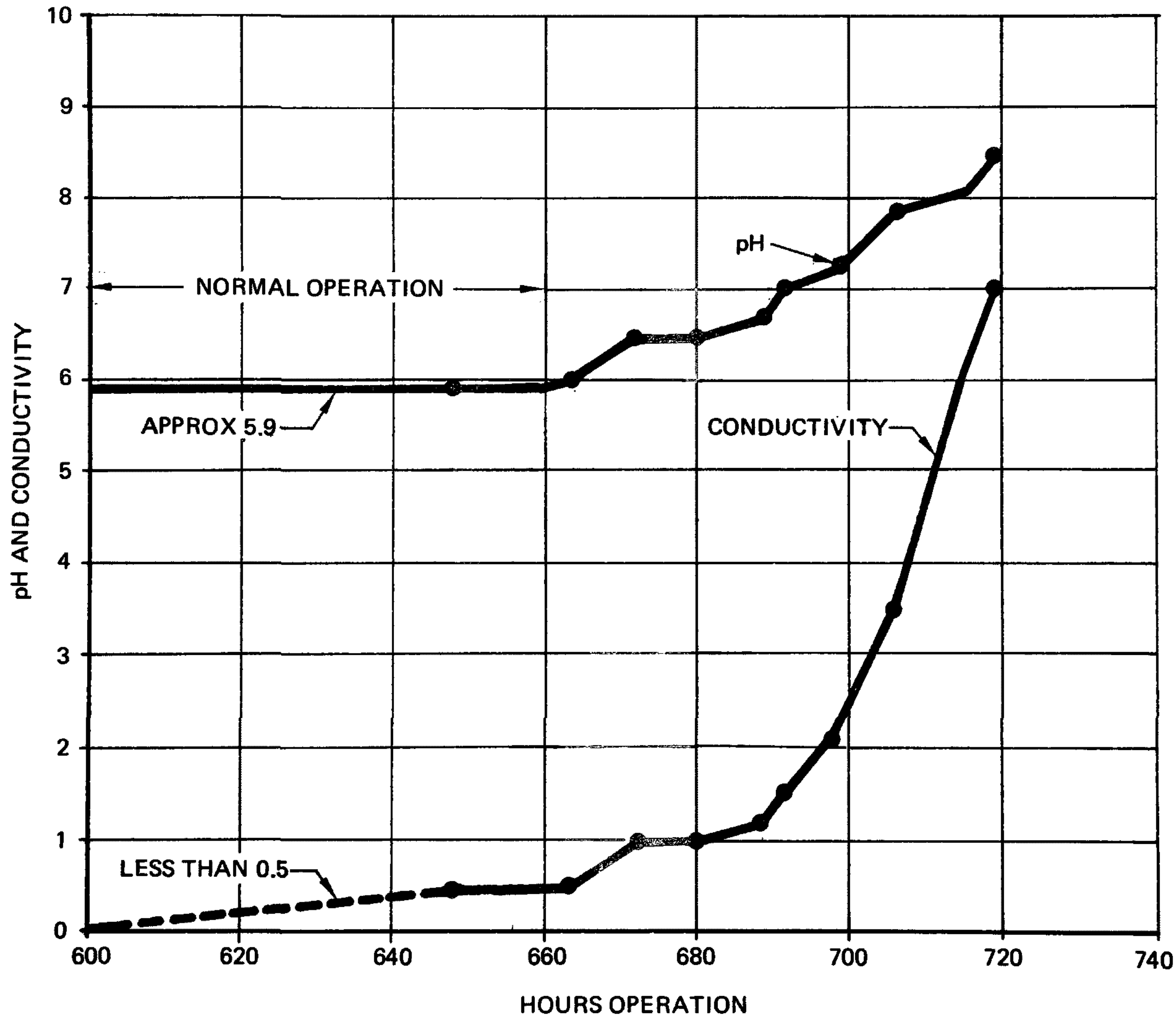


Figure 3. Ion-exchange purification of chemical process rinse water, showing rapid rise in pH and conductivity at exhaustion.

* The Burhans-Sharpe Company, 2255 Harbor Ave. S.W., Seattle, Washington

Activated Carbon Capacity

The small amount of surfactant present in the simulated rinse water, 0.8 mg/l, was readily absorbed by the 54-liter carbon column which showed no signs of exhaustion during the 488 hours it was in use. The calculated weight of surfactant absorbed in this period amounted to 0.26 g/100 g of activated carbon.

An attempt to determine the ultimate capacity of the carbon was defeated by the unexpected ability of the ion exchange column to absorb at least small amounts of surfactant. (No surfactant has ever been detected in the recycled water due to this effect. Subsequent discussions with the resin vendors have confirmed that ion-exchange resins, particularly cation-exchange resins, will absorb surface active agents in addition to the ions they are intended to absorb.) The attempted tests indicated only that the carbon capacity was less than 14 g surfactant/100 g of activated carbon.

Regeneration of the Ion-Exchange Resin

The amounts of acid, alkali, and water used in regenerating the ion-exchange column were as follows:

Commercial sulfuric, 66^{o} Baume 93.2% H_2SO_4	18.8 kg (41.5 lb)
Commercial sodium hydroxide	22.7 kg (50.0 lb)
Water	6,957 l (1,838 gal)

Thus, the ion exchange system may be considered as producing two streams: the "product," 81,642 liters containing essentially zero dissolved matter, and a waste stream of 6,957 liters containing 11,646 mg/l dissolved minerals.* The ratio of product water to regenerant water is 11.7 to 1.

The water used for regeneration was trucked away for disposal by state-licensed chemical waste processors.

The volume of water used for regeneration was as recommended by the vendors of the equipment. It is possible that smaller amounts could have been used, particularly in this case where high quality de-ionized water was not an actual requirement.

Demonstration of Ion-Exchange Purification—Conclusions

This demonstration unit has been operated successfully for over 700 hours, producing very high quality (de-ionized) water with a minimum of attention.

The ratio of product water to waste regenerant water was 11.7 to 1. Virtually all of the contaminants in the simulated rinse water were collected and transferred to the regenerant water, giving it a total solids content of 11,646 mg/l.

* 5778 mg/l from the regenerating chemicals, 5868 mg/l from the simulated rinse water.

The process has the advantages of being well-established, relatively trouble-free, and it produces a high quality recyclable water. A waste stream containing approximately equal parts of regenerating chemicals and contaminants, amounting to approximately one-twelfth the volume of process water stream, remains for disposal.

REVERSE OSMOSIS PURIFICATION OF CHEMICAL PROCESS RINSE WATER

General

Simulated chemical process rinse water was treated in this loop by a triple RO unit system, preceded by a clarifier, to produce a high-volume, low-solids recycled water, and a low-volume, high-solids waste concentrate. As in the case of the ion-exchange unit, rinse water simulation was accomplished by a continuous addition of chemical process solutions to the recycled water.

Figures 4 and 5 show the demonstration equipment for this loop.

Spiral-wrapped cellulose acetate-type membranes were selected for this work because of their availability, and relatively lower cost, in a wide range of small and pilot-scale sizes.

Simulation of Rinse Water

Continuous addition of chemical process solutions to the purified recycled water to simulate the production of chemical process rinse water was achieved by a steady drip feed from the same type of metering pumps used for the ion-exchange loop.

Clarifier

It is *essential* that the feed to any RO unit be both filtered to remove all particles that could clog the membranes, and maintained at such a pH, temperature, composition, etc., that precipitation cannot occur on the membranes. Precipitation resulting from an increase in concentration must be avoided because of the natural increase in concentration at the membrane surface.

Tests carried out on the simulated rinse water showed that although a pH 7 was necessary to produce a heavy precipitate (aluminum hydroxide plus heavy metal hydroxides), some precipitation occurred after standing for a few days, even at pH values below 3.0. Since the membrane life is drastically reduced by chromic acid solutions having pH values of less than 3.0, it was decided to use a "clarifier" operation on the simulated rinse water before feeding it to the RO units, in order to avoid all risk of precipitation.

The simulated rinse water was clarified in 379-liter (100-gallon) batches. The pH of the rinse water was adjusted to 8.5 using (2.5 normal) sodium hydroxide solution. Betz polyelectrolyte no. 1110 was added to aid flocculation. The clear supernatant liquor was drawn off after approximately 30 minutes of settling and its pH adjusted to 6.0 before treatment by the RO system.

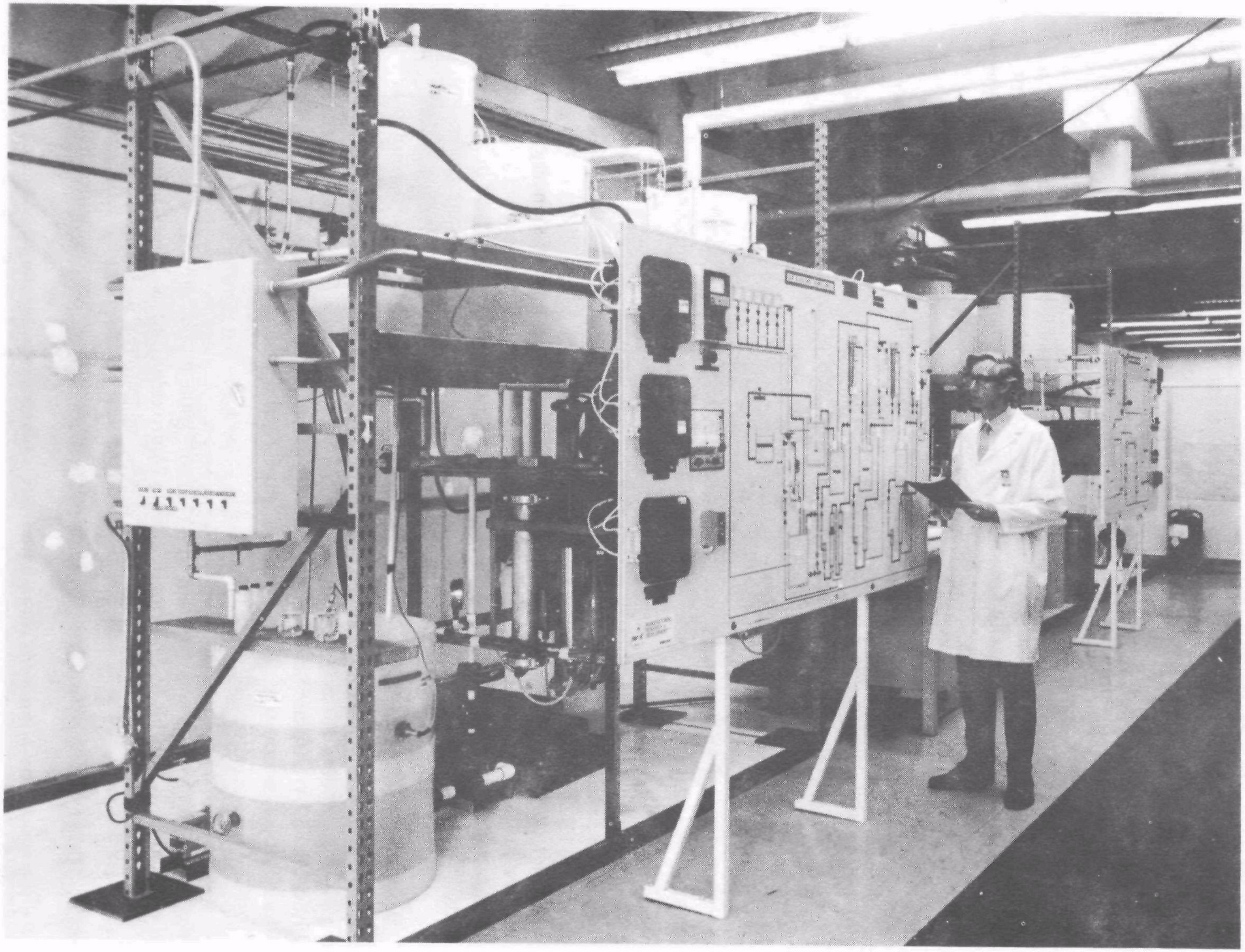


Figure 4. *Demonstration equipment for reverse osmosis purification of chemical process rinse water.*

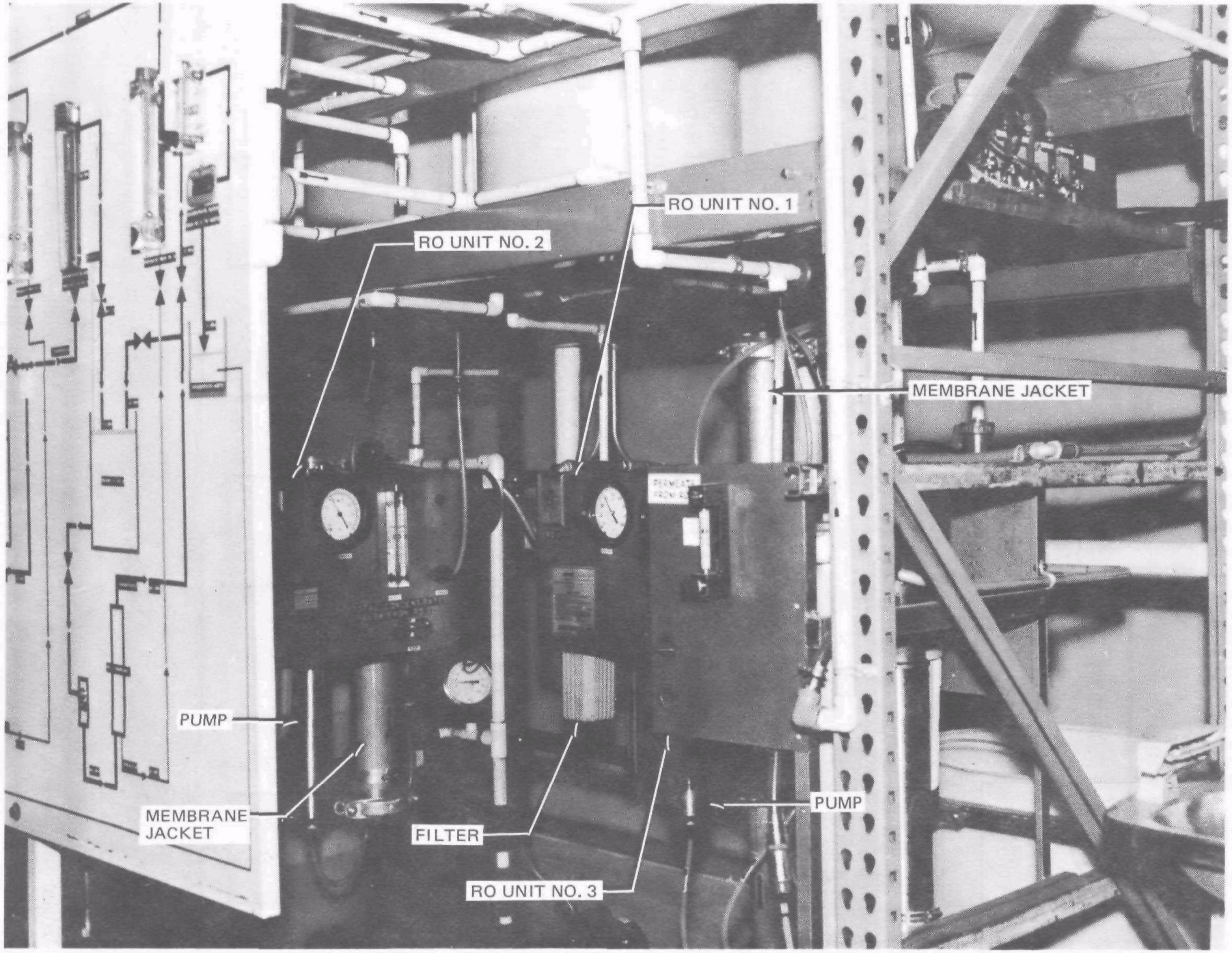
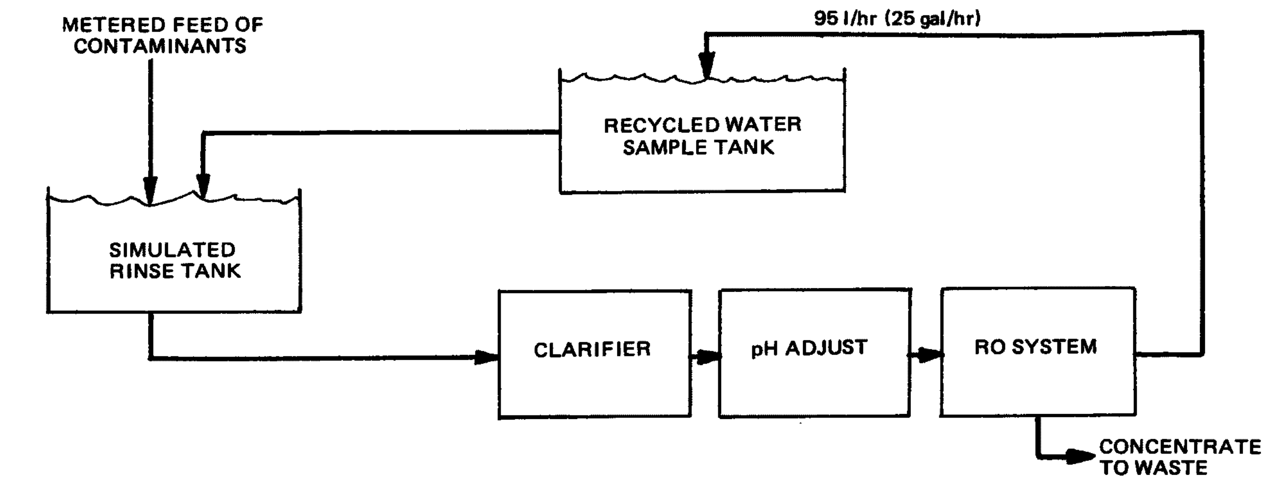


Figure 5. Detail view of reverse osmosis equipment showing reverse osmosis units.

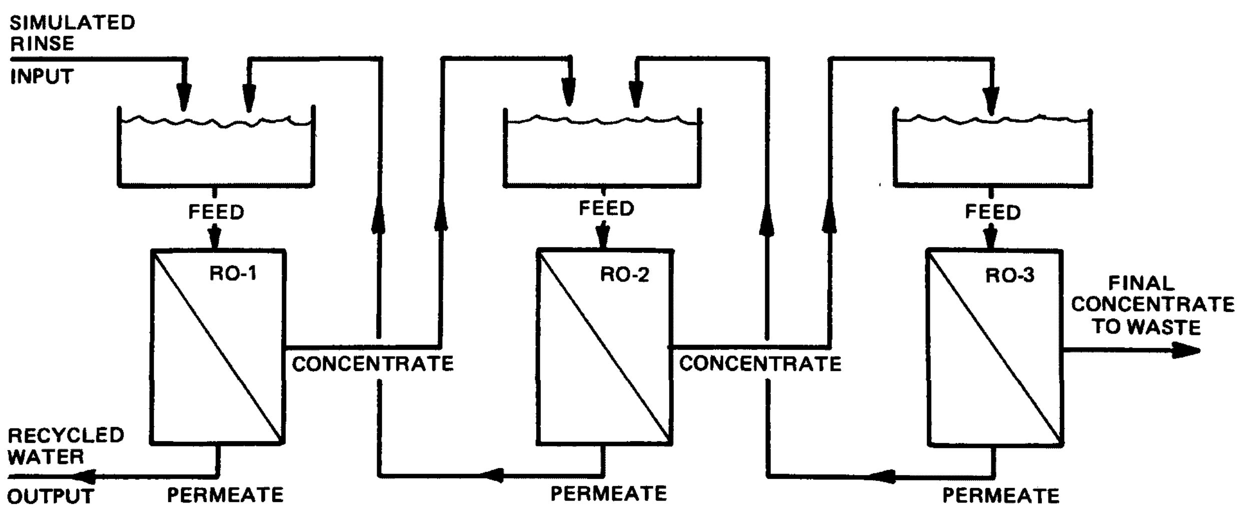
Reverse Osmosis Purification of Chemical Process Rinse Water



Special Counterflow Arrangement of RO Units

A special arrangement of three reverse osmosis membranes was developed to give maximum efficiency of separation of the contaminants from the rinse water. This special arrangement (Arrangement No. 1) is illustrated below:

ARRANGEMENT NO. 1 OF RO UNITS (COUNTERFLOW ARRANGEMENT)



Chem-Mill Feed

Hydrogen sulfide generation, from the sulfides present in the chem-mill feed was a problem, as in the case of the ion exchange purification loop. The problem was overcome by deleting the chem-mill constituent from the metered drip feeds, and instead adding it as a single shot immediately before clarification. At the clarification pH of 8.5, H_2S was not generated.

Operation of Reverse Osmosis System

The loop has been operated for a total of 153.5 hours, 104 hours in the "counterflow" arrangement shown on page 20 and Figure 7, and the remainder of the time in special tests described in Appendix B, "Reverse Osmosis Tests–Rejection Ratio of Nitrates Compared with Other Ions," and Appendix C, "Reverse Osmosis–Experimental Verification of Math Analysis."

A typical set of analyses for the system in counterflow arrangement is shown in Table 1.

TABLE 1. ANALYSIS FOR OPERATION OF REVERSE OSMOSIS SYSTEM COUNTERFLOW ARRANGEMENT

	Simulated rinse water	Clean water return	Concentrate to waste
Flow	98.4 l/hr	89.9 l/hr	8.5 l/hr
pH	3.0	5.8	6.2
Conductivity	680 S/cm	208 S/cm	3510 S/cm
TDS	534 mg/l	172 mg/l	3009 mg/l
NO_3	325 mg/l	150 mg/l	560 mg/l
SO_4	85 mg/l	8.5 mg/l	1200 mg/l
PO_4	0.32 mg/l	0.05 mg/l	0.85 mg/l
Cl	12.4 mg/l	13.3* mg/l	460* mg/l
Na	210 mg/l	40 mg/l	930 mg/l
Total Cr	43 mg/l	6.3 mg/l	240 mg/l
Cr^{+++}	None detected**	None detected**	None detected**
Al	11.4 mg/l	Removed in clarifier	Removed in clarifier
Zn	0.95 mg/l	Removed in clarifier	Removed in clarifier
Cu	0.18 mg/l	Removed in clarifier	Removed in clarifier
B	None detected**	None detected**	None detected**
Surfactant	0.77 mg/l	0.23 mg/l	3.47 mg/l

* Higher than simulated rinse input because HCl used internally as pH adjustment.

** Less than 5 mg/l.

The pH values of the clean water return (5.8) and the concentrate to waste (6.2) merely reflect the value of pH 6.0 chosen to ensure a slightly acid condition to preclude the possibility of precipitation on the membranes.

An examination of Table 1 shows that the nitrate concentration in the clean water return is unexpectedly high, 150 mg/l, for a feed nitrate concentration of 325 mg/l. Measurements of the rejection ratios* for each RO unit gave the results detailed in Table 2, showing nitrate rejection ratios of only 0.54 to 0.63 compared with 0.79 to 0.99 for the other ions measured.

* Rejection ratio = $(C_m - C_p)/C_m$. See equation (4), Appendix A.

TABLE 2. CALCULATED REJECTION RATIOS

Ion	RO-1	RO-2	RO-3
NO_3	0.63	0.55	0.54
Total Cr	0.89	0.87	0.86
Na	0.85	0.79	0.84
Mg	0.93	0.94	0.98
Ca	0.98	0.99	0.99
K	0.82	0.79	0.81

Additional tests, to explore and confirm these low rejection ratios for nitrates are detailed in Appendix B. These tests showed an unexpected, far lower, rejection ratio of less than 0.2 for the nitrate ion in acid solution. Tests with the sulfate ion at the same pH showed the expected values of R = 0.9 or higher.

Comparison of Reverse Osmosis and Ion-Exchange Systems

Comparison of the two systems on the basis of performance shows that they produce roughly the same volumes of waste water for equal volumes of recycled water. Capture of the solids dissolved in the rinse water is, however, 100% for the ion exchange system, but only 71% for the RO system. The behavior of the two systems, adjusted to a feed of 100 volumes, 500 mg/l TDS, is shown in Table 3.

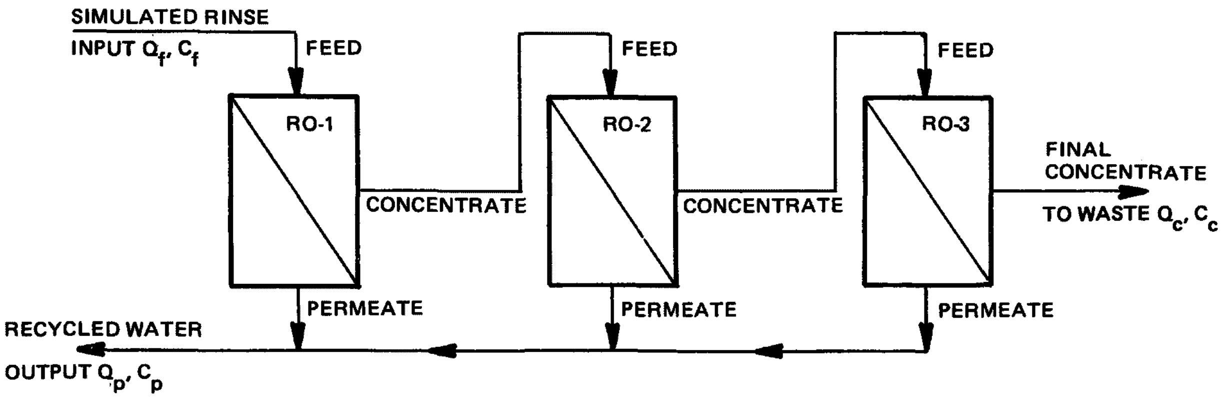
TABLE 3. COMPARISON OF REVERSE OSMOSIS AND ION-EXCHANGE SYSTEMS

System	Feed		Recycle		Dump	
	Volume	TDS	Volume	TDS	Volume	TDS
Ion exchange	100	500 mg/l	92.2	NIL	7.8	11,648* mg/l
Reverse osmosis	100	500 mg/l	93.3	161 mg/l	6.6	2,817 mg/l

* Including 5780 mg/l from the regenerant acid and alkali

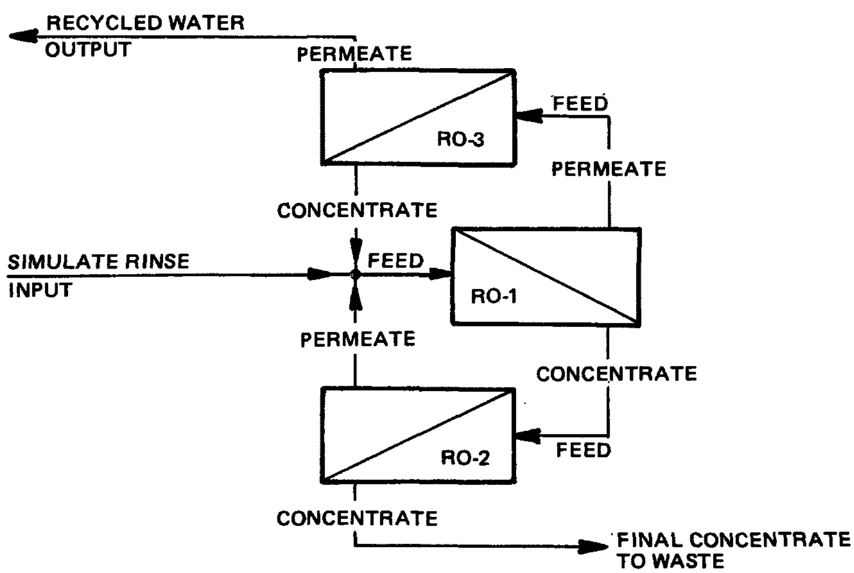
Alternative RO Arrangements

The arrangement of three RO units into a "counterflow" system, page 14, is only one of a number of possible arrangements. The more conventional arrangement (No. 2) of three units is as shown in the following sketch.



As in the case of the counterflow system (Arrangement No. 1), the concentrate stream passes from RO-1 to RO-3, becoming progressively enriched, and finally dumped. Unlike Arrangement No. 1, however, the three permeate streams are united to form a single output, the recycle stream.

Another arrangement is shown below:



In this arrangement (No. 3), the concentrate from RO-1 is further concentrated in RO-2, and the permeate from RO-1 is further purified by permeation through RO-3. The final concentrate has thus been rejected by two membranes, RO-1 and RO-2, and the final permeate has been passed through two membranes, RO-1 and RO-3. The concentrate from RO-3 and the permeate from RO-2 are added to the primary feed to RO-1.

Mathematical Analysis of Arrangements Nos. 1, 2, and 3

Mathematical models were constructed of all three arrangements, and calculator programs written to solve the equations relating input and output flow rates and concentrations for each arrangement. The equations and their solutions, in the form of operating characteristic curves, are given in Appendix A.

As examples, the following values were taken from the characteristic curves of Appendix A. The values selected for recovery ratio R, 0.7 and 0.8, are typical for the mixed ion species present in the chemical process rinse water, and the values selected for E (recovery ratio)* are commonly employed in this type of RO unit. A feed rate of 100 l/hr, and a feed concentration of 500 mg/l, are assumed. (See Table 4).

TABLE 4. COMPARISON OF THREE ARRANGEMENTS FOR SELECTED VALUES OF R AND E

Item	Rejection ratio (R) and recovery ratio (E)								
	R = 0.7 E = 0.7			R = 0.7 E = 0.8			R = 0.8 E = 0.7		
Arrangement number	1	2	3	1	2	3	1	2	3
Permeate quantity Q_p l/hr	95.3	97.3	84.5	98.8	99.2	94.1	95.3	97.3	84.5
Concentrate qualtity Q_c l/hr	4.7	2.7	15.5	1.2	0.8	5.9	4.7	2.7	15.5
Permeate concentration C_p mg/l	317	409	195	412	457	314	231	351	105
Concentrate concentration C_c mg/l	4240	3760	2163	7917	5865	3484	6014	5870	2617
Overall performance ratio C_c/C_p	13.4	9.2	11.1	19.2	12.8	11.1	25.0	16.7	24.9

* Recovery ratio - Ratio of clean water recovered to input = Q_p/Q_f

In all three examples, the overall performance of the system, as measured by the ratio of the concentration of salts in the final concentrate, divided by the concentration of salts in the permeate, i.e., C_c/C_p, is the highest for the counterflow Arrangement No. 1.

Examination of the operating characteristic curves, Figures A-1 through A-7, Appendix A, shows clearly that a high rejection ratio R results in the desired low permeate concentrations, and high concentrate concentrations. The curves also show, however, that the same result cannot be achieved by adjustments to the recovery ratio E, since increasing E always increases concentrate concentration (desired) but also always increases permeate concentration (undesired). Consequently, the choice of recovery ratio becomes a compromise: the highest value possible is selected, consistent with obtaining an acceptable, recyclable quality of permeate. The influence of recovery ratio E on the volume of concentrate produced by each arrangement is shown in Figure A-7, Appendix A.

* Recovery ratio = Ratio of clean water recovered to input = Q_p/Q_f

Calculation of Permeate Concentration and Concentrate Concentration for a Single RO Unit Employing Feedback

The full calculation of concentrations in the outputs from a single RO unit employing feedback (i.e., returning a portion of the concentrate stream to the intake) is time consuming. A calculator program, for use on a Hewlett-Packard HP-65 programmable calculator for making this calculation, is given in full detail in Appendix D.

Use of this program, which employs a reiterative technique, is useful where feedback rates are small (less than twice the feed). Where the feedback rates are high (above 10 times the feed), the approximations used in Appendix A, equations (2) and (4), allow simpler calculations to be used without introducing significant error.

Demonstration of Reverse Osmosis Purification—Conclusions

Reverse osmosis purification and recycling of simulated chemical process rinse water has been successfully demonstrated in operation for over 150 hours.

Addition of a clarifier stage was found necessary to avoid the possibility of chemical precipitation on the membranes.

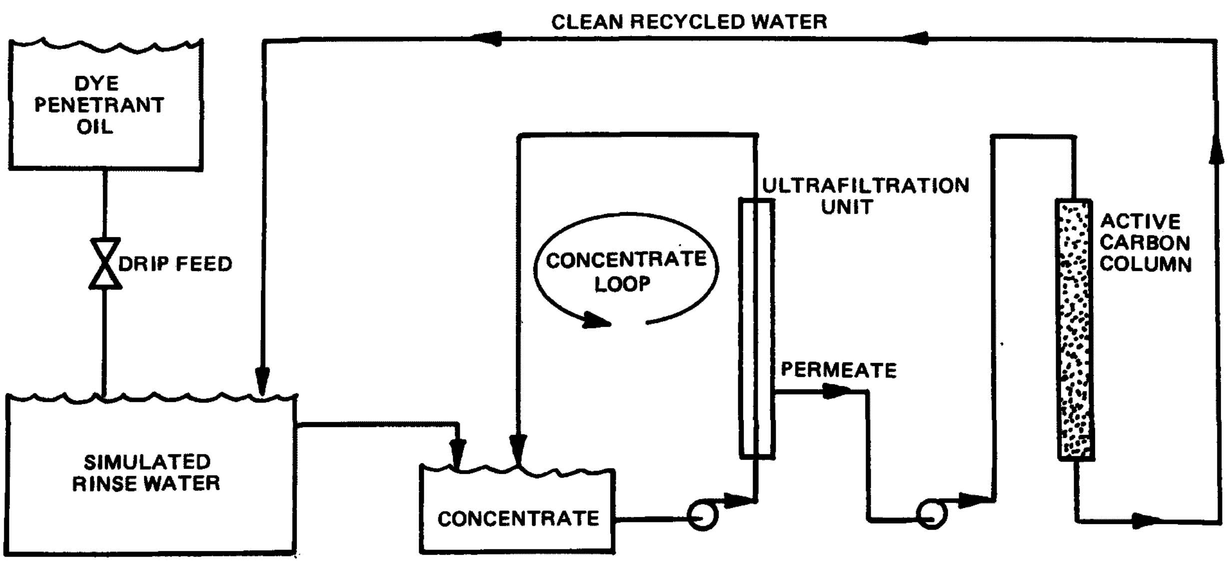
Due to the low rejection rate of the nitrate ion, relatively low quality recycled water was obtained; with an input of 534 mg/l total dissolved solids, a recycled water containing 172 mg/l was obtained.

ULTRAFILTRATION AND ACTIVE CARBON PURIFICATION OF DYE PENETRANT INSPECTION RINSE WATER

General

Water containing 400 mg/l of emulsified oil, used to rinse airplane parts after crack detection, was purified in this loop by passage through an ultrafiltration membrane, followed by "polishing" in an activated carbon column.

Figures 6 and 7 show the demonstration equipment for this loop. An outline flow diagram of the equipment is shown below.



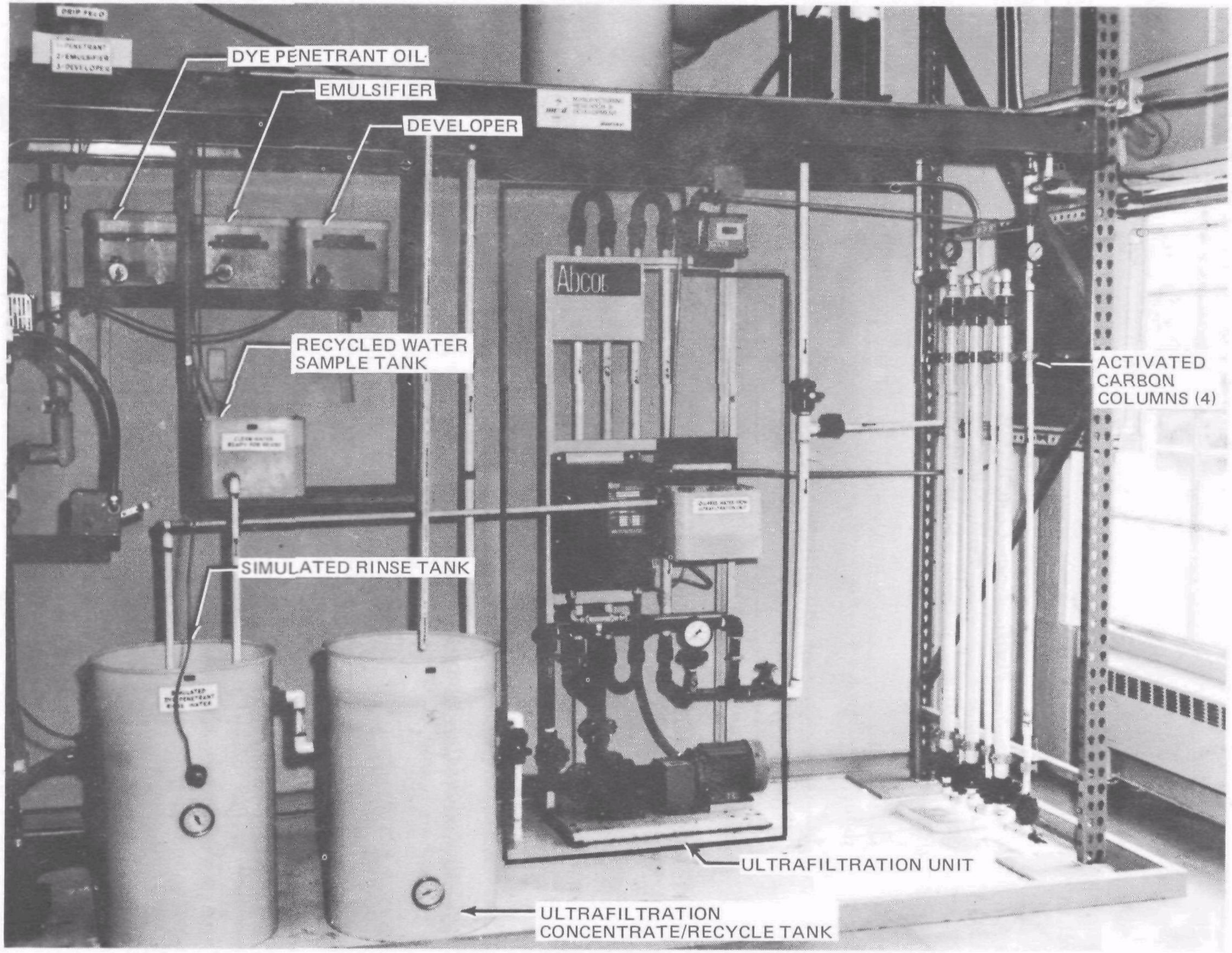


Figure 6. Demonstration equipment for recycling dye penetrant inspection rinse water.

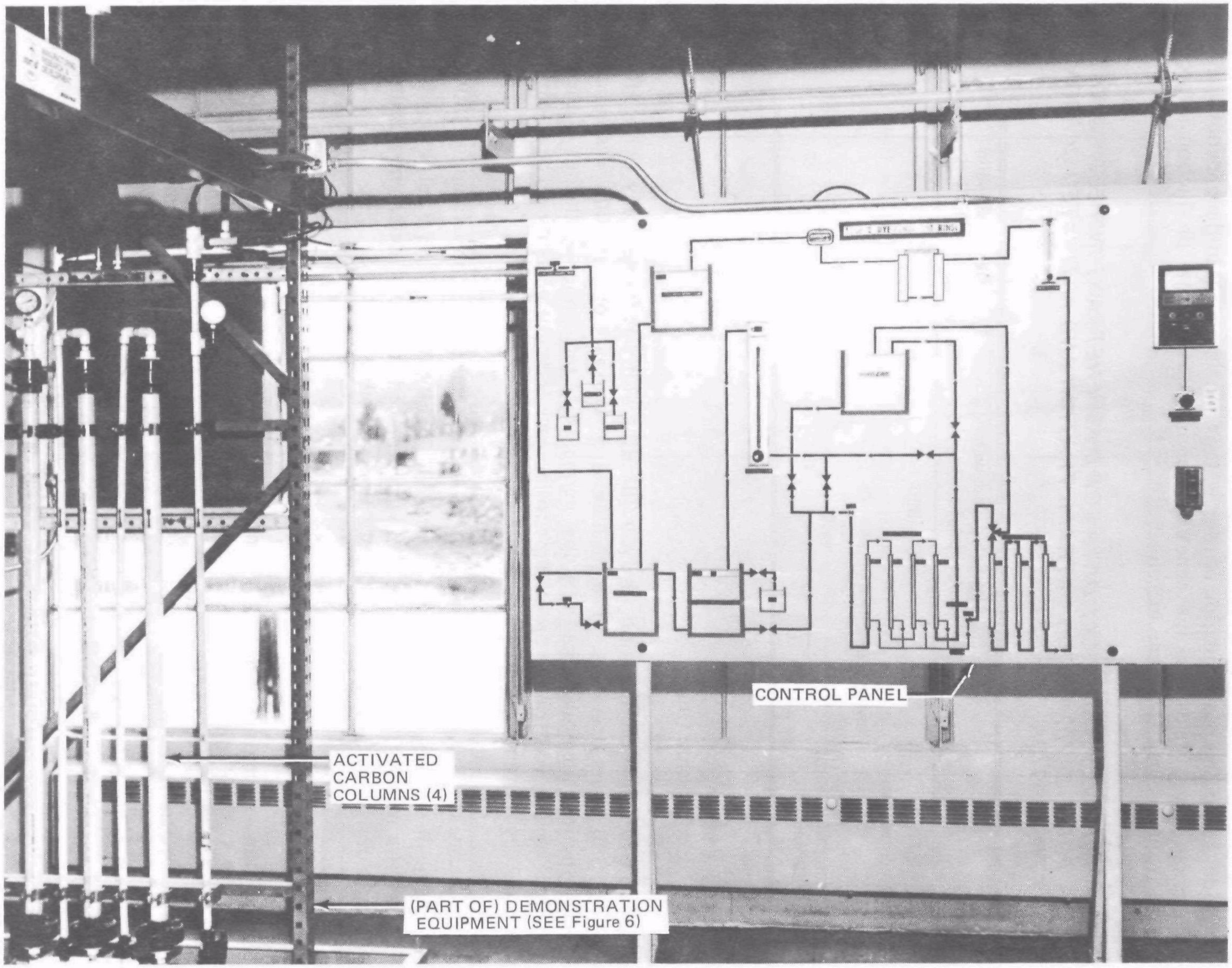


Figure 7. Control panel for demonstration equipment recycling dye penetrant inspection rinse water.

Operation as Designed

The loop was operated as designed, recycling 5.7 to 7.6 l/hr (1½ to 2 gal/hr) for a total of 627 hours over 98 days. Continuous simulation of rinse water was achieved, as in the previous sections, by small metering pumps delivering dye penetrant solutions taken from production inspection tanks. Typical analytical data are shown in Table 5.

TABLE 5. TYPICAL ANALYTICAL DATA FOR DYE PENETRANT INSPECTION WATER PURIFICATION USING ULTRAFILTRATION AND ACTIVATED CARBON FILTRATION

	Simulated rinse water (mg/l)	Recycled water (mg/l)
Emulsified oil (by freon extraction)	400–500	1–2
Surfactant (as lauryl alkyl sulfonate)	1–2	0.06

Flushing of the Ultrafiltration Unit

During the 627 hours of operation, the ultrafiltration unit was flushed only twice, after 41 hours and after 330 hours operation. The flushing after 41 hours of operation was conducted because two of the four membranes had very low permeability rates, one-fourth that of the other membranes, and flushing was tried in an attempt to improve their permeability. The attempt was unsuccessful, and the membranes were replaced.

The high permeate flow rates obtained immediately after flushing, approximately 280 $nl/m^2 \cdot s \cdot Pa$ (4 $gal/ft^2 \cdot day \cdot lb/in.^2$) declined rapidly and levelled off at 9.0 $nl/m^2 \cdot s \cdot Pa$ (1.3 $gal/ft^2 day \cdot lb/in.^2$). Figure 8 shows the permeate rates achieved during and immediately after detergent flushing, and much lower rates obtained on a 3000 to 5000 mg/l penetrant oil concentrate.

Maximum Concentration Reached by the UF Unit

The maximum concentration reached during the 627 hours of operation was 5000 mg/l, representing a 12.5 times concentration of the original 400 mg/l. Fracture of a pump housing, and consequent loss of concentrate, prevented higher values from being reached during the test period. There appears to be no reason why much higher concentrations could not be reached, given sufficient time, since the emulsion was stable, with no signs of "breaking."

Variation in Membrane Permeate Rates

Considerable variation was noted between nominally identical membranes. As an example of this variation, Figure 9 shows the first 55 hours of operation of the four membranes in the UF unit.

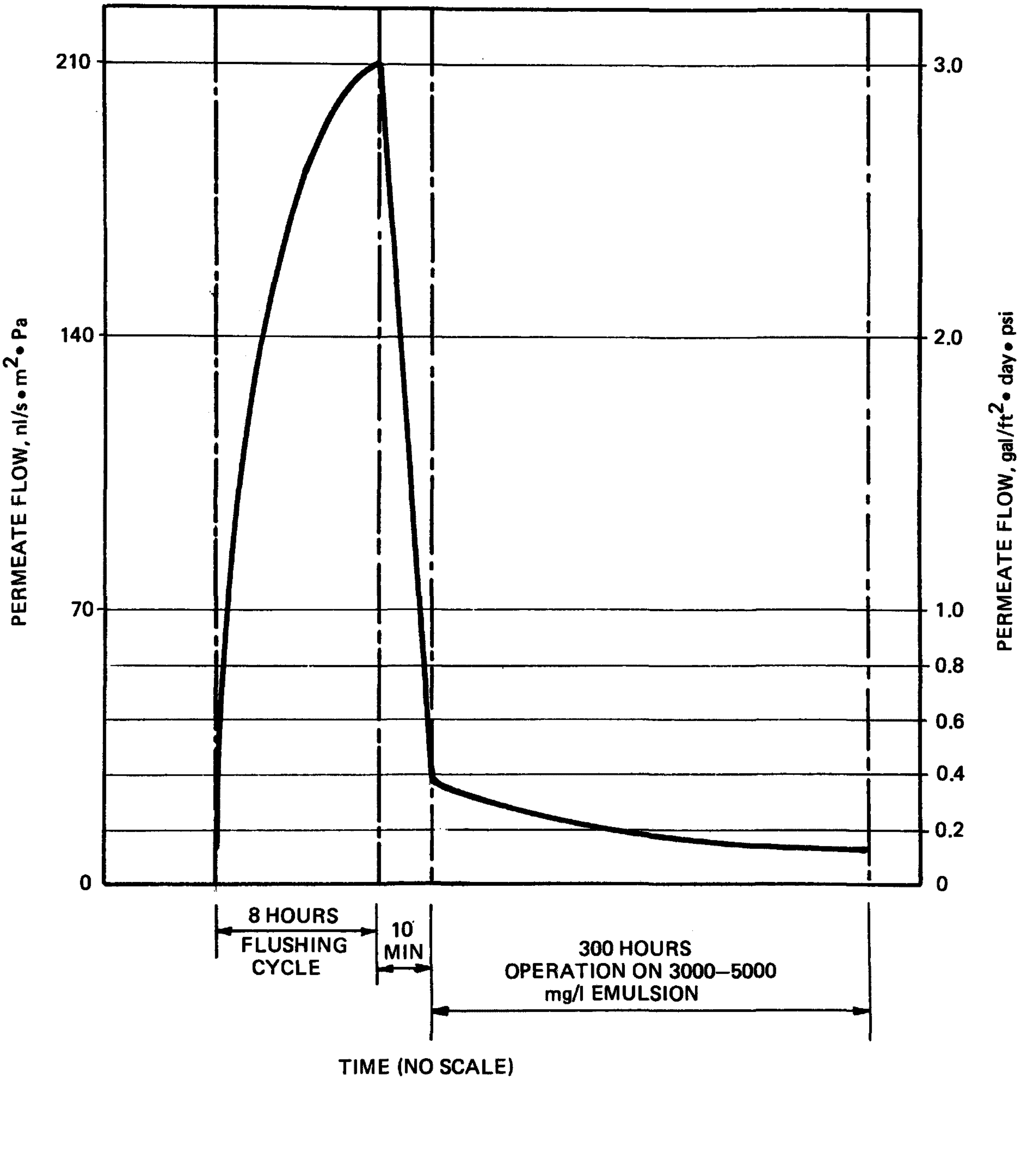


Figure 8. Ultrafiltration unit, permeate flow rate characteristics during flushing and operation on dye penetrant rinse concentrate.

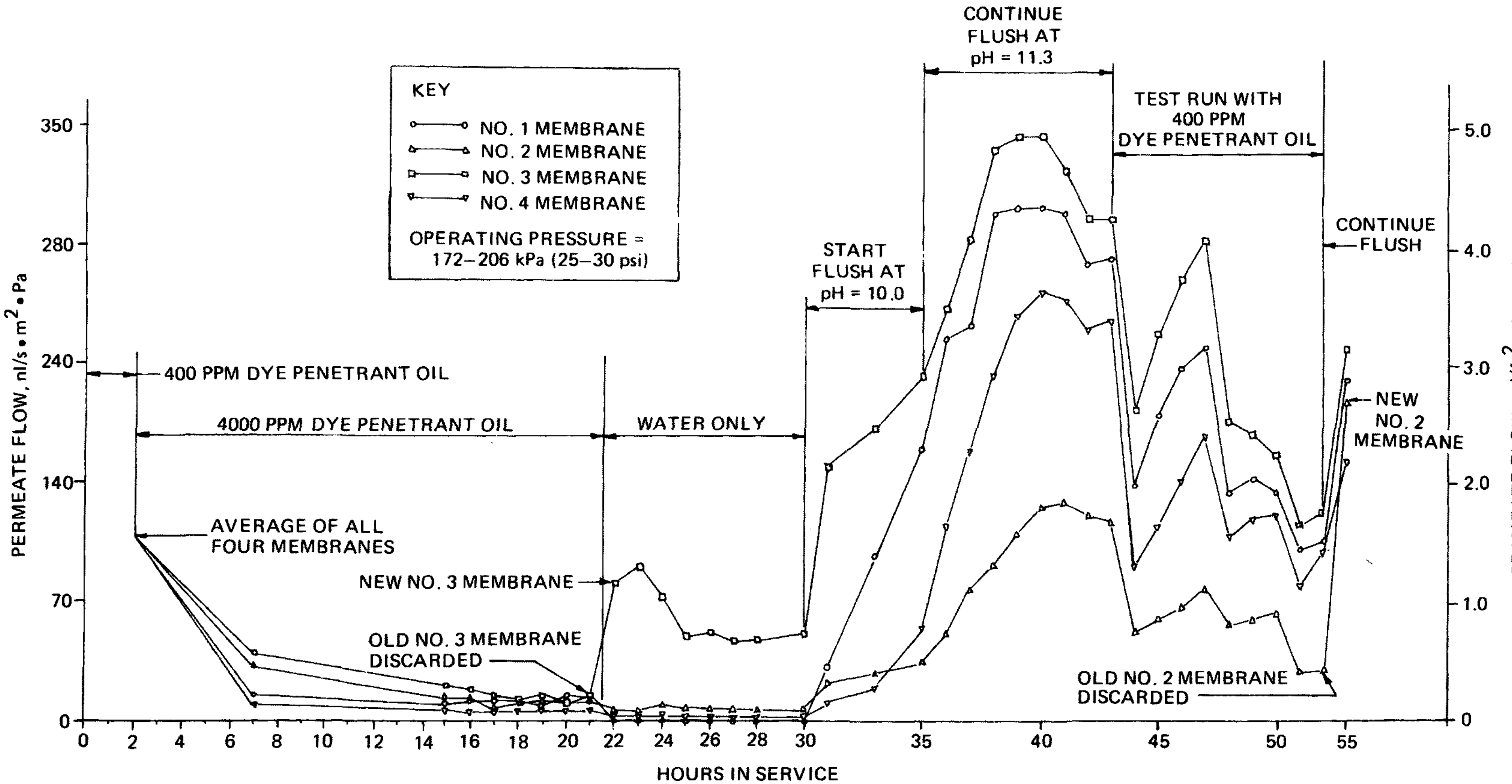


Figure 9. Service record of ultrafiltration unit, dye penetrant rinse water purification.

Simplification of Loop to Operate on Carbon Column Alone

It was reported that one company marketing a dye penetrant crack detection system* recommended recycling its rinse water using only activated carbon filtration for purifying the rinse water. With this recommendation in mind, a test was made in which simulated dye penetrant rinse water was passed at rates of between 2.5 and 7.6 l/hr through 6.6 liters of active carbon ("Nuchar") Grade WV-G 12 x 40) in two columns each 3.7 cm diameter by 45 cm long.

The filtrate from the carbon columns was clear for the first hour of operation, after which it began to show a white turbidity, i.e., all the yellow dye in the feed appeared to have been removed, even after 179 hours of operation, by the activated carbon. Examination of the water under UV light confirmed that the dye was absent (no yellow fluorescence). At this point however, the water was judged unsuitable for final rinsing of parts undergoing crack detection due to a tendency for small amounts of free oil to separate from the water, together with the only marginal acceptability of the water in a laboratory test on residual surface fluorescence. Details of this test are given below.

Analyses of the feed and carbon-filtered recycled waters gave the results shown in Table 6.

TABLE 6. ANALYSES OF FEED AND CARBON FILTERED RECYCLED WATERS

Test	Untreated feed	Carbon-filtered	
		After 13 hours operation	After 179 hours operation
Appearance	Deep yellow	White turbidity	White turbidity
UV illumination	Vivid yellow fluorescence	Moderate bluish-white fluorescence	Stronger bluish-white fluorescence
Freon extractables	280–515 mg/l	68 mg/l	277 mg/l
Surfactant as lauryl alkyl sulfonate	0.04–0.12 mg/l	Less than 0.01 mg/l	0.04 mg/l
Suitability for reuse, based on tests of residual surface fluorescence	Marginally acceptable	Acceptable	Marginally acceptable

Test for Acceptability of Rinse Water

Acceptability was determined by comparing fresh and treated water for absence of background fluorescence and effect on crack sensitivity. Absence of background fluorescence was determined with a water wash penetrant qualified to Group VI sensitivity with developer, using the water washability test called out in MIL-I-25135C. Crack sensitivity comparisons were performed on thermally cracked aluminum blocks, using the same water wash penetrant. The penetrant was rinsed with

* Brent Chemicals, Commerce Road, Brentford, Middlesex, England.

either fresh or treated water, using the apparatus and rinse conditions of the water washability test. Polaroid photographs were taken of the test blocks under a black light intensity of 2200 $\mu W/cm^2$. The initial exposure was adjusted to give the same intensity of indication in the photo observed on the test block. All subsequent test blocks were photographed, using the initial exposure. The results are indicated in Table 6.

Dye Penetrant Inspection Rinse Water Recycling–Conclusions

Dye penetrant rinse water has been successfully recycled in the demonstration unit, using two methods. A partial purification, using filtration through activated carbon only, has been demonstrated in operation for 179 hours, and a more complete purification, using ultrafiltration followed by activated carbon "polishing," has been demonstrated over a period of 627 hours.

Partial purification by filtration through activated carbon yields a dye-free, but not oil-free, water that is only marginally acceptable for rinsing parts undergoing crack detection.

Purification by ultrafiltration followed by carbon "polishing" yields a higher quality water (only 1 to 2 mg/l of oil compared with up to 277 mg/l oil in the carbon-only filtered water) of more than adequate purity for its intended purpose.

The simplicity and lack of moving parts in the carbon-only treatment make it an attractive process. A cost analysis for recycling dye penetrant rinse water, based on a full-scale factory-sized plant, is given in Section 6.

MACHINE SHOP COOLANT WASTE WATER PURIFICATION

General

In this demonstration loop, clean water was reclaimed from waste machine shop coolant and reused to make fresh coolant. The total running time was 290 hours over a period of 54 days.

Actual waste machine shop coolant was used for the initial charge in the loop, and metered additions of new cutting oil concentrates were fed continuously to the recycled water to maintain coolant strength. Maximum use was made of actual used coolant for replacing evaporation losses, replacing samples withdrawn, etc., because of the marked differences between used and unused coolant. Used coolant is vile-smelling, dark, and has a surface layer of "tramp" oil and organic slime, whereas the fresh product is usually clear to milky white, with an antiseptic odor.

Treatment in this loop consisted of decanting and filtering to remove floating "tramp" oil, scum, grinding grit and metal particles; ultrafiltration to remove emulsified oil and precipitated soaps; and reverse osmosis to remove dissolved material. Adjustment of pH from alkaline (pH 7.5 to 9.0) to slightly acid (pH 6.5) was made because the cellulose acetate membranes of the RO unit could not be used in alkaline conditions.

Figure 10 shows the demonstration equipment and Figure 11 shows the waste coolant, recycle, and UF concentrate tanks. The floating scum and "tramp" oil on the waste coolant is clearly shown in Figure 11. Carry over of the scum and oil to the UF concentrate tank, retained by the divider, was skimmed off daily.

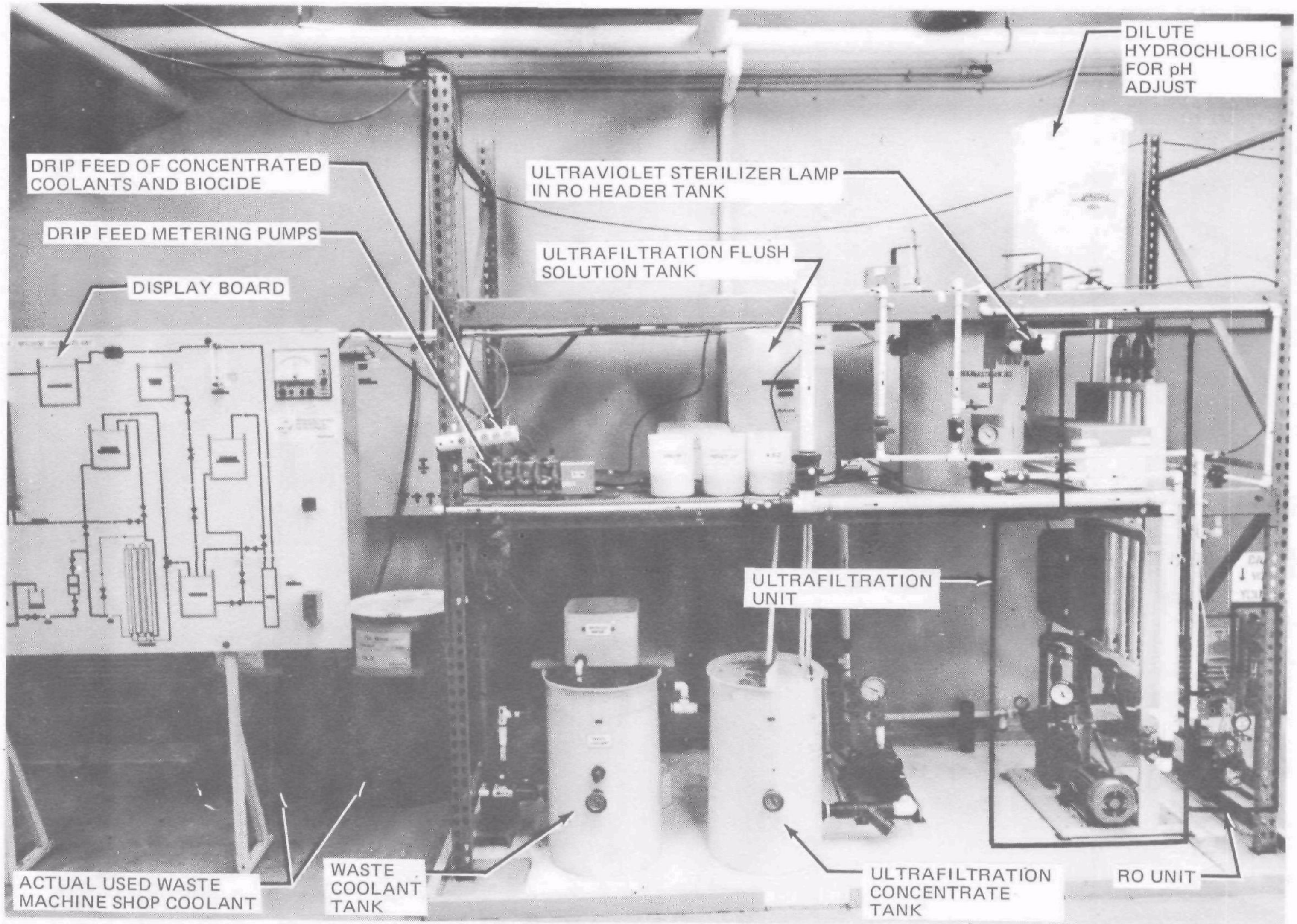


Figure 10. Demonstration equipment for machine shop coolant waste water purification.

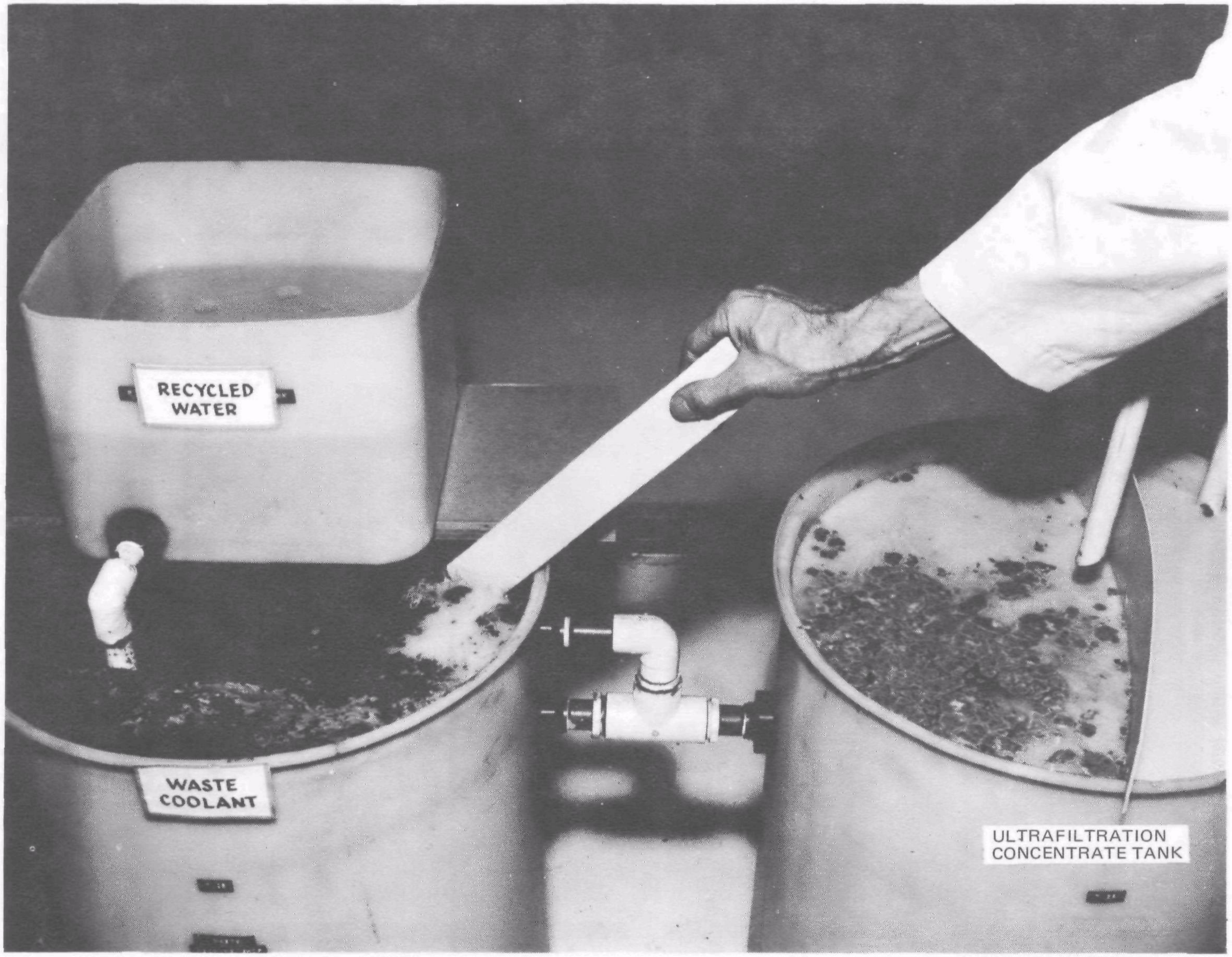
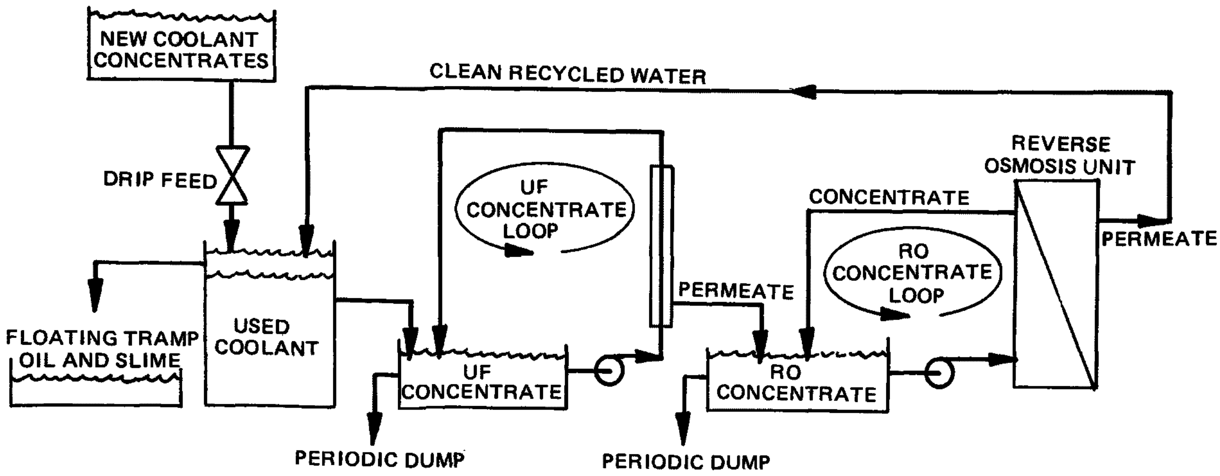


Figure 11. Machine shop coolant waste water purification, waste coolant and recycled-water tanks.



OPERATION

Operation of this loop presented three problems:

- o Near-intolerable odor levels unless biocides and sterilizer were used.
- o Frequent flushing of the UF membrane was required to maintain adequate permeate flow rates.
- o Organic growths, unless removed, tended to block filters and pipes.

After the above problems were solved (see the following sections for details), the loop was operated to give the following results.

	Waste coolant	Reclaimed water
Total dissolved solids	1500 to 2500 mg/l	500 to 1500 mg/l
Suspended solids	1000 to 2000 mg/l	Nil
Freon extractables	250 to 1000 mg/l	50 to 100 mg/l
pH	7.5 to 8.0	6.5
Floating "tramp" oil and slime	1 to 2% by volume	Nil
Plate count	10^6 to 10^7 micro-organisms/ml	–

Offensive Odor of Waste Coolant

Discarded coolants from a machine shop are normally rancid and offensive in odor. A "plate" count, i.e., a microbiological count of the number of micro-organisms that can be grown on an agar plate of over 0.1 million/ml of coolant is sometimes taken as an indication that a coolant has reached the end of its useful life. At the time of testing, several days after collection from the machine shops, the 50-gallon samples used to charge the loop contained between one and 10 million micro-organisms/ml.

Due to the heat generated by the UF and RO pumps in the demonstration loop, temperature of the waste coolant was 21° to 29°C (70° to 85°F), in spite of the provision of water cooling. At these temperatures, conditions for micro-organism growth were highly favorable, and a dark slimy crust formed on the waste coolant, and a highly offensive odor surrounded the equipment.

Addition of a proprietary biocide, Pace Chemical N-136B, was effective in destroying odors when added at one percent (10,000 parts per million) by volume to the waste coolant. However, this is a substantial addition when it is considered that the original coolant contained only 2 to 2½% by volume of added coolant concentrate, i.e., the biocide additive constitutes almost one-third of the total dissolved load carried by the water.

In spite of the use of biocide in the raw waste coolant, the header tank to the RO unit still continued to darken, develop a mold-like skin, and emit a decaying odor. As it was undesirable to add additional biocide to this header tank, (since the whole purpose of the loop was to remove material from the water) an ultraviolet sterilizer lamp was fitted to the tank. This technique proved completely successful in eliminating surface growths, and substantially eliminated the odor from this tank.

Flushing of UF Unit

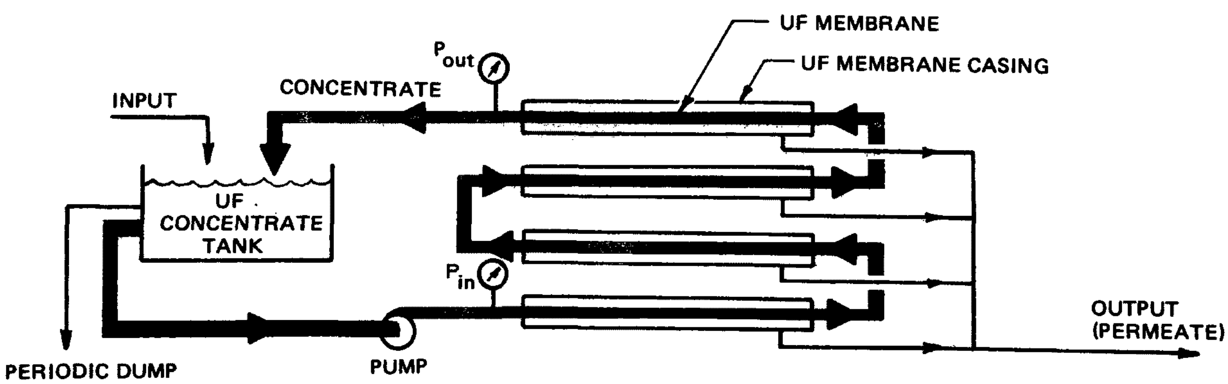
The ultrafiltration unit required much more frequent flushing—six times in 290 hours operation—than the identical unit used in the dye penetrant rinse water unit (page 22), which was flushed only twice in 627 hours.

Immediately after flushing with alkaline detergent solution (see Appendix H), a permeate flow of over 200 nl/m^2·s·Pa (2.92 gal/ft^2·day·lb/in.^{2}) was usual. Within an hour of introducing the waste coolant, however, the flow dropped to approximately 20 nl/m^2·s·Pa, (0.29 gal/ft^2·day·lb/in.^{2}).

Operating Pressure of the UF Unit

The ultrafiltration unit was operated with an input pressure of 206.9 kPa (30 lb/in.^{2}) during the flushing cycle, and for the first part of its duty cycle. When permeate rates dropped below 50 ml/min (after approximately 20 hours operation) the input pressure was raised, first to 275.8 kPa (40 lb/in.^{2}) and then to 344.8 kPa (50 lb/in.^{2}), in order to sustain a flow sufficient to feed the RO unit (approximately 50 ml/min).

A constant difference of 69 kPa (10 lb/in.^{2}) was maintained between P_{in} and P_{out} (see sketch below of ultrafiltration unit), ensuring a constant high velocity inside the membrane tubes.



This high velocity was recommended by the manufacturers of the unit, to provide a high velocity inside the tubes and minimize any tendency to form a coating that would block the membranes.

Adjustment of pH

Because the cellulose acetate membranes of the RO unit were unsuited to use in alkaline conditions, the pH of the UF permeate, i.e., the RO feed, was experimentally lowered from an original 7.5 to 9.0, to less than 7.0, using 4% hydrochloric acid. However, this procedure resulted in the formation of a precipitate which rendered the solution unsuitable for introduction to the RO unit unless completely filtered. After tests, it was found that if the feed *to the UF unit* was acidified to pH 6.5, then the permeate from the UF–also at pH 6.5–was suitable for feeding to the RO unit. The unit was accordingly operated in this manner.

Reverse Osmosis Unit

This unit has operated with a minimum of attention, except for weekly operation for 10 minutes at increased recycle rates, to "wash" the membranes, plus mild chlorination (5 ppm) during periods of shutdown of more than two weeks. At an operating pressure of 1345 kPa (195 $lb/in.^2$), the permeate flow was between 50 and 100 ml/min (0.79 to 1.59 gal/hr). Membrane area on this unit was 0.46 $m^2/(5\ ft^2)$.

A rejection ratio of approximately 0.77, based on conductivity, was obtained for the unit when the demonstration loop was operated on actual machine shop waste coolant. At the upper limit of 1500 mg/l total dissolved solids in the recycled water, with this rejection ratio, the waste from the RO unit, concentrated in the header tank, contains slightly more than 6520 mg/l total dissolved solids.

Factory Test of Recycled Water

A sample of 76 liters (20 gallons) of reclaimed water from the demonstration unit was used in a production turret type drilling, tapping and honing machine (a Burgermaster Model 2B). Used to prepare a proprietary coolant (CIMCOOL "Five Star") at a dilution of 40:1, the coolant was indistinguishable from coolant made from the city water supply, over a period of at least 2½ months.

The water had the following characteristics:

pH	6.75
Freon extractables	64 mg/l
TDS (50°C)	1413 mg/l
Ash on TDS	437 mg/l
Appearance	Faintly cloudy
Odor	Musty

Machine Shop Coolant Waste Water Purification—Conclusions

The demonstration unit has successfully reclaimed water from used machine-shop coolant. However, more problems were encountered in operating this loop than were originally anticipated. These included:

- The development of a strongly offensive odor unless relatively large amounts of biocide were added to the waste coolant tank
- A considerable organic growth in the RO header tank unless UV sterilizer used
- Only 50 hours average operating time before the UF unit required flushing to restore its permeate flow rate
- A relatively low concentration of 6500 mg/l total dissolved solids in the concentrated waste from the RO unit before dumping becomes necessary

CYANIDE RINSE WATER PURIFICATION

Electrolytic Destruction of Cyanide

The original plan for this loop was to destroy the cyanide in the rinse water from plating shop waste, by electrolysis. Experiments with a prototype unit had demonstrated the feasibility of this plan, which converts cyanide to carbon dioxide and nitrogen, and at the same time removes heavy metals from the rinse water by plating them out onto the electrodes.

The prototype unit had a unique design in which electrode area and electrode velocity were maximized by passing the electrode successfully through a series of concentric stainless steel cylinder electrodes. In the prototype development runs, d.c. current reversal was employed to prevent the buildup of copper, etc. on the electrodes.

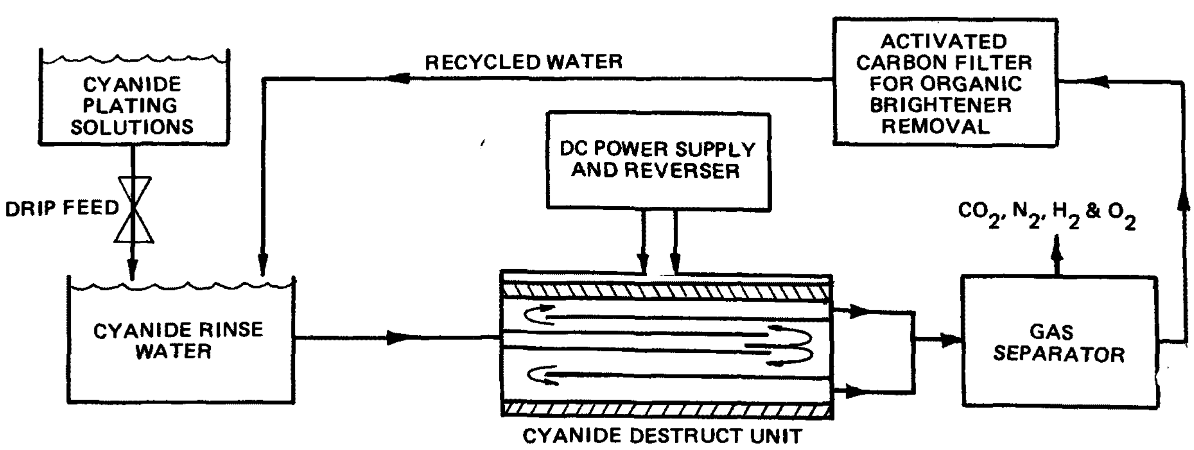
The simplified cyanide destruction equations are as follows:

$$\text{ANODE:}\quad 2CN^- + 4H_2O \rightarrow 2CO_2\uparrow + N_2\uparrow + 8H^+ + 10e^-$$

$$\text{CATHODE:}\quad 8H^+ + 8e^- \rightarrow 4H_2\uparrow$$

$$Me^{++} + 2e^- \rightarrow 2Me\downarrow$$

The flow diagram of the original plan (not used) is shown below:



Change to Nonelectrolytic Cyanide Destruction

During the equipment design phase of this program, it became evident that the generation of hydrogen and oxygen within the electrolytic cyanide destruction unit posed a safety problem, particularly if the equipment was to operate semicontinuously with the minimum of attention. The safety concern was that metals such as copper, loosely deposited on the electrodes, could possibly form flakes that might internally short the electrodes and ignite the explosive gas mixture. In brief, the unit was a potential "bomb."

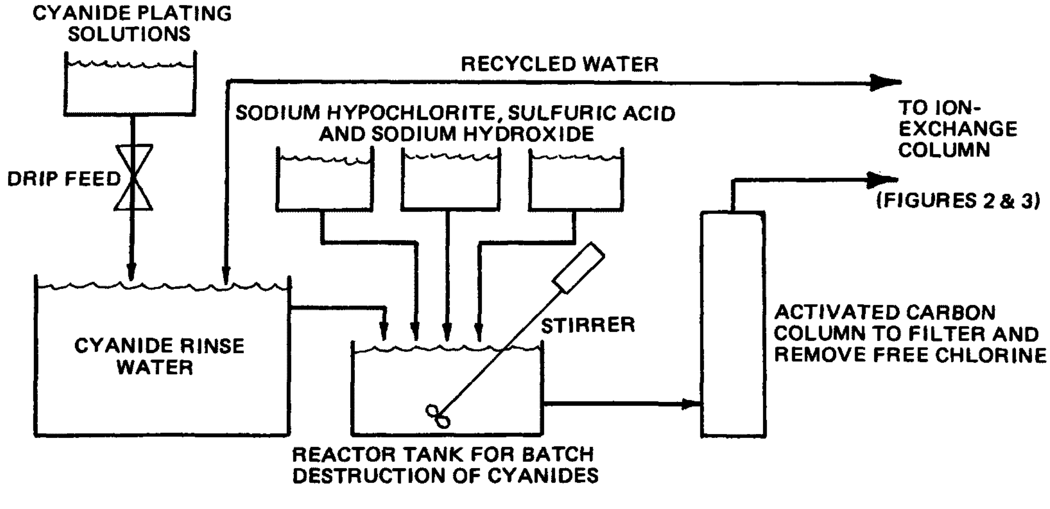
Therefore, in this demonstration program, it was decided to use a well-established chemical destruction method for removing cyanide.

Outline of Cyanide Destruct Unit

The purification and recycling of rinse water containing 100 to 200 mg/l of cyanides was demonstrated in a four-step operation:

- o Accumulation of a batch of cyanide-containing rinse water
- o Destruction of the cyanide in the batch by addition of sodium hypochlorite
- o Removal of solids and excess chlorine
- o Removal of all anions and cations by ion-exchange resin*

The last operation was accomplished by feeding the treated, cyanide-free water to the ion-exchange loop to avoid duplication of equipment. The flow diagram of the plan actually used is shown below.



*Cyanide must be removed (except in certain special cases) from the feed to an ion-exchange system because of the risk of toxic HCN production during regeneration with acid.

Batch Treatment of Cyanide Rinse Water

Simulated cyanide rinse water was fed to the reactor tank at a rate of 50 ml/min,accumulating a batch of 30 liters (8 gallons) every 10 hours of operation. A series of valves, timer-controlled, together with pH and ORP (oxidation-reduction potential) probes governed the addition of oxidant (5% sodium hypochlorite solution), and pH adjusting solutions, over a pre-set time schedule as follows:

0 – 30 minutes	Adjust pH to 9.0 and add excess sodium hypochlorite to ORP 400 mV minimum
30 – 60 minutes	Lower pH to 8.0 and maintain ORP 400 mV minimum
60 – 75 minutes	Dwell
75 – 90 minutes	Empty reactor tank

Cyanide Rinse Water Simulation

Rinse water from cyanide plating operations was simulated by metering actual plating shop solutions into the recycled water stream at the following rates:

Copper Plating Bath	0.057 ml/min
Cadmium Plating Bath	0.057 ml/min
Titanium-Cadmium Plating Bath	0.057 ml/min
Enstrip *	0.029 ml/min
Recycled Water	50.0 ml/min

Composition of each of the above plating and stripping solutions is detailed in Appendix E.

Analysis of Simulated Rinse Water, Detoxified Rinse Water and Recycled Water

Typical analysis of the input, output and recyled waters are as follows:

	Simulated rinse	Detoxified	De-ionized
Free CN	186 mg/l	Nil	Nil
Cu	30 mg/l	–	Nil
Cd	63 mg/l	–	Nil
N_aOH	45 mg/l	–	Nil
Free Cl_2	–	0.05 mg/l	0.05 mg/l
pH	9.5	8.0	5.9

Figure 12 shows the demonstration equipment for the cyanide destruct system.

* Enthone Inc., 2751 El Presidio St., Long Beach, California 90810

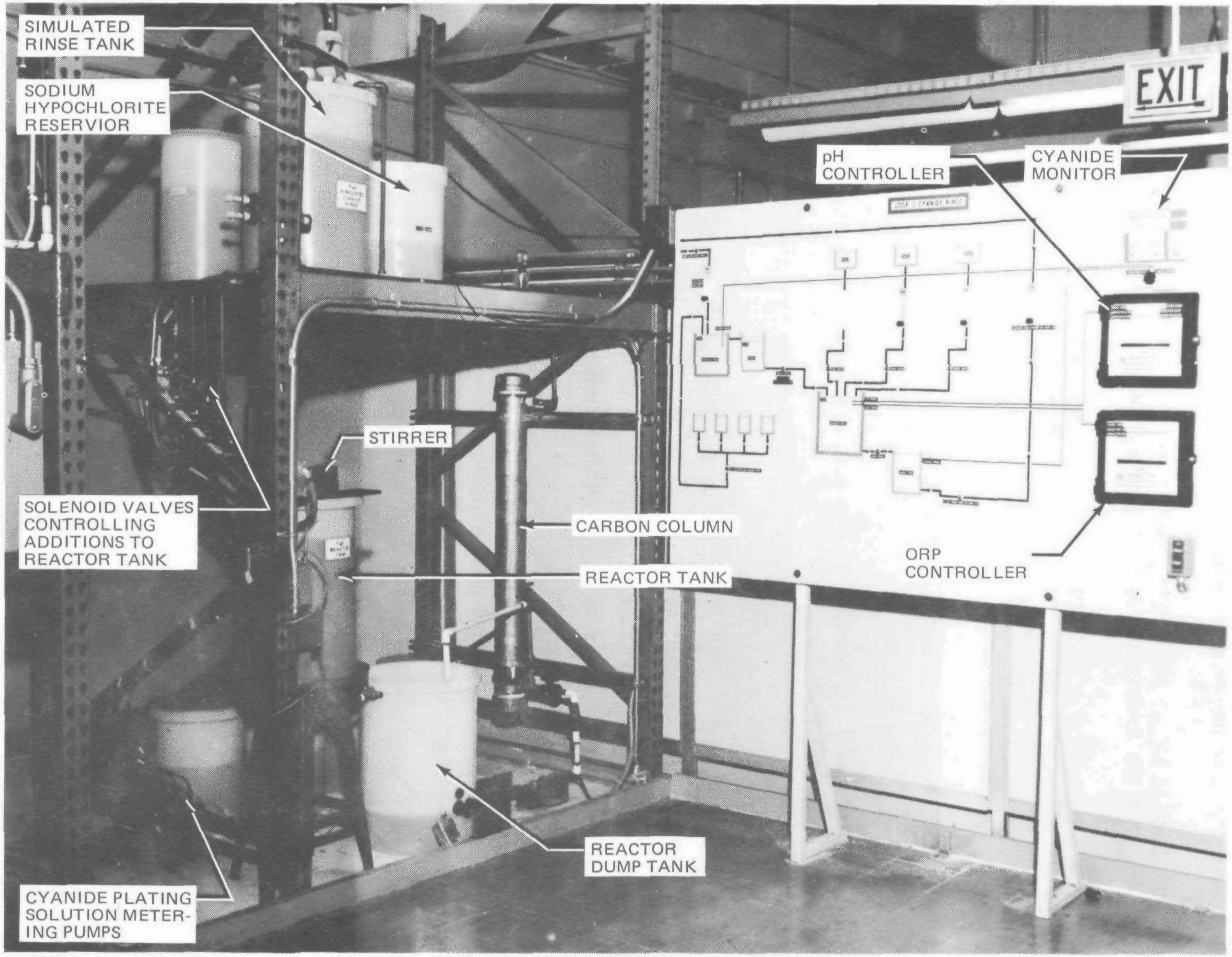


Figure 12. Demonstration equipment for cyanide rinse water purification.

Cyanide Rinse Water Purification—Conclusions

The recycling of rinse water containing approximately 200 mg/l cyanide was demonstrated in a conventional chlorine oxidation operation to destroy cyanides followed by ion-exchange treatment to remove the remaining dissolved minerals.

Original plans to use an electrolytic cell to destroy cyanide were abandoned because of the explosion risk from the hydrogen-oxygen mixture generated as a byproduct of the electrolysis.

SECTION 5

COST OF FULL-SCALE PLANT

GENERAL

The estimated cost of installing a full-scale facility, excluding land cost, is detailed in this section.

The facility would receive an average flow of 1.68 million l/day (444,000 gal/day) made up as follows:

	l/day	gal/day
Chemical process rinse water	1,514,000	400,000
Dye penetrant rinse water	121,120	32,000
Machine shop coolant	24,224	6,400
Cyanide process rinse water	22,710	6,000

Figures 13 and 14 show overall flow diagrams for the full-scale facilities of this cost estimate.

Water used for cooling compressors, air-conditioning units and other machines, and sanitary waste water would not be treated by the facility.

ESTIMATE

Cost Summary 1—By Process

Process	Equipment purchase cost	Site preparation, building, wiring installation	Total
Chemical process rinse water	$1,050,173	$1,695,668	$2,745,841
Dye penetrant rinse water	100,253	161,901	262,154
Machine shop coolant	79,927	129,051	208,978
Cyanide rinse water	64,980	105,047	170,027
Totals	$1,295,333	$2,091,667	$3,387,000

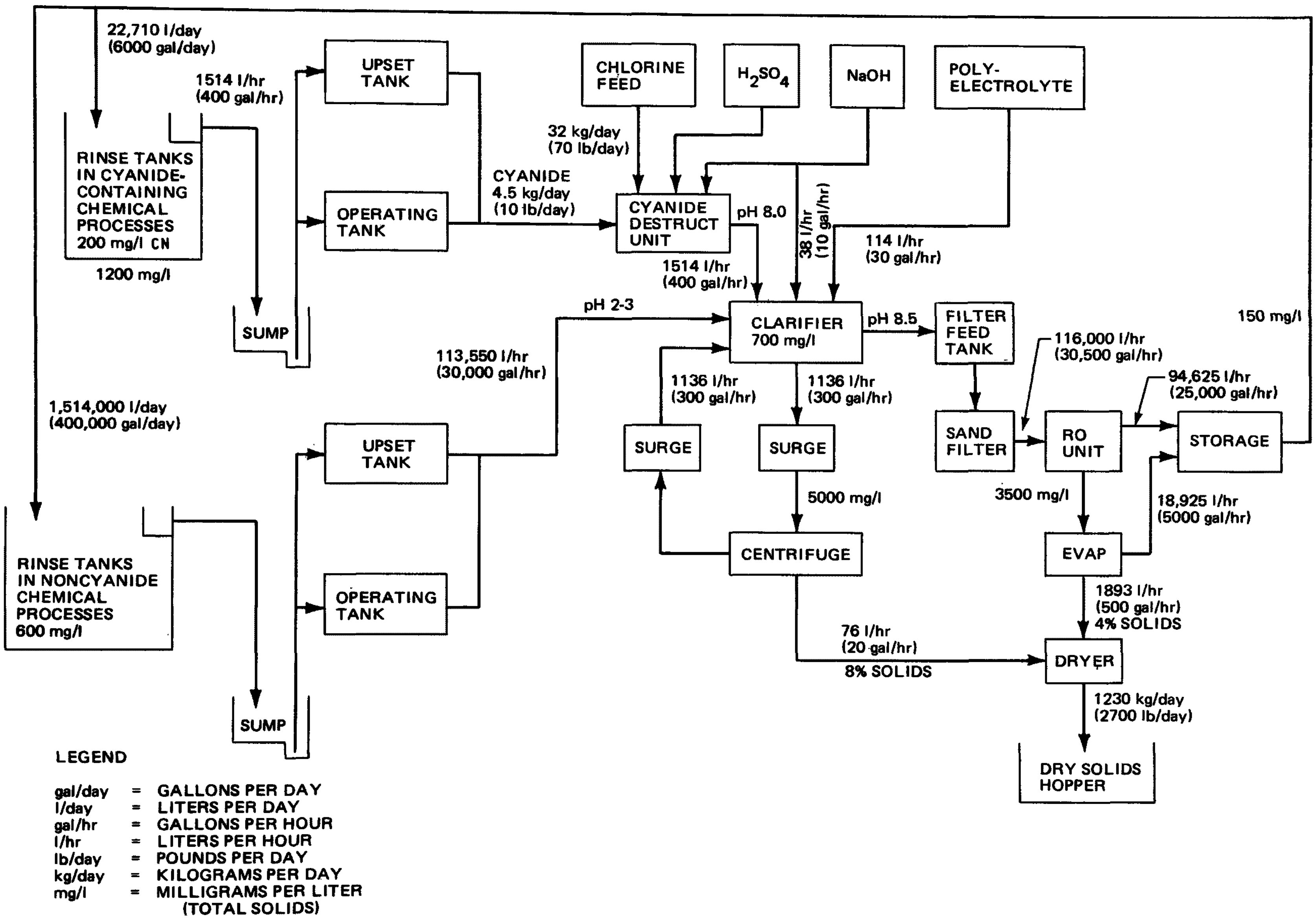


Figure 13. Flow diagram for cyanide and noncyanide chemical process rinse water.

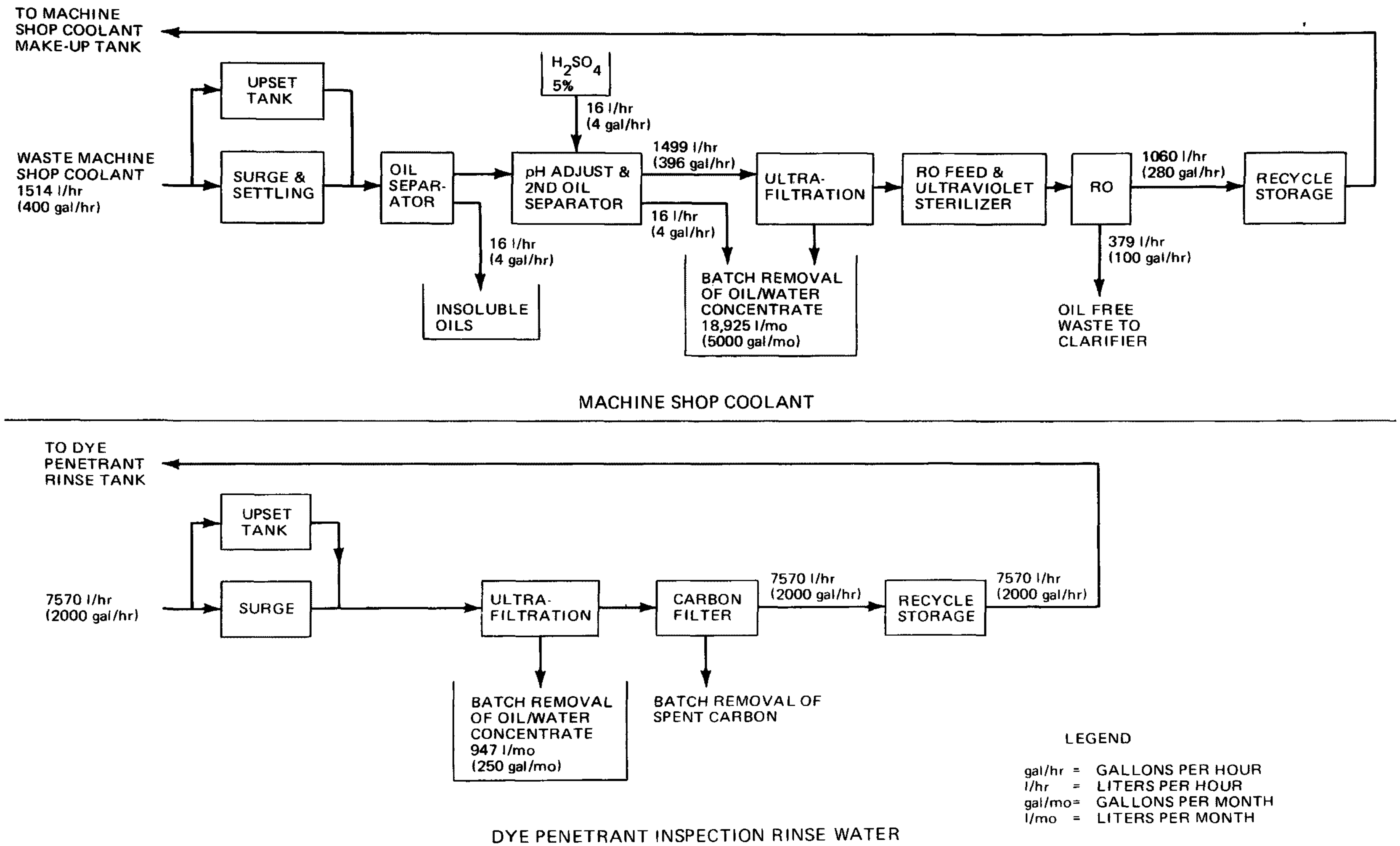


Figure 14. Flow diagram for machine shop coolant and dye penetrant rinse water recycling.

PROCESS OPTION

The above cost summary assumes that the chemical process rinse water is purified by the reverse osmosis process. If the reverse osmosis option were replaced by ion exchange, there would be a saving of $40,800 (1.2% of total).

Cost Summary 2—By Overall Items

Item	Cost
Building, approach road, drains, fence, sumps, (capital cost plus installation)	$ 740,000
Tanks, equipment, plumbing, controls (capital cost plus installation)	1,976,000
Electrical (capital cost plus installation)	308,000
Construction management (4%), architectural and engineering fee (8%)	363,000
Total	$3,387,000

Equipment List

An equipment list of all pumps, tanks, RO units, UF units, separators, centrifuges, driers, evaporators, filters, etc., is included in Appendix F, together with a complete schematic for the full-scale recycling plant.

SECTION 6

OPERATING ECONOMICS OF A FULL-SCALE PLANT

GENERAL

The operating cost of a full-scale recycling plant, based on the principles of the pilot scale demonstration units, is developed in this section.

A summary of the operating costs, and conclusions, are presented first. Details of the costs of each process, and the calculations on which these costs are based, can be found in later pages in this section.

For comparison purposes, the cost of operating a full-scale conventional treatment plant is also included.

SUMMARY

Table 7 summarizes the operating economics of a recycling system compared with the economics of a conventional treatment plant discharging to waste.

TABLE 7. SUMMARIZED OPERATING ECONOMICS, RECYCLING SYSTEM COMPARED WITH CONVENTIONAL TREATMENT PLANT DISCHARGING TO WASTE

	Cost of recycled water		Cost of once-through water	
	$ per 1000 l	$ per 1000 gal	$ per 1000 l	$ per 1000 gal
Chemical process rinse water	0.94	3.57	0.52	1.97
Dye penetrant rinse water	1.65	6.25	0.54	2.06
Machine shop coolant	12.18	46.09	2.56	9.69
Cyanide process rinse water	4.36	16.50	3.21	12.17
TOTAL	1.21	4.57	0.59	2.24

DISCUSSION AND CONCLUSIONS

The calculations show that, in all four cases, the cost of recycling is higher than the cost of single-use. Recycled chemical process water costs 80% more, dye penetrant rinse water 203% more, machine shop coolant water 376% more, and cyanide rinse water 36% more. Except in the case of machine shop coolant water recycling, higher equipment cost is the major expense factor. (The major cost item for machine shop cooling recycling is labor.)

The minimum cost, $0.94/kl of recycled water applies to water that can be purified with relatively little difficulty, and which is used in large volumes (the chemical process rinse water). The cost of recycling rises steeply with the technical difficulty of purification, and with decreasing volumes to be treated (e.g., the cyanide rinse water and the machine shop coolant).

It should be noted that the cost of fresh water, taken as $0.0794/kl or $0.30/1000 gal, is the average cost for water in large airplane factories in the States of Washington, California, and New York. This is only 3 to 15% of the costs of treating that water after use, before it can be discharged to waste.

The high cost of extracting clean water from used machine shop coolant by ultrafiltration and reverse osmosis, $12/kl or $46/1000 gal, compares very unfavorably with the $2.56/kl or $9.69/1000 gal to purify the same coolant by chemical methods. However, the chemical method cannot be used by itself in a closed loop system because it involves the addition of soluble sulfates to the water. These sulfates are permitted additives to water discharged to a natural waterway or sewer, but are forbidden to any closed system where they could accumulate without limit. Further research is needed to reduce the high cost of treatment of machine shop waste coolants for recycling.

Since equipment is the major factor governing treatment cost, it is evident that reduction of rinse water volumes will effect the greatest overall economies in the cost of water treatment. Standard procedures for water volume reduction, such as provision of multiple counter-current rinses, "on-demand" provision of rinse water (e.g., by conductivity-controlled supply valves), and vigilance by factory operators, supervision and maintenance in shutting off rinse tank feeds during inactive shifts and weekends, will become of increasing importance when water recycling is employed.

OPERATING ECONOMICS–CALCULATIONS

Assumptions Used

1. All costs are in 1976 dollars.

2. The following volumes of water are received daily:

Chemical process rinse water	1.54 Ml/day (400,000 gal/day)
Dye penetrant rinse water	0.121 Ml/day (32,000 gal/day)
Machine shop coolant	24.2 kl/day (6,400 gal/day)
Cyanide process rinse water	22.7 kl/day (6,000 gal/day)

3. Amortization of chemical process equipment cost (purchase price plus installation cost) is calculated at 8% over a 12-year life.

4. Amortization of building and utilities (materials, construction and installation cost) is calculated at 8% over a 15-year life.

5. Operating labor costs are $30/hr total, including basic wage, overtime, fringe benefits and management and overhead burden.

6. Cost of fresh water is $0.0794/kl ($0.30/1000 gal).

7. Other assumptions, such as cost of disposal of sludge, disposition of operator time, etc. are treated in the detailed calculations, pages 43 through 50.

8. The recycling plant has been designed for operation by one operator on each of two shifts. The nonrecycling plant requires one operator on only one shift. The reason for this is to reduce overall costs. Operating on two shifts obviously doubles the total operating labor costs, but allows a reduction in equipment costs (the major cost item) since the equipment can be sized to handle one half of the load of a single shift operation.

9. The following items are not taken into account in this study: startup costs, operating profit, site purchase cost, sewer disposal charges, tax advantages.

Operating Cost Details

Tables 8 through 11 itemize the operating costs on which the summary table, page 41, is based. Costs are identified by a letter: this letter refers to a calculation given on pages immediately following the table.

BASES AND CALCULATIONS FOR TABLE 8

(a) From Appendix F, summarized on page 37.

(b) From unpublished Boeing data for its Auburn waste treatment plant. Dollar costs for 1967 have been converted to 1976 dollars, using an inflation factor of 1.739 (average of *Chemical Engineering* and *Marshall & Swift* indices for 1967 to 1976).

Equipment plus installation cost	Equivalent 1976 dollars
Chemical process rinse water	$ 809,499
Dye penetrant rinse water	80,950
Machine shop coolant	52,800
Cyanide rinse water	112,751
Total	$1,056,000

TABLE 8. CHEMICAL PROCESS RINSE WATER, ITEMIZED OPERATING ECONOMICS

	Recycling Plant		Nonrecycling Plant	
Total equipment cost including installation	**$2,745,841**	**(a)**	**$809,499**	**(b)**
Equipment amortization cost per day	1,014	(c)	299	(d)
Operating labor cost per day	192	(e)	180	(f)
Chemicals—cost per day	52	(g)	114	(h)
Electric power cost per day	12	(i)	3	(j)
Maintenance cost per day	14	(k)	15	(l)
Sludge disposal cost per day	56	(m)	56	(n)
Fresh water purchase cost per day	12	(o)	120	(p)
Membrane replacements	76	(g)	——	
Total	**$1,428**		**$787**	
Total volume processed per day	1,514,000 liters (400,000 gallons)		1,514,000 liters (400,000 gallons)	
Cost per 1000 liters	$0.94		$0.52	
Cost per 1000 gallons	$3.57		$1.97	

(c) $2,145,923 (equipment) x 0.132695*/350 days/year = $ 813.58/day

$ 599,918 (buildings) x 0.116830**/350 days/year = $ 200.25/day

$2,745,841 (total) x (0.0003692)***days/year = $1,013,83/day

(d) $809,499 (total) x (0.0003692)*** † = $298.89

* 0.132695 = Periodic payment for annuity, 8%, 12 years (2)

** 0.116830 = Periodic payment for annuity, 8%, 15 years (2)

*** 0.000369 = Combined periodic payment for annuity calculated from $1,013.83 ÷ $2,745,841

† It is assumed that the same relative percents of costs between equipment and buildings exist for the nonrecycle plant as in the recycle plant.

(e) Labor distribution, recycle plant:

Chemical process rinse water	=	40%
Dye penetrant rinse water	=	15%
Machine coolant	=	40%
Cyanide rinse water	=	5%

Labor cost:

Chemical process rinse	=	16 hr/day x $30/hr x 40%	=	$192/day
Dye penetrant rinse	=	16 hr/day x $30/hr x 15%	=	$ 72/day
Machine coolant	=	16 hr/day x $30/hr x 40%	=	$192/day
Cyanide rinse	=	16 hr/day x $30/hr x 5%	=	$ 24/day

(f) Labor distribution, nonrecycling plant:

Chemical process rinse water	=	75.0%
Dye penetrant rinse water	=	7.5%
Machine coolant	=	8.75%
Cyanide rinse water	=	8.75%

Labor cost:

Chemical process rinse water	=	8 hr/day x $30/hr x 75%	=	$180/day
Dye penetrant rinse water	=	8 hr/day x $30/hr x 7.5%	=	$ 18/day
Machine coolant	=	8 hr/day x $30/hr x 8.75%	=	$ 21/day
Cyanide rinse water	=	8 hr/day x $30/hr x 8.75%	=	$ 21/day

(g) Cost of chemicals, chemical process rinse water, recycling plant:

Lime for clarifier	=	$5976/hr	350 days/yr x 90%	=	$14.90/day
Flocculant clarifier	=	$1944/hr	350 days/yr x 90%	=	$ 5.00/day
Antifoam clarifier	=	$12,600/hr	350 days/yr x 90%	=	$32.40/day
Total					$52.30/day

(h) Cost of chemicals, chemical process rinse water, nonrecycling plant:

Lime for clarifier	=	$ 5,796/yr	350 days/yr x 90%	=	$14.90/day
Flocculant clarifier	=	$ 1,944/yr	350 days/yr x 90%	=	$ 5.90/day
Antifoam clarifier	=	$12,600/yr	350 days/yr x 90%	=	$32.40/day
Sulfuric acid (Cr reduction)	=	10,552/yr	350 days/yr x 100%	=	$30.15/day
Sulfur dioxide	=	$11,205	x 100%	=	$32.01/day
Total					$114.46/day

(i) Electric power, chemical process rinse water recycling:

RO pumps:

210 hp x 0.746 kW/hp x 0.0035 $/kWh x 16 hr/day = $8.77/day

Other pumps: (160 hp total, from Appendix F)

160 hp x 50% duty cycle x 0.746 kW/hp x 0.0035 $/kWh x 16 hr/day = $3.34 /day

Total $12.11/day

(j) Same as (i), "Other pumps"

(k) 10% of operating labor costs

(l) Same as (k)

(m) From 49.7 m^3/mo (65 yd^3/mo) at $32.70/$m^3$ ($25/$yd^3$)

49.7 m^3/mo x $32.70/$m^3$ ÷ 29.25 days/mo = $55.56/day

(n) Same as (m)

(o) 151,400 liters (40,000 gallons) @ $0.0793/kl ($0.030/1000 gal) = $12/day

(p) 1,514,000 liters (400,000 gallons) @ $0.0793/kl ($0.30/1000 gal) = $120.06/day

(q) Membrane replacement cost, 20% x $400,000 (Appendix F, page 78 , item 70) every 3 years = $80,000 ÷ (3 yr x 350 days/yr) = $76.19/day

BASES AND CALCULATIONS FOR TABLE 9

(a) From Section 5, page 37.

(b) From (b), page 43.

(c) $100,252 (equipment) x 0.132695*/350 days/yr = $38.01/day

$161,901 (buildings) x 0.116830**/350 days/yr = $54.04/day

$262,154 (total) x (0.0003511)/350 days/yr = $92.05/day

(d) $80,950 x 0.0003511 [from (c) above] = $28.42

(e) See (e), page 44 = $72.00

(f) See (f), page 45 = $18.00

(g) Chemicals for recycling dye penetrant rinse water:

Activated carbon 35.3 kg/day (77.7 lb/day)

77.7 lb/day x $0.50/lb x 50% (saved by pyrolytic regeneration) = $19.4/day

*0.132695 = Periodic payment for annuity, 8%, 12 years (2).

**0.116830 = Periodic payment for annuity, 8%, 15 years (2).

TABLE 9. DYE PENETRANT RINSE WATER, ITEMIZED OPERATING ECONOMICS

	Recycling Plant		Nonrecycling Plant	
Total equipment cost including installation	**$262,154**	**(a)**	**$80,950**	**(b)**
Equipment amortization cost per day	92	(c)	28	(d)
Operating labor cost per day	72	(e)	18	(f)
Chemicals—cost per day	19	(g)	4	(h)
Electric power cost per day	1	(i)	——	
Maintenance cost per day	7	(j)	2	(k)
Sludge disposal cost per day	0	(l)	4	(m)
Fresh water purchase cost per day	1	(o)	10	(n)
Membrane replacements	9	(p)	——	
Total	**$200**		**$66**	
Total volume processed per day	121,120 liters (32,000 gallons)		121,120 liters (32,000 gallons)	
Cost per 1000 liters	$1.65		$0.54	
Cost per 1000 gallons	$6.25		$2.06	

(h) 8% of chemical process rinse water chemical costs [(g), page 45]

(i) 10% of power for RO [(i), page 46]
$12/day x 10% = $1.20/day

(j) 10% of operating labor cost

(k) Same as (j)

(l) 947 l/mo (250 gal/mo) of water/oil mixture
250 gal/mo 29.25 days/mo x $0.04/gal = $0.34/day

(m) 8% of sludge disposal costs for chemical process rinse water,
[(m), page 63) $55.56 x 8% = $4.44/day

(n) 121,120 liters (32,000 gallons)/day @ $7.93/kl ($0.30/100 gal)

(o) 10% of (n)

(p) Membrane replacement cost, 20% x $45,000 (Appendix F, page 79, item 83) every 3 years = $9,000/3 yr/350 day/yr = $8.57/day

TABLE 10. MACHINE SHOP COOLANT, ITEMIZED OPERATING ECONOMICS

	Recycling Plant		Nonrecycling Plant	
Total equipment cost including installation	**$208,978**	**(a)**	**$52,800**	**(b)**
Equipment amortization cost per day	73	(c)	19	(d)
Operating labor cost per day	192	(e)	21	(f)
Chemicals—cost per day	——		11	(g)
Electric power cost per day	1	(h)	——	
Maintenance cost per day	19	(i)	2	(j)
Sludge disposal cost per day	7	(k)	7	(l)
Fresh water purchase cost per day	——		2	(m)
Membrane replacements	3	(n)	——	
Total	**$295**		**$62**	
Total volume processed per day	24,224 liters (6,400 gallons)		24,224 liters (6,400 gallons)	
Cost per 1000 liters	$12.18		$2.56	
Cost per 1000 gallons	$46.09		$9.96	

BASES AND CALCULATIONS FOR TABLE 10

(a) From Section 5, page 37.

(b) From (b), page 43.

(c) $79,927 (equipment) x 0.132695*/350 days/yr = $30.30
$129,927 (buildings) x 0.116830**/350 days/yr = $43.08
$208,978 (total) x (0.0003511) = $73.78

*0.132695 = Periodic payment for annuity, 8%, 12 years (2).

**0.116830 = Periodic payment for annuity, 8%, 15 years (2).

(d) \$52,800 x 0.0003511 [from (c) above].

(e) See (e), page 45.

(f) See (f), page 45.

(g) Hydrated lime \$1320/yr
Ferric sulfate \$2520/yr
Total \$3840/yr
\$3840/350 days/yr = \$10.97/day

(h) 10% of power for RO [(i), page 46].

(i) 10% of operating labor cost.

(j) Same as (i) above.

(k) 18,925 l/mo (5000 gal/mo) at \$0.04/gal disposal cost.
5000 gal/29.25 days/mo x \$0.04 = \$6.84/day

(l) Same volume and cost as (k) above.

(m) 24,224 l/day (6,400 gal/day) @ \$0.0793/kl (\$0.30/1000 gal) = \$1.92/day

(n) Membrane replacement cost, 20% x \$15,000 every 3 years
= 20% x \$15,000/3 yr/350 day/yr = \$2.86

BASES AND CALCULATIONS FOR TABLE 11

(a) From Section 5, page 37.

(b) From (b), page 43.

(c)

\$ 64,980 (equipment)	x 0.132695*/350 days/yr	=	\$24.64/day
\$105,047 (buildings)	x 0.116830**/350 days/yr	=	\$35.06/day
\$170,027 (total)	x (0.0003511)	=	\$59.70/day

(d) \$112,751 x 0.0003511 [from (c) above] = \$39.59/day

(e) See (e), page 45.

(f) See (f), page 45.

*0.132695 = Periodic payment for annuity, 8%, 12 years (2).
**0.116830 = Periodic payment for annuity, 8%, 15 years (2).

TABLE 11. CYANIDE RINSE WATER, ITEMIZED OPERATING ECONOMICS

	Recycling Plant		Nonrecycling Plant	
Total equipment cost including installation	**$170,027**	**(a)**	**$112,751**	**(b)**
Equipment amortization cost per day	60	(c)	40	(d)
Operating labor cost per day	24	(e)	21	(f)
Chemicals—cost per day	7	(g)	7	(h)
Electric power cost per day	—	(i)	—	
Maintenance cost per day	7	(j)	2	(k)
Sludge disposal cost per day	1	(l)	1	(m)
Fresh water purchase cost per day	0	(o)	2	(n)
Total	**$99**		**$73**	
Total volume processed per day	22,710 liters (6,000 gallons)		22,710 liters (6,000 gallons)	
Cost per 1000 liters	$ 4.36		$ 3.21	
Cost per 1000 gallons	$16.50		$12.17	

(g) Chlorine = $2430/yr/350 days/yr = $ 6.94

(h) Same as (g) above.

(i) 1.4% of power for RO unit [(i), page 46] = less than $1.00

(j) 10% of operating cost = $ 7.20

(k) 10% of operating labor cost = $ 2.10

(l) 1.4% of sludge disposal cost for chemical process rinse water [(m), page 46] = $ 0.78

(m) Same as (l) above

(n) 22,710 l/day (6,000 gal) at $0.0793/kl ($0.30/1000 gal) = $ 1.80

(o) 10% of (n)

* 0.132695 = Periodic payment for annuity, 8%, 12 years (2).

** 0.116830 = Periodic payment for annuity, 8%, 15 years (2).

SECTION 7

MOVIE

SHORT TITLE: "Closing the Loop"

DESCRIPTIVE TITLE: "Water Recycling in the Airplane Manufacturing Industry"

GENERAL

A 16mm color and sound movie dealing with the subject of water usage and water recycling in the airplane industry has been made. The movie explains where, how and why water is used in the manufacture of airplanes, emphasizes the importance of protecting the environment, and shows how the airplane industry and the Environmental Protection Agency are working together to develop water recycling techniques. The water treatment loops described in this report are shown in the movie.

Intended Audience

The movie is suitable for showing to a broad range of audiences including those in:

- Technical societies
- High schools
- Colleges
- Companies employing electropolating and metal finishing processes
- Ecology groups
- Government agencies concerned with environmental protection
- Aircraft manufacturing companies

Equipment costs and operating costs of water recycling equipment are not discussed in the movie.

Duration of movie: 13 minutes - 30 seconds

Availability

The movie is available from Boeing. Requests should be addressed to, and should refer to "Closing the Loop," Boeing movie reference no. 4249.

▶ Boeing Commercial Airplane Company
Public Relations, Organization 6-1051
Mail Stop 65-47
P. O. Box 3707
Seattle, WA 98124

SECTION 8

ANALYTICAL METHODS

The chemical analyses were made using the following methods:

Nitrate	Specific ion electrode, *Orion Research Analytical Methods Guide 7th Edition,* May 1975
Sulfate	ASTM D 516 Method A
Orthophosphate	ASTM D 151 Method A
Chloride	Silver nitrate titration using chloride specific ion electrode, *Orion Research Analytical Methods Guide,* 7th Edition, May 1975
Surfactant	Methylene blue method, *Standard Methods of Water Analysis,* 13th Edition, Section 159A
Freon extractables	Method No. 0056, *Methods for Chemical Analysis of Water and Waste,* U.S. Environmental Protection Agency
Total cyanide	Liberation by Method No. 00722, *Methods for Chemical Analysis of Water and Waste,* U.S. Environmental Protection Agency; Measurement by specific ion electrode, *Orion Research Analytical Methods Guide,* 7th Edition, May 1975
Free Chlorine	Colormetric Test per ASTM D1253
Floating oil and slime	Visual measurement of sample in graduated cylinder
Plate count	Tryptone agar incubation, *Standard Methods of Water Analysis,* 13th Edition, Section 400
Sodium, magnesium, potassium, aluminum, zinc, total chrome, copper, cadmium	Atomic absorption spectrophotometry, *Methods for Chemical Analysis of Water and Waste,* U.S. Environmental Protection Agency
Trivalent chrome	Cerimetric titration, Treatise on Analytical Chemistry, Part II, *Analytical Chemistry,* Volume 8
Total dissolved solids	Evaporation at 50°C per ASTM D 1888

REFERENCES

1. Anon., *Standard Methods for the Examination of Water and Wastewater,* American Public Health Association, Washington, D. C. 1193 pp.

2. Gushee, C. H., *Financial Compound Interest and Annuity Tables,* Boston Financial Publishing Company. 884 pp.

3. *ASTM Metric Practice Guide,* E-380-74, American Society for Testing and Materials. 34 pp.

4. "Crack Extension Test," para. 4.4.2, *Qualification of Subcontractors to Perform Structural Bonding,* Boeing Document No. D-16925.

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Sourirajan, S. *Reverse Osmosis,* Academic Press Inc., New York. 580 pp.

Webber, Jr., W. J. *Physicochemical Processes.* Wiley-Interscience, New York. 640 pp.

Wixon, R., W. G. Kell, and N. M. Bedford. *Accountants' Handbook.* The Ronald Press Company, New York. 800 pp.

APPENDIX A

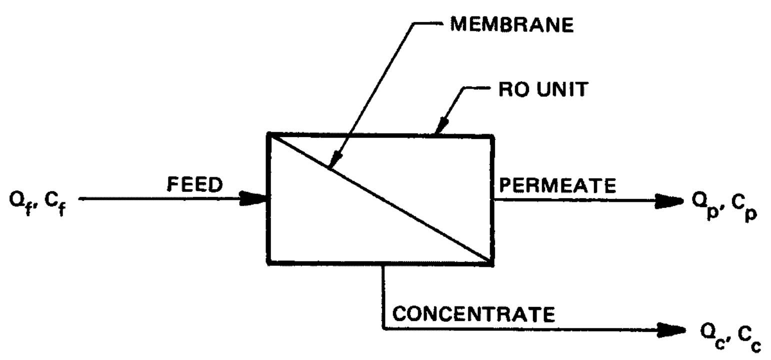
MATHEMATICAL ANALYSIS OF THREE RO SYSTEMS

Abbreviations

C_f	=	Concentration of feed
C_p	=	Concentration of permeate
C_c	=	Concentration of concentrate
Q_f	=	Flow rate (quantity) of feed
Q_p	=	Flow rate (quantity) of permeate
Q_c	=	Flow rate (quantity) of concentration
C_m	=	Mean concentration, pressure side of membrane
R	=	Rejection ratio of membrane
		= $\frac{\text{Concentration difference across membrane}}{\text{Concentration on pressure side of membrane}}$
		= $(C_m - C_p)/C_m = 1 - C_p/C_m$
E	=	Recovery of RO unit = Q_p/Q_f

Basic Formula for a Single RO Unit

A single RO unit is represented diagrammatically as follows:



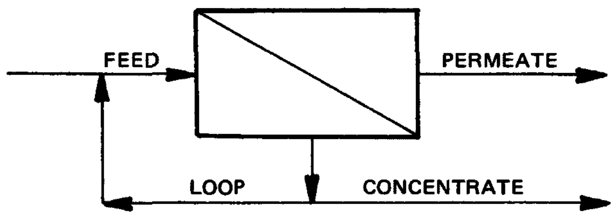
Derivation of Output of a Single RO Unit in Terms of Input E, and R

By definition, $$E = Q_p/Q_f \quad (1)$$

and, $$R = 1 - C_p/C_m \quad (2)$$

By volume balance, $$Q_f = Q_p + Q_c \quad (3)$$

The RO units used in the experimental work all employed feedback of concentrate in a vendor-installed loop:



Since the loop flow was at least ten times the feed flow, the mean concentration at the membrane differs negligibly from the concentrate concentration.

In this study, therefore, C_m and C_c are assumed to be the same, so that

$$R = 1 - C_p/C_c \quad (4)$$

From (1) and (3)

$$Q_p = E\,Q_f \quad (5)$$

$$Q_c = Q_f - Q_p = Q_f\,(1\text{-}E) \quad (6)$$

By material balance, and (5) and (6):

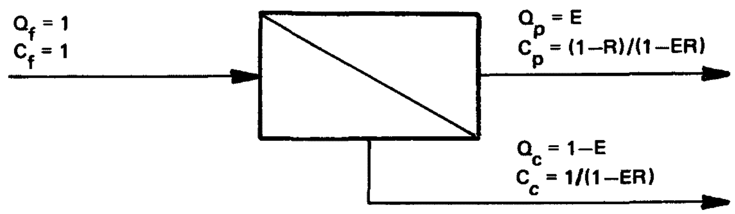
$$Q_f\,C_f = Q_f\,(1\text{-}E)\,C_c + Q_f\,E\,C_p \quad (7)$$

which can be simplified, using (4), to:

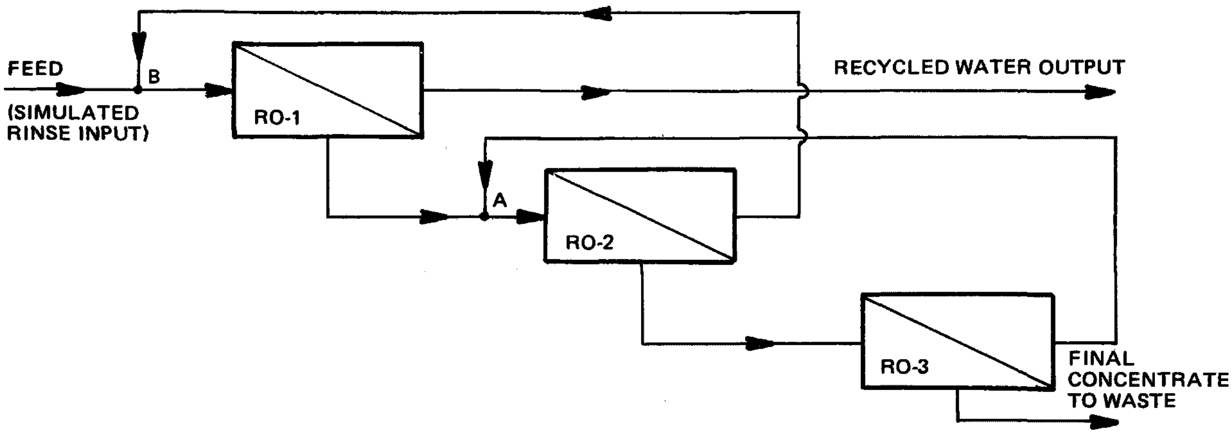
$$C_p = C_f\,(1\text{-}R)/(1\text{-}ER) \quad (8)$$

$$C_c = C_f/(1\text{-}ER) \quad (9)$$

The basic single RO unit thus has the following outputs for unit inputs, i.e., for $Q_f = 1, C_f = 1$.



Derivation of Formula for Arrangement No. 1



By starting with RO-2, assigning values of flow and concentration to each stream in accordance with (5), (6), (8) and (9), using flow balance and material balances at junctions A and B, the following relations were arrived at:

Q_p = Flow of permeate when feed flow (Q_f) = 1

$$= E - E^2(1\text{-}E)/A(1\text{-}E) \qquad (10)$$

Q_c = Flow of concentrate when feed flow (Q_f) = 1

$$= (1\text{-}E)^2/A \qquad (11)$$

C_p = Concentration of permeate when C_f = 1

$$= YD\,(1\text{-}R) \qquad (12)$$

C_c = Concentration of concentrate when C_f = 1

$$= Y/(1\text{-}ER) \qquad (13)$$

The parameters A, Y, and D are:

$$A = [(1\text{-}(1\text{-}E)E)/(1\text{-}E)] - E \qquad (14)$$

$$Y = A/[(A + E)\,D\,(1\text{-}ER) - E\,(1\text{-}R)] \qquad (15)$$

$$D = [(1\text{-}ER)^2 - (1\text{-}E)\,E\,(1\text{-}R)]/[1-(1\text{-}E)E]\,(1\text{-}ER) \qquad (16)$$

Numerical values derived from formulae (10), (11), (12) and (13) are shown graphically in Figures A-1 and A-2 and tabulated in Table A-1.

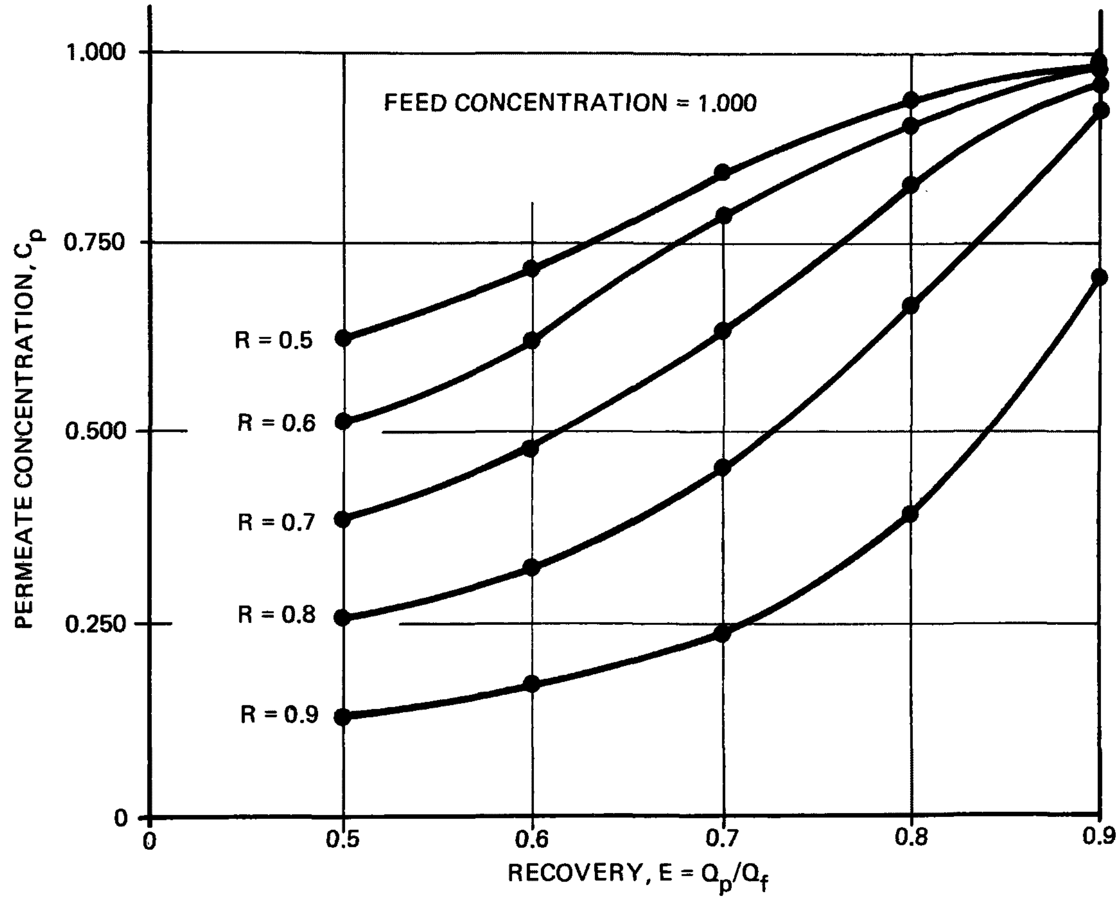


Figure A-1. Permeate concentration plotted as a function of recovery (E) and rejection ratio (R) for RO Arrangement No. 1.

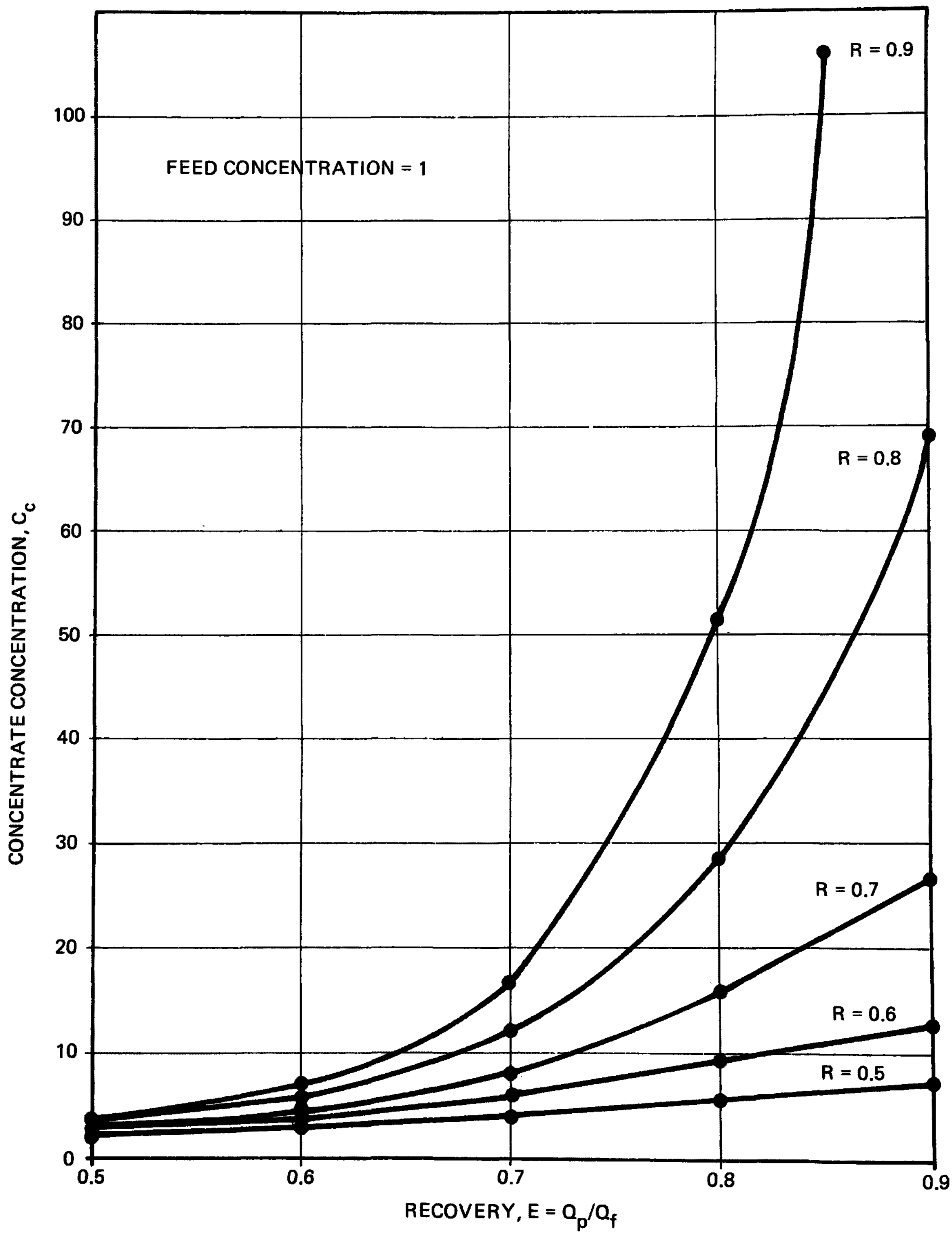


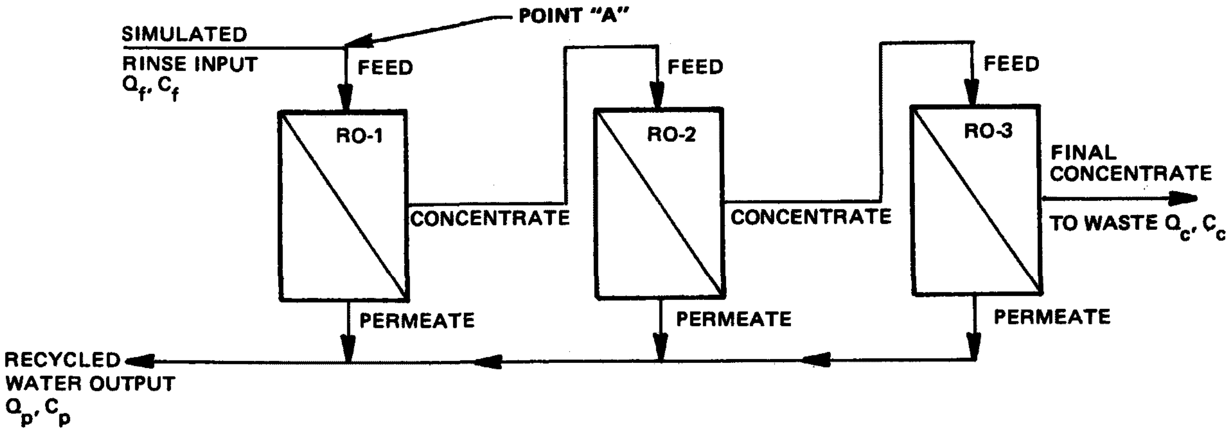
Figure A-2. Concentrate concentration plotted as a function of recovery (E) and rejection ratio (R) for RO Arrangement No. 1.

TABLE A-1. CALCULATED FLOWS AND CONCENTRATIONS FOR RO ARRANGEMENT NO. 1, WITH UNIT INPUT FLOW AND CONCENTRATION

E	R	Q_p	Q_c	C_p	C_c
	0.5			0.62	2.1
	0.6			0.51	2.5
0.5	0.7	0.750	0.250	0.39	2.8
	0.8			0.26	3.2
	0.9			0.13	3.6
	0.5			0.72	3.0
	0.6			0.62	3.7
0.6	0.7	0.877	0.123	0.49	4.7
	0.8			0.34	5.7
	0.9			0.17	6.9
	0.5			0.84	4.2
	0.6			0.76	5.9
0.7	0.7	0.953	0.047	0.63	8.5
	0.8			0.46	12.0
	0.9			0.24	16.5
	0.5			0.94	5.7
	0.6			0.90	9.2
0.8	0.7	0.988	0.012	0.82	15.8
	0.8			0.67	28.8
	0.9			0.39	52.3
	0.5			0.98	6.4
	0.6			0.95	11.0
0.85	0.7	0.996	0.004	0.91	21.0
	0.8			0.80	45.3
	0.9			0.52	106.7
	0.5			0.99	7.0
	0.6			0.99	12.8
0.9	0.7	0.999	0.001	0.97	26.7
	0.8			0.92	69.1
	0.9			0.71	238.4

Derivation of Formula for Arrangement No. 2

Arrangement No. 2, the conventional arrangement in which all permeate flows are united, is as follows:



Starting at point A, and assigning the values $Q_f = 1$ and $C_f = 1$, applying equations (5), (6), (8) and (9) leads to the following:

Q_p = Flow of permeate

$$Q_p = E^3 - 3E^2 + 3E \qquad (17)$$

Q_c = Flow of concentrate

$$= (1\text{-}E)^3 \qquad (18)$$

C_p = Concentration of permeate

$$= [1-((1\text{-}E)/(1\text{-}ER))^3]/(E^3 - 3E^2 + 3E) \qquad (19)$$

C_c = Concentration of concentrate

$$= (1\text{-}ER)^{-3} \qquad (20)$$

Numerical values derived from equations (17), (18), (19) and (20) are shown graphically in Figures A-3 and A-4 and tabulated in Table A-2.

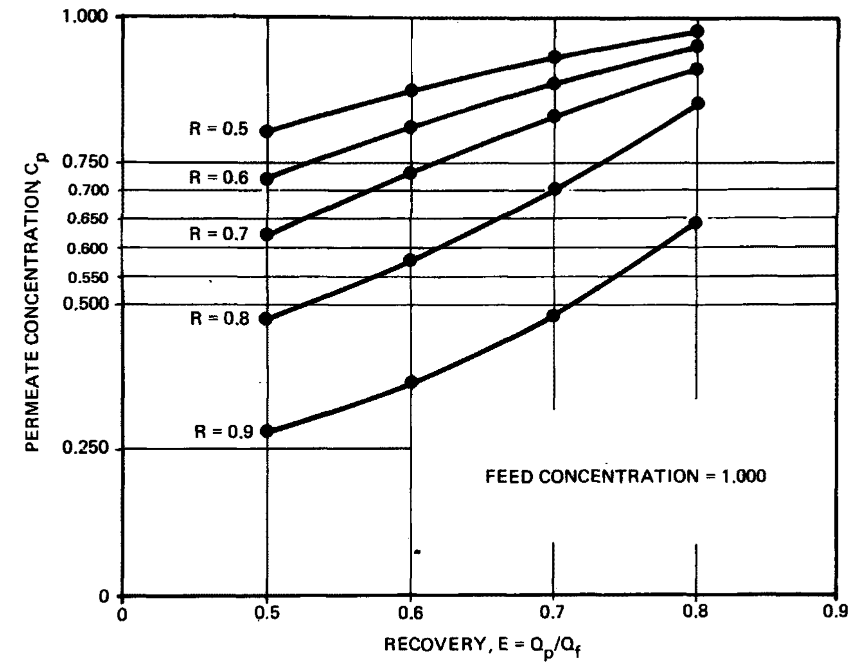


Figure A-3. Permeate concentration plotted as a function of recovery (E) and rejection ratio (R) for RO Arrangement No. 2.

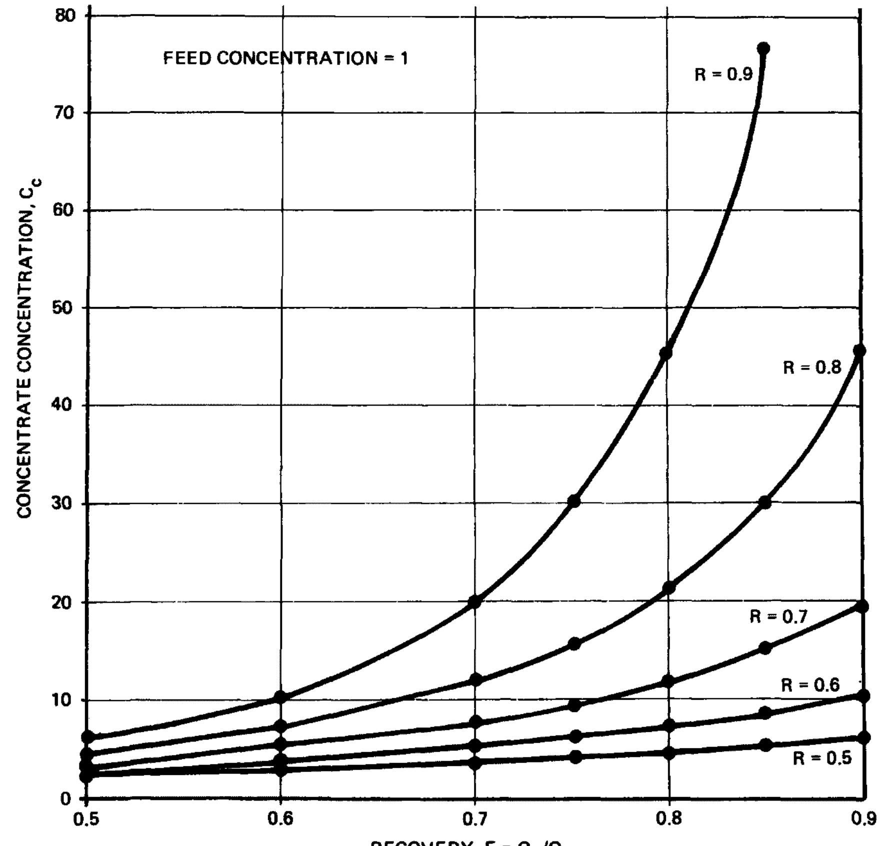


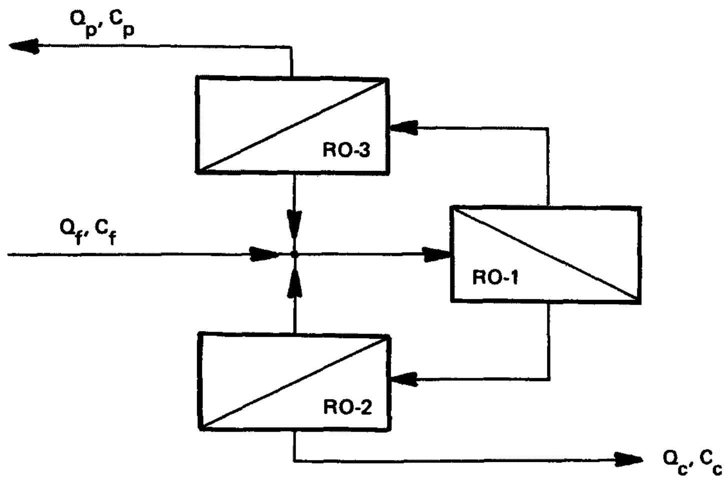
Figure A-4. Concentrate concentration plotted as a function of recovery (E) and rejection ratio (R) for RO Arrangement No. 2.

TABLE A-2. CALCULATED FLOWS AND CONCENTRATIONS FOR RO ARRANGEMENT NO. 2, WITH UNIT INPUT FLOW AND CONCENTRATION

E	R	Q_p	Q_c	C_p	C_c
	0.5			0.80	2.4
	0.6			0.73	2.9
0.50	0.7	0.875	0.125	0.62	3.6
	0.8			0.48	4.6
	0.9			0.28	6.0
	0.5			0.87	2.9
	0.6			0.81	3.8
0.60	0.7	0.936	0.064	0.72	5.1
	0.8			0.58	7.1
	0.9			0.37	10.3
	0.5			0.93	3.6
	0.6			0.89	5.1
0.70	0.7	0.973	0.027	0.82	7.5
	0.8			0.70	11.7
	0.9			0.48	19.7
	0.5			0.95	4.1
	0.6			0.92	6.0
0.75	0.7	0.983	0.016	0.87	9.3
	0.8			0.77	15.6
	0.9			0.55	29.1
	0.5			0.97	4.6
	0.6			0.95	7.1
0.80	0.7	0.992	0.008	0.91	
	0.8			0.84	21.4
	0.9			0.64	45.6
	0.5			0.99	5.3
	0.6			0.97	8.5
0.85	0.7	0.997	0.003	0.95	15.0
	0.8			0.90	30.5
	0.9			0.74	77.1
	0.5			1.00	6.0
	0.6			0.99	10.3
0.90	0.7	0.999	0.001	0.98	19.7
	0.8			0.96	45.6
	0.9			0.86	145.8

Derivation of Formula for Arrangement No. 3

Arrangement No. 3 is as below:



Applying equations (5), (6), (8) and (9) to the arrangement leads to the following values of output for the unit input of $Q_f = 1, C_f = 1$:

Q_p = Flow of permeate

$$= E_2/[1\text{-}2E(10E)] \qquad (21)$$

Q_c = Flow of concentrate

$$= (1\text{-}E)^2/[1\text{-}2E(1\text{-}E)] \qquad (22)$$

C_p = Concentration of permeate

$$= [(1\text{-}R)/(1\text{-}RE)]^2/X \qquad (23)$$

C_c = Concentration of concentrate

$$= (1\text{-}RE)^{-2}/X \qquad (24)$$

The parameter X is:

$$X = (1+RE\text{-}2E\text{-}2E^2R + 2E^2)/(1\text{-}2E + 2E^2 - ER + 2\,E^2R - 2E^3R) \qquad (25)$$

Numerical values calculated from (21), (22), (23) and (24) are shown graphically in Figures A-5 and A-6 and tabulated in Table A-3.

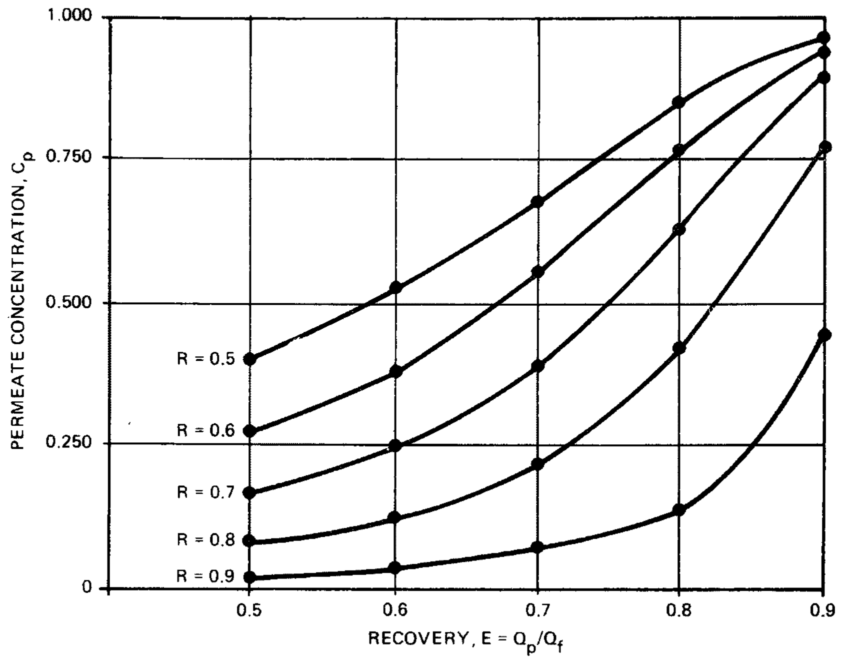


Figure A-5. *Permeate concentration plotted as a function of recovery (E) and rejection ratio (R) for RO Arrangement No. 3.*

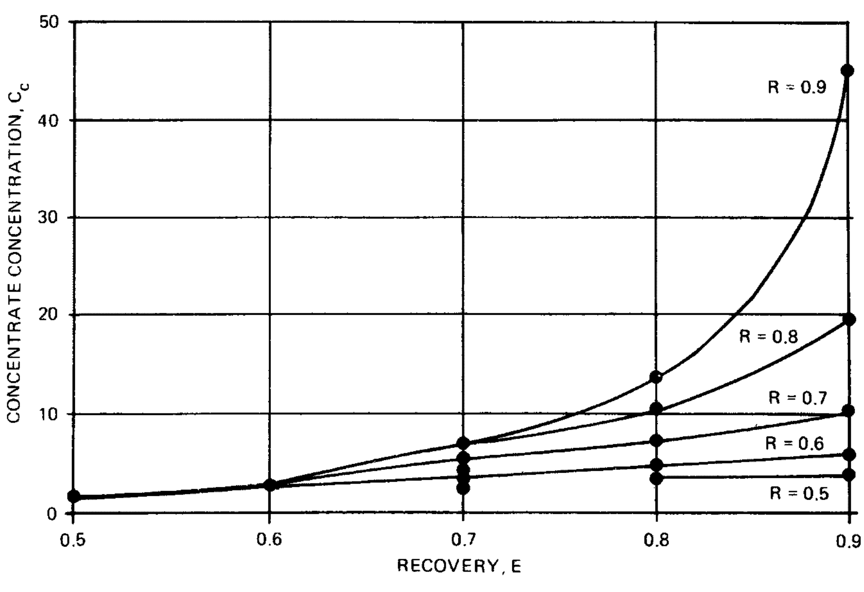


Figure A-6. *Concentrate concentration plotted as a function of recovery (E) and rejection ratio (R) for RO Arrangement No. 3.*

TABLE A-3. CALCULATED FLOWS AND CONCENTRATIONS FOR RO ARRANGEMENT NO. 3, WITH UNIT INPUT FLOW AND CONCENTRATION

E	R	Q_p	Q_c	C_p	C_c
	0.5			0.40	1.6
	0.6			0.28	1.7
0.5	0.7	0.500	0.500	0.17	1.8
	0.8			0.08	1.9
	0.9			0.02	2.0
	0.5			0.52	2.1
	0.6			0.38	2.4
0.6	0.7	0.692	0.308	0.24	2.7
	0.8			0.12	3.0
	0.9			0.03	3.2
	0.5			0.68	2.7
	0.6			0.55	3.4
0.7	0.7	0.845	0.155	0.39	4.3
	0.8			0.21	5.2
	0.9			0.07	7.0
	0.5			0.85	3.4
	0.6			0.76	4.8
0.8	0.7	0.941	0.059	0.63	7.0
	0.8			0.42	10.4
	0.9			0.14	13.5
	0.5			0.96	3.9
	0.6			0.94	5.9
0.9	0.7	0.988	0.012	0.89	9.9
	0.8			0.77	19.3
	0.9			0.45	45.3

Volume of Permeate and Concentrate

The volumes of permeate and concentrate for each of the RO arrangements are shown graphically in Figure A-7.

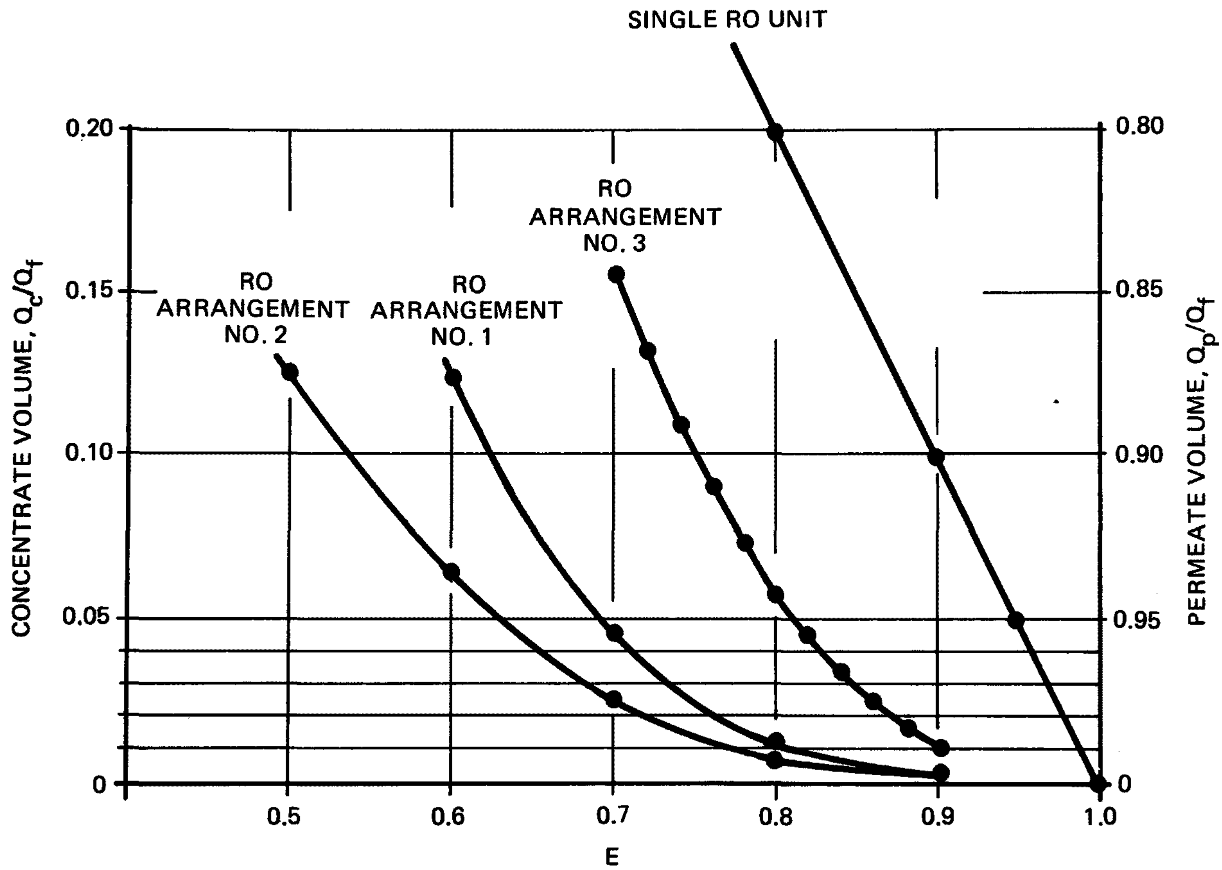


Figure A-7. Volume yields for Arrangements Nos. 1, 2 and 3.

APPENDIX B

REVERSE OSMOSIS TESTS–REJECTION RATIO OF NITRATES COMPARED WITH OTHER IONS

The very low rejection ratios obtained on NO_3 by chemical analysis, on solutions of mixed ions (simulated rinse water from anodizing, deoxidizing conversion coating, alkaline cleaning and chem-milling), suggested the need for confirmatory tests. Accordingly, the series of tests shown in Table B-1 was run, all with conductivity measurements as a measure of concentration. All conductivities were corrected to a standard temperature of 20°C.

TABLE B-1. REVERSE OSMOSIS TESTS, REJECTION RATIO OF NITRATES COMPARED WITH OTHER IONS

Test no.	Electrolyte	Purpose of test	RO units	Conductivities P/C, S/cm	Rejection ratio R
1	NaCl	Confirm overall functioning	RO-1 RO-2 RO-3	370/2909 395/2645 187/2310	0.87 0.85 0.92
2	Tap water	Clean out equipment	RO-1 RO-2 RO-3	10/81 10/89 10/110	0.88 0.89 0.91
3	HNO_3, approximately 1500 mg/l pH = 2.0	Measure rejection ratio	RO-1 RO-2 RO-3	2932/3788 2500/3060 2339/3069	0.23 0.18 0.24
4	H_2SO_4 pH = 2.0	Measure rejection ratio of SO_4—at low pH	RO-1 RO-2 RO-3	Not tested	—
5	$MgSO_4$ pH = 7.0	Reconfirm overall functioning	RO-1 RO-2 RO-3	28/985 35/1532 243/5523	0.91 0.97 0.96

APPENDIX C

REVERSE OSMOSIS–EXPERIMENTAL VERIFICATION OF MATH ANALYSIS

Purpose of Tests

Practical tests were made using the (modified) demonstration equipment, to check the overall accuracy of the mathematical models.

Test and Results

The demonstration equipment was modified to operate in Arrangement Nos. 1 and 2. Recovery ratios for each RO unit were adjusted by reducing pressure on the membranes.

Arrangement No. 1	Recovery ratio E = 0.6	Rejection ratio R = 0.70 (av.)
	Actual	Predicted by math analysis
Feed concentration C_f	563	–
Permeate concentration C_p	236	275
Concentrate concentration C_c	2967	2646

Arrangement No. 2	Recovery ratio E = 0.6	Rejection ratio R = 0.72 (av.)
	Actual	Predicted by math analysis
Feed concentration C_f	638	–
Permeate concentration C_p	401	440
Concentrate Concentration C_c	3622	3510

Discussion of Test Results

Agreement between theoretical and actual concentrations was excellent for both arrangements at the value of recovery ratio E, (0.6) used. Equipment limitations prevented testing at other values of E. (If RO-1 is adjusted to a recovery of, e.g., 0.8, then the feed to RO-2 becomes inadequate to maintain it in operation. Similar considerations apply to RO-2 and RO-3.)

APPENDIX D

CALCULATOR PROGRAM FOR COMPUTING REVERSE OSMOSIS UNIT PRODUCT AND CONCENTRATE CONCENTRATIONS

The general problem of calculating concentrate concentration and permeate concentration in an RO unit employing feedback (i.e., having a proportion of the concentrate stream fed to the intake) is best solved by a reiterative technique. Such calculation is time consuming unless a computer or programmable calculator is available. This appendix contains a 99-step program devised for use on a Hewlett-Packard HP-65 calculator, that reiterates the necessary calculations until two successive results differ by less than one part in 1000.

REVERSE OSMOSIS PROGRAM–CALCULATION OF PRODUCT AND CONCENTRATE CONCENTRATIONS HP PROG. NO. 04198A

Program Description, Equations, Variables

This program computes the concentrations of permeate and concentrate in an idealized reverse osmosis system employing feedback.

Input data required:	Q_f	=	Quantity of feed
	Q_p	=	Quantity of permeate
	Q_c	=	Quantity of concentrate
	Q_l	=	Quantity of loop (feedback)
	C_f	=	Concentration of feed
	R	=	Rejection of membrane

The program computes C_p and C_c (concentrations of permeate and concentrate)

CALCULATION STEPS

1. Calculates a first rough approximation for C_p from $C_p = C_f/3$

2. Uses this value of C_p to compute C_c from $C_c = (Q_f C_f - Q_p C_p)/Q_c$

3. $C_m = [Q_f C_f + C_c(2\,Q_l + Q_c)]/(Q_f + 2\,Q_l + Q_c)$

4. Uses this value of C_m to compute C_p from $C_p = (1-R) \times C_m$

5. Inserts this value of C_p into step 2 and recalculates C_c

6. Repeats steps 3, 4, and 5 until two successive values of C_c differ by less than one part in a thousand.

Operating Limits and Warnings

1. Any units may be used for Q_f, Q_p, etc., such as gallons per hour, liters per hour, etc., but must be consistent.

2. Similarly, C_f may be in any units. C_p and C_c will be in the same units as C_f.

3. Rejection, R, must be in the form of a decimal fraction, e.g., 0.8, not 80%.

Sample Problem

Given a reverse osmosis unit with rejection R = 0.8 for a given ionic species, a feed concentration of 200 mg/l in the same ionic species, and the following flow rates, $Q_f = 3.0$, $Q_p = 2.0$, $Q_c = 1.0$, and $Q_1 = 5.0$ (all in gallons per hour), calculate the concentration of the ionic species in the permeate (C_p) and in the concentrate (C_c).

Solution

INPUTS: A 3 R/S 2 R/S 1 R/S 5 R/S 200 R/S 0.8 R/S

ANSWERS: B 78.25 (i.e., $C_p = 78.25$ mg/l)
C 443.41 (i.e., $C_c = 443.41$ mg/l)

Reference

Weber, Formulae 7-14 through 7-21, Physicochemical Processes for Water Quality Control, Wiley Interscience, 1972, pages 326, 327.

PROGRAM

KEY ENTRY	CODE SHOWN	COMMENTS
LBL	23	INITIALIZE
A	11	
f	31	
SF 1	51	
O	00	
STO 7	33 07	STORE o IN REG 7
STO 8	33 08	STORE o IN REG 8
STO	33	STORE o IN REG 9
g	09	
R/S	84	STOP FOR ENTRIES
STO 1	33 01	STORE Q_f IN REG 1
R/S	84	
STO 2	33 02	STORE Q_p IN REG 2
R/S	84	
STO 3	33 03	STORE Q_c IN REG 3
R/S	84	
STO 4	33 04	STORE Q_1 IN REG 4
R/S	84	
STO 5	33 05	STORE C_f IN REG 5
R/S	84	
STO 6	33 06	STORE R IN REG 6
RTN	24	–END OF PROG. "A"–
LBL	23	
B	12	
D	14	RUN PROG. "D"
RCL 7	34 07	RECALL C_p
RTN	24	–END OF PROG. "B"–
LBL	23	
C	13	
D	14	RUN PROG. "D"
RCL 8	34 08	RECALL C_c
RTN	24	–END OF PROG. "C"–
LBL	23	(MAIN PROGRAM)
D	14	
f^{-1}	32	IS FLAG 1 LOWERED?
TF1	61	IE HAS CALC. BEEN RUN?
CLX	44	IF SO, CLEAR DISPLAY
RTN	24	AND RETURN
RCL 5	34 05	OTHERWISE, PROCEED
3	03	WITH CALC. CALC.
÷	81	APPROX. C_p
STO 7	33 07	STORE APPROX C_p IN 7
LBL	23	IDENTIFY BEGINNING
3	03	OF MAIN CALCULATION
RCL 2	34 02	
X	71	
CHS	42	CALCULATE C_c
RCL 5	34 05	FROM
RCL 1	34 01	$= Q_fC_f - Q_pC_p$
X	71	Q_c

KEY ENTRY	CODE SHOWN	COMMENTS
+	61	
RCL 3	34 03	
÷	81	
RCL 8	34 08	
g x z y	35 07	
STO8	33 08	CALCULATE
–	51	FRACTIONAL CHANGE
g	35	IN C_c SINCE LAST
ABS	06	
RCL 8	34 08	
÷	81	
EEX	43	IS FRAC. CHANGE
CHS	42	LESS THAN 10^{-3}?
3	03	
g x z y	35 24	
f^{-1}	32	IF SO, LOWER FLAG 1
SF 1	51	"CALCULATION OVER"
RCL 1	34 01	OTHERWISE, GO
RCL 5	34 05	ON WITH CALC.
X	71	
RCL 8	34 08	
RCL 4	34 04	
2	02	
X	71	CALCULATE C_m
RCL 3	34 03	
+	61	FROM C_m =
X	71	
+	61	$Q_fC_f + C_c(2Q_1+Q_c)$
RCL 1	34 01	$Q_f + 2Q_1 + Q_c$
RCL 4	34 04	
2	02	
X	71	
+	61	
RCL 3	34 03	
+	61	
÷	81	
RCL 6	34 06	
CHS	42	CALCULATE C_p
ENTER	41	
1	01	$= C_m$ (1-R)
+	61	
X	71	
STO 7	33 07	
f	31	IS FLAG 1 STILL
TF 1	61	FLYING?
GTO	22	IF SO, REITERATE
3	03	CALCULATION
CLX	44	OTHERWISE, CLEAR
RTN	24	DISPLAY AND STOP.

APPENDIX E

COMPOSITION OF CYANIDE PLATING SHOP SOLUTIONS

The cyanide solutions used to simulate plating shop rinse water were production plating shop solutions of the following compositions:

	Copper plate		Cadmium plate		Ti-cadmium plate		Enstrip S	
	g/l	oz/gal	g/l	oz/gal	g/l	oz/gal	g/l	oz/gal
Cu	23.9	3.19	–	–	–	–	–	–
NaOH	–	–	18.95	2.53	17.15	2.29	–	–
Rochelle salt	46.0 to 43.8	6.15 to 5.85	–	–	–	–	–	–
NaCN	9.2	1.23	103.3	13.8	107.1	14.3	144.5	19.3
Cd	–	–	24.6	3.24	26.28	3.51	–	–
Ti	Nil	Nil	Nil	Nil	0.100	1.33×10^{-2}	–	–

APPENDIX F

EQUIPMENT LIST AND BREAKDOWN DIAGRAMS FOR FULL-SCALE WATER TREATMENT PLANT

The equipment list for the water recycle system (Table F-1) precedes Figures F-1 through F-8, breakdown diagrams of the overall schematic for the full-scale water recycling plant.

The circled numbers on these diagrams also appear in the left-hand columns in Table F-1, Equipment List, where they are listed in numerical order.

TABLE F-1. EQUIPMENT LIST, WATER RECYCLE SYSTEM †

Item	Name	Size	Hp	Capacity	Material	Remarks	
	Pumps						
1	Acid operating tank to clarifier, pump	6 in.	20	500 gal/min	SS Pacific pump model 4070-5	In-line easy removal	$5,850
2	Acid upset tank to clarifier pump	6 in.	20	500 gal/min	SS 4070-5	In-line easy removal	5,850
3	Cyanide operating tank to cyanidestruct unit, pump	1 in.	½	7 gal/min	Iron 1250-1 LN		400
4	Cyanide upset tank to cyan destruct unit, pump	1 in.	½	7 gal/min	Iron 1250-1 LN		400
5	Treated cyanide - cyan destruct unit to clarifier pump	1 in.	½	7 gal/min	Penton		800
6	Centrifuge surge tank to clarifier pump	1 in.	½	5 gal/min	Iron 1250-1 LN		400
7	Acid underground tank 50,000 gal, to upset and opertaing tanks pump	4 in.	10	200 gal/min	SS	Duplex sump pump with float switch and auto alternator	10,000
8	Cyanide underground tank, 10,000 gal, to upset and operating tanks pump	1 in.	2	10 gal/min	Iron	Duplex sump pump with floor switch and auto alternator	1,200
9	Caustic metering pump NaOH to clarifier and cyanide destruct unit	½ in.	1	20 gal/hr	Iron	Variable meter	1,000
10	Pump polyelectrolyte tank to clarifier	½ in.	1	30 gal/hr	SS	Variable meter	1,400
11	Filter feed tank to sand filters pump	6 in.	20	500 gal/min	Iron 4070-5	In-line easy removal	1,125
12	RO feed tank to sand filters pump	4 in.	10	300 gal/min	Iron 3070-5	In-line easy removal	780
13	RO feed tank to reverse osmosis pump	6 in.	15	500 gal/min	Iron 4070-5	In-line easy removal	950
14	Reverse osmosis to evaporator pump	2 in.	5	100 gal/min	Iron 1570-5	In-line easy removal	520
15	Reverse osmosis to water recycle storage pump	6 in.	20	500 gal/min	Iron 4070-5	In-line easy removal	1,150

† A conversion table for the engineering units used in Table F-1 and Figures F1 thru F8 is provided on page viii.

Item	Name	Size	Hp	Capacity	Material	Remarks	
16	Evaporator to water recycle storage pump	2 in.	5	100 gal/min	Iron 1570-5	In line easy removal	$520
17	Evaporator to dryer pump	1 in.	½	10 gal/min	Iron 1250-1 LN		400
18	Water recycle storage to process rinse tank pump	6 in.	25	500 gal/min	Iron 4070-5	In-line	1,200
20	Coolant upset and surge tank to oil separator tank pump	1 in.	½	7 gal/min	Iron 1250-1 LN		400
21	98% H_2SO_4 drum to 5% H_2SO_4 tank pump	½ in.	1/3	5 gal/min	Polypropylene	Drum pump, metering	1,200
22	5% H_2SO_4 tank to pH adjust and 2nd oil separator pump	½ in.	1/3	4 gal/min	Polypropylene or H_2SO_4 acid res.	Metering pump	1,200
23	pH adjust and 2nd oil separator to ultrafilter pump	1 in.	1	7 gal/min	Iron 1250-1 LN		400
24	RO feed tank to RO pump	1 in.	½	7 gal/min	Iron		400
25	Coolant recycle tank to coolant make up tank pump	1 in.	½	6 gal/min	1250-1 LN		400
26	Dye upset and surge tanks to ultrafiltration pump	2 in.	3	70 gal/min	Iron 1270-5	In-line easy removal	500
27	Ultrafiltration to carbon filters pump	2 in.	3	70 gal/min	Iron 1270-5	In-line easy removal	500
28	Recycle tank to dye penetrant rinse pump	2 in.	3	70 gal/min	Iron 1270-5	In-line easy removal	500
29	50% H_2SO_4 tank to cyanide destruct unit	½ in.	1	10 gal/hr	Polypropylene	Metering pump	1,400
30	50% H_2SO_4 tank to RO feed tank	½ in.	1	1 gal/hr	Polypropylene	Metering pump	1,400

TABLE F-1. (continued)

Item	Name	Size	Hp	Capacity	Material	Remarks	
33	Coolant RO unit sump pump to sewer	1 in.	1	10 gal/hr	Iron	Duplex sump pump with float switch and auto alternator	$1,000
34	Cyanide spillage sump pump	2 in.	2	50 gal/min	Iron 2095-0	Duplex sump pump with float switch and auto alternator	2,000
35	Acid spillage sump pump	2 in.	7½	200 gal/min	SS or acid reservoir 2011-0	Duplex sump pump with float switch and auto alternator	8.500
36	Yard sump pump	2 in.	1	30 gal/min	SS or acid reservoir 2095-0	Duplex sump pump with float switch and auto alternator	8,000
	Tanks						
39	50% H_2SO_4 tank	5 ft dia 7 ft hi		1,000 gal	Steel lined with polyethylene or PVC		330
40	Acid upset tank No. 1	35 ft dia 35 ft hi		250,000 gal	Steel w/epoxy paint		24,875
41	Acid upset tank No. 2	35 ft dia 35 ft hi		250,000 gal	Steel w/epoxy paint		24,875
42	Acid operating tank	15 ft dia 15 ft hi		20,000 gal	Steel w/epoxy paint		9,370
43	Acid spillage underground tank	12 ft dia 60 ft lg		50,000 gal	Steel w/epoxy paint		19,611
44	Cyanide upset tank	15 ft dia 15 ft hi		20,000 gal	Steel		9,600
45	Cyanide operating tank	7 ft dia 7 ft hi		2,000 gal	Steel		465
46	Cyanide spillage underground tank	8 ft dia 27 ft lg		10,000 gal	Steel		2,900

TABLE F-1. (continued)

Item	Name	Size	Hp	Capacity	Material	Remarks
47	50% NaOH tank	9 ft dia 11 ft hi		5,000 gal	Steel	$1,500
48	Polyelectrolyte tank	9 ft dia 11 ft hi		5,000 gal	Steel w/epoxy paint	1,937
49	Centrifuge surge tank	5 ft dia 7 ft hi		1,000 gal	Steel	300
50	Filter feed tank	15 ft dia 15 ft hi		20,000 gal	Steel	10,289
51	RO feed tank	15 ft dia 15 ft hi		20,000 gal	Steel w/epoxy paint	10,389
52	Water recycle storage tank No. 1	35 ft dia 35 ft hi		250,000 gal	Steel w/epoxy paint	29,956
53	Water recycle storage tank No. 2	35 ft dia 35 ft hi		250,000 gal	Steel w/epoxy paint	30,590
54	Coolant upset tank	10 ft dia 10 ft hi		6.000 gal	Steel	6,640
55	Coolant surge tank	5 ft dia 5 ft hi		600 gal	Steel	235
56	5% H_2SO_4 tank	3½ ft dia 4 ft hi		300 gal	Steel lined with polyethylene or PVC	140
	Tanks and equipment					
57	pH adjust and 2nd oil separator			300 gal	Steel lined w/ polyethylene or PVC	206
58	Insoluble oil tank	3½ ft dia 4 ft hi		300 gal	Steel	206
59	Oil/water concentrate batch removal tank	8 ft dia 8 ft hi		3,000 gal	Steel lined w/PVC	810

TABLE F-1. (continued)

Item	Name	Size	HP	Capacity	Material	Remarks
60	RO feed and ultraviolet sterilizer	2 ft dia 3 ft hi		75 gal	Steel w/epoxy paint	$1,000 for sterilizer
61	Coolant recycle storage tank	10 ft dia 10 ft hi		6,000 gal	Steel w/epoxy paint	$2,118
62	Dye penetrant rinse water upset tank	17 ft dia 18 ft hi		30,000 gal	Steel	11,400
63	Dye penetrant rinse water-surge tank	8 ft dia 8 ft hi		3,000 gal	Steel	1,118
64	Dye penetrant oil/water concentrate batch removal tank	3½ ft dia 4 ft hi		250 gal	Steel	206
65	Dye penetrant water recycle tank	17 ft dia 17 ft hi		30,000 gal	Steel w/epoxy paint	12,847
66	Centrifuge to clarifier surge tank	2 ft dia 3 ft hi		75 gal	Steel	200
67	Cyanide destruction unit			10 lb/day at 400 gal/hr	Steel, rubber lined or equivalent	29,000
68	Chlorine supply			Four 400 lb cylinders	Steel	Tanks by vendor
69	Sludge dryer			520 gal/hr	Stainless steel	50,000
70	RO unit (2) 500 gal/min units			Two 500 gal/hr	By supplier	Two units = 400,000
71	Evaporator 10:1			5000 gal/hr	Steel, brass SS	200,000
72	Clarifier			30,000 gal/hr	Steel	45,000
73	Centrifuge			500 gal/hr	Stainless steel	25,000
74	Dry solids hopper			5 tons	Steel	2,000

TABLE F-1. (continued)

Item	Name	Size	HP	Capacity	Material	Remarks	
75	Sand filter unit			30,000 gal/hr	Steel		$55,000
76	Mixer, surge tank No. 49		2		SS shaft and propeller		2,500
77	Motor, surge tank No. 49		2				
78	Mixer, H_2SO_4 tank No. 56		2		Corrosion reservoir elastomer coated shaft propeller		
79	Motor, H_2SO_4 tank No. 56		2				3,000
80	Coolant oil separator			200 gal	Steel		21,300
81	Coolant ultrafiltration unit			400 gal/hr	By supplier		15,000
82	Coolant reverse osmosis unit			400 gal/hr	By supplier		15,000
83	Dye penetrant rinse water ultrifiltration unit			2000 gal/hr	By supplier		45,000
84	Cargon filters unit			2000 gal/hr	Polypropylene		20,000
85	Chlorine ORP controller unit complete						
86	NaOH pH controller unit complete, cyanide destruct unit					Included in item 67	
87	NaOH pH controller unit complete, clarifier unit						
88	Conveyor system centrifuge solids to dryer			200 lb/hr	Steel		2,000
89	Conveyor system dryer to hopper			100 lb/hr	Steel		1,500
90	50% H_2SO pH controller unit complete, cyanide destruct unit					Included in item 67	

TABLE F-1. (continued)

Item	Name	Size	HP	Capacity	Material	Remarks	
91	50% H_2SO_4 pH controller unit complete, RO feed tank						$5,000
92	5% H_2SO_4 pH controller unit complete, pH adjust and 2nd oil separator						
93	Control room monitoring instrumentation						50,665
94	Level control						
95	Level control						
96	Level control						
97	Gate	½ in.screwed			Steel	Required	
98	Ball	½ in.screwed		125 lb	316 SS crane No. 950 TF	30 required x $24 =	720
99	Ball	1 in.screwed		125 lb	316SS crane No. 950 TF	48 required x $38	1,824
100	Check, swing	1 in.screwed		125 lb	All iron No. 36	6 required x $24	144
101	Ball	2 in.flg		125 lb	316 SS	28 required x $87	2,436
102	Gate	4 in.flg		125 lb	Cast iron No. 465½	18 required x $190	3,420
103	Gate	6 in.flg		125 lb	Cast iron No. 465½	24 required x $295	7,080
104	Gate	4 in.flg		150 lb	316 SS 61176	5 required x $620	3,100
105	Ball	6 in.flg		150 lb	316 SS 61176	12 required x $1100	13,200
106	Check, swing	6 in.flg		150 lb	316 SS 61676	4 required x $1243	4,972
107	Check, swing	4 in.flg		150 lb	316 SS 61676	1 required x $710	710

TABLE F-1 (continued)

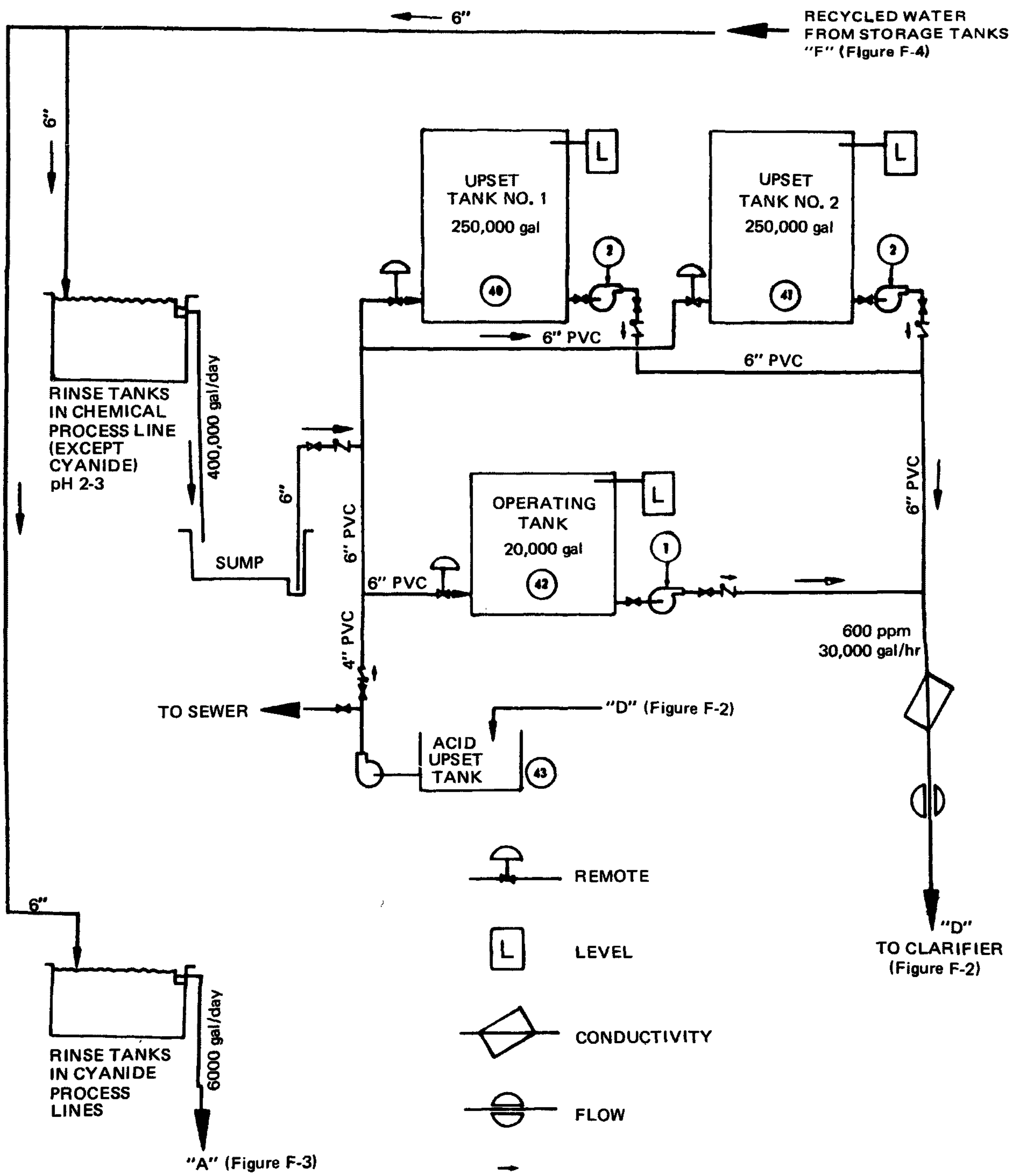


Figure F-1. *Collection and return system for chemical process and cyanide process rinse waters.*

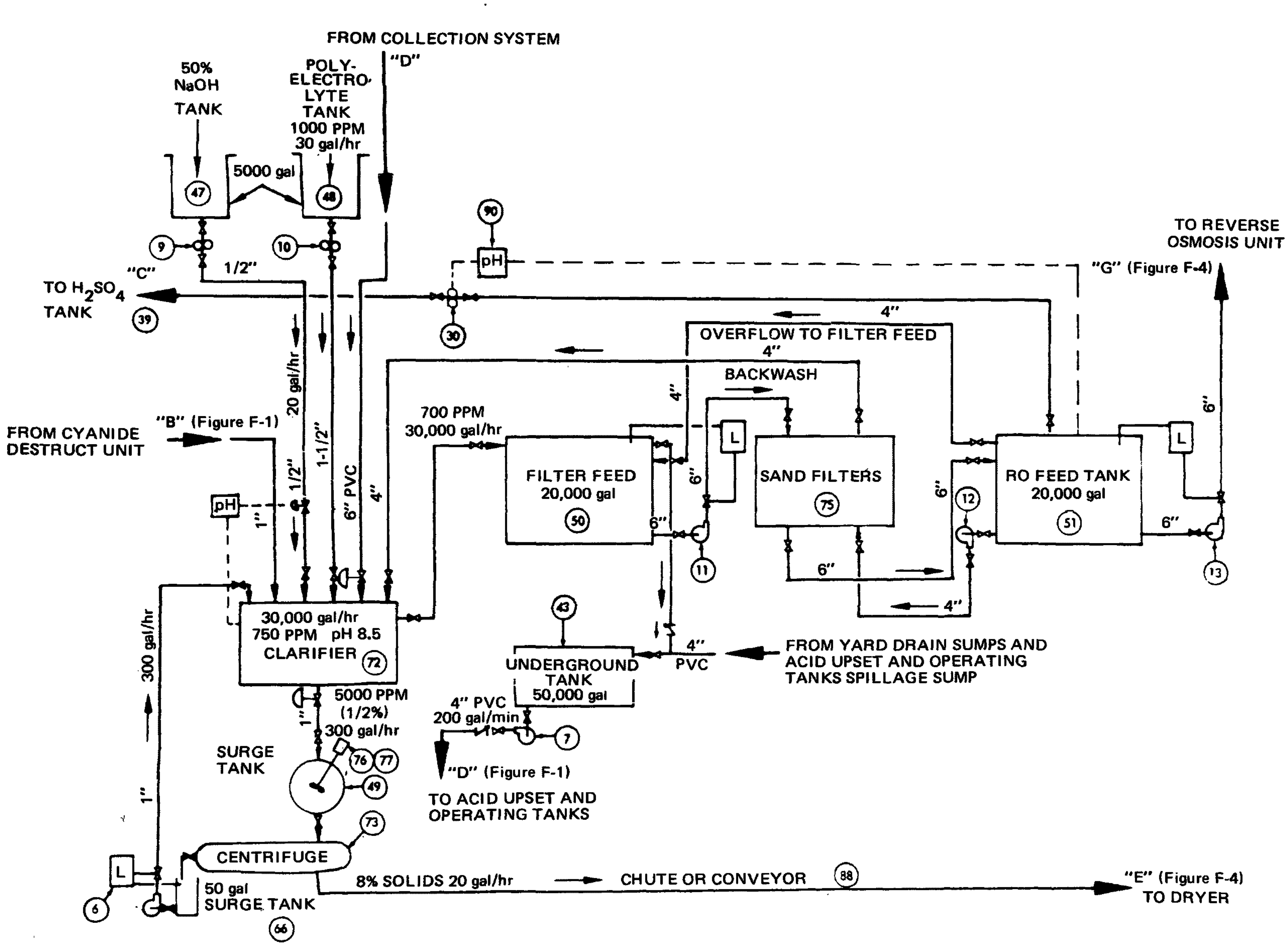


Figure F-2. Clarifier and filters, chemical process rinse water purification.

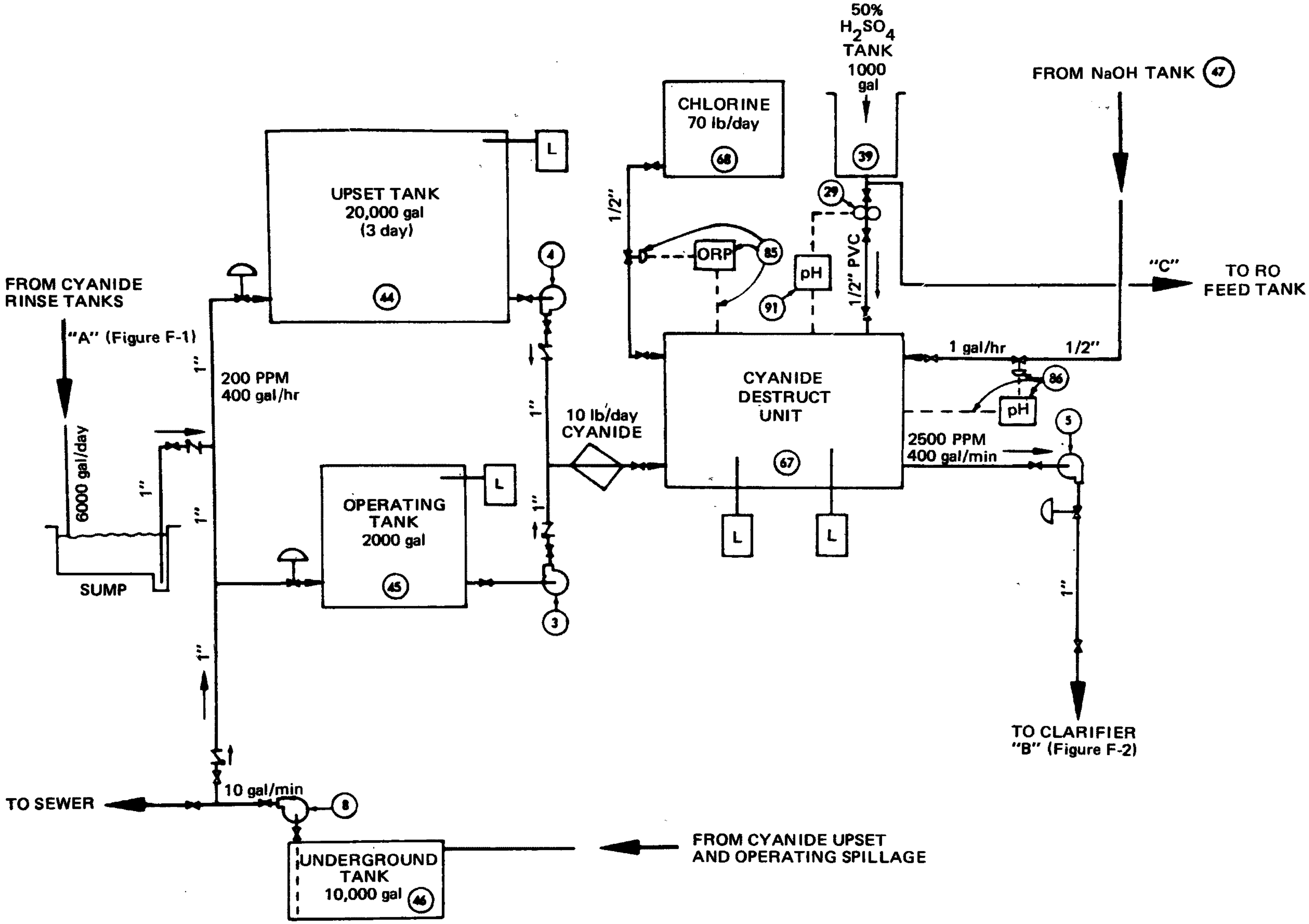


Figure F-3. Cyanide destruct unit.

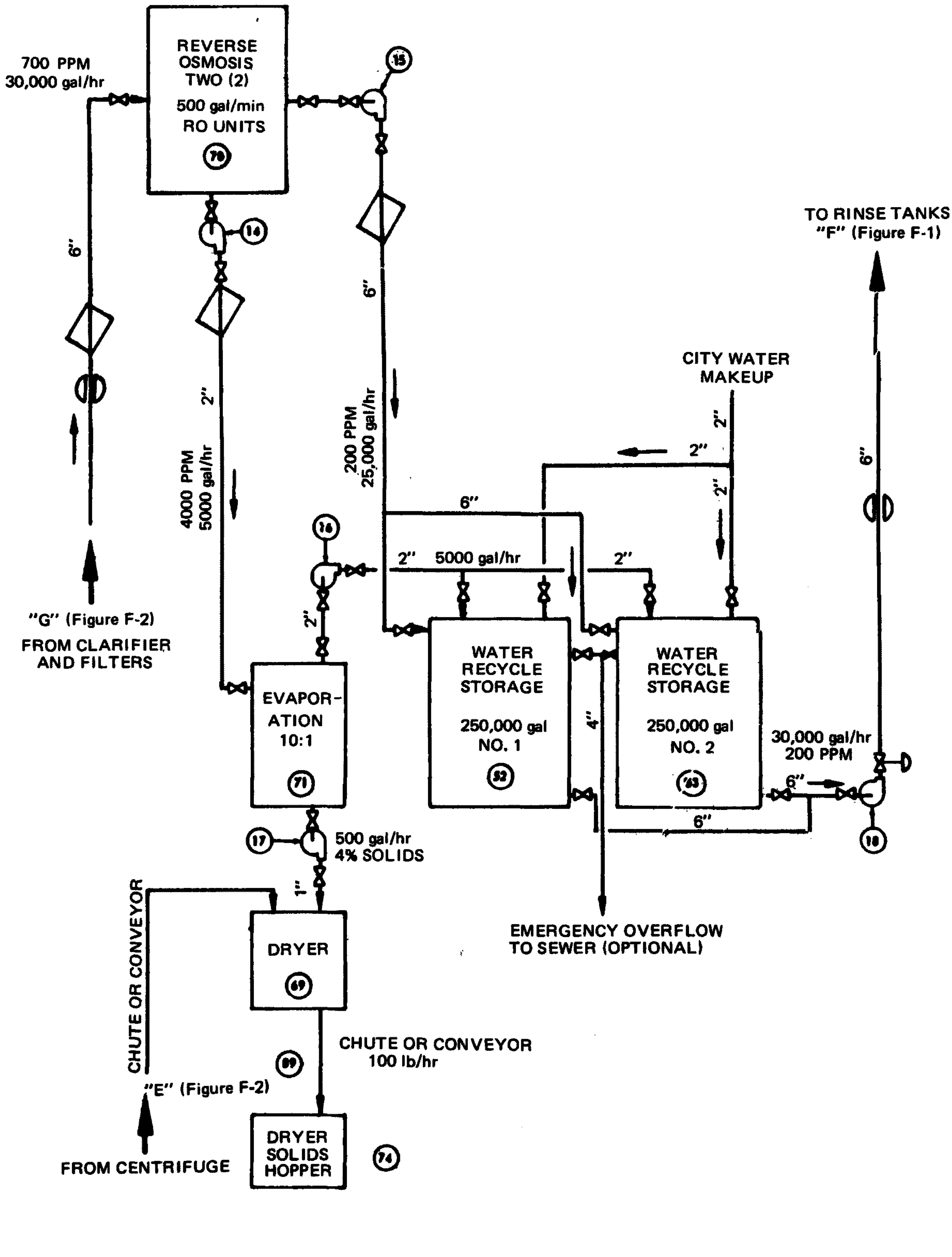


Figure F-4. Reverse osmosis unit, chemical process rinse water purification.

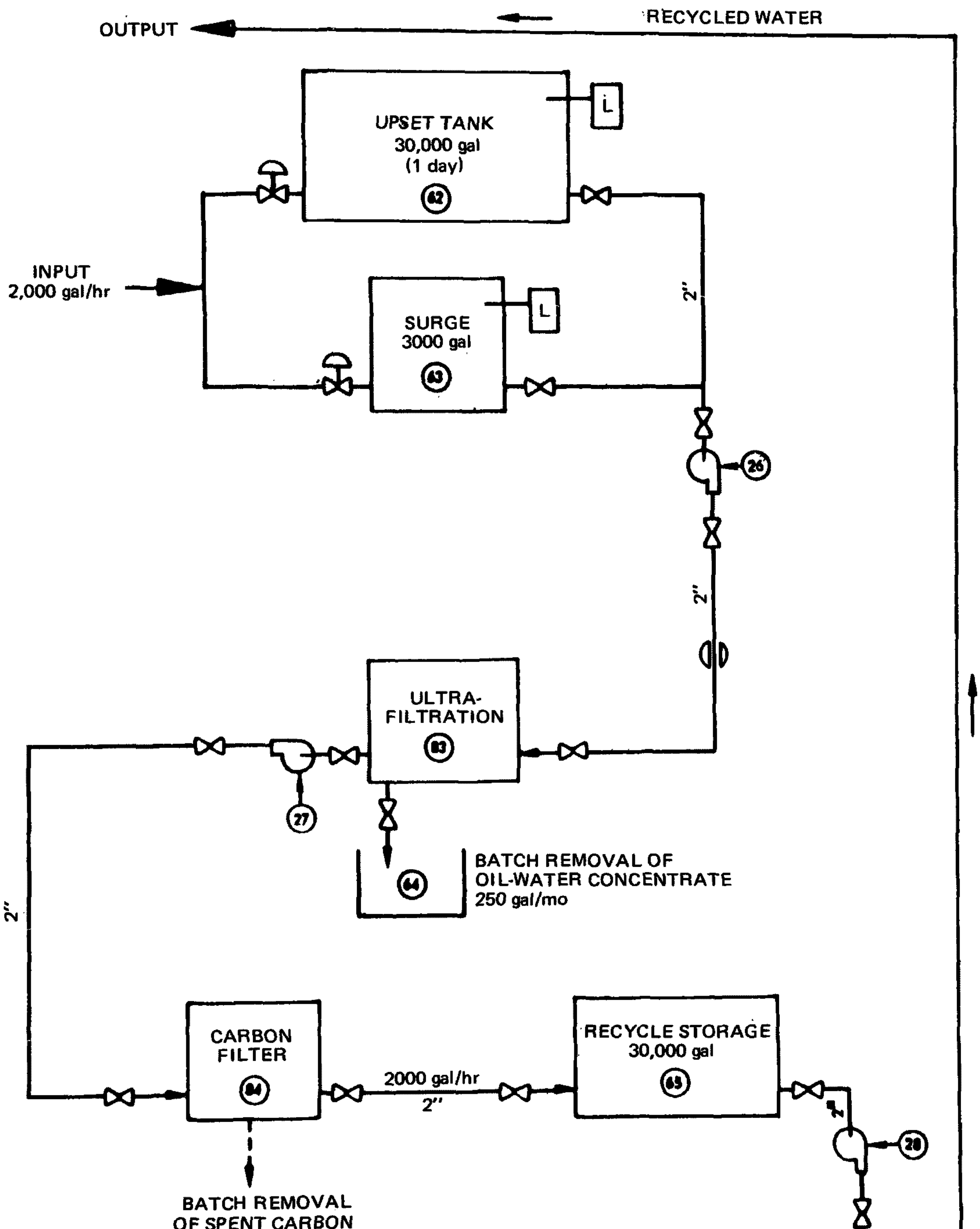


Figure F-5. Dye penetrant inspection rinse water purification.

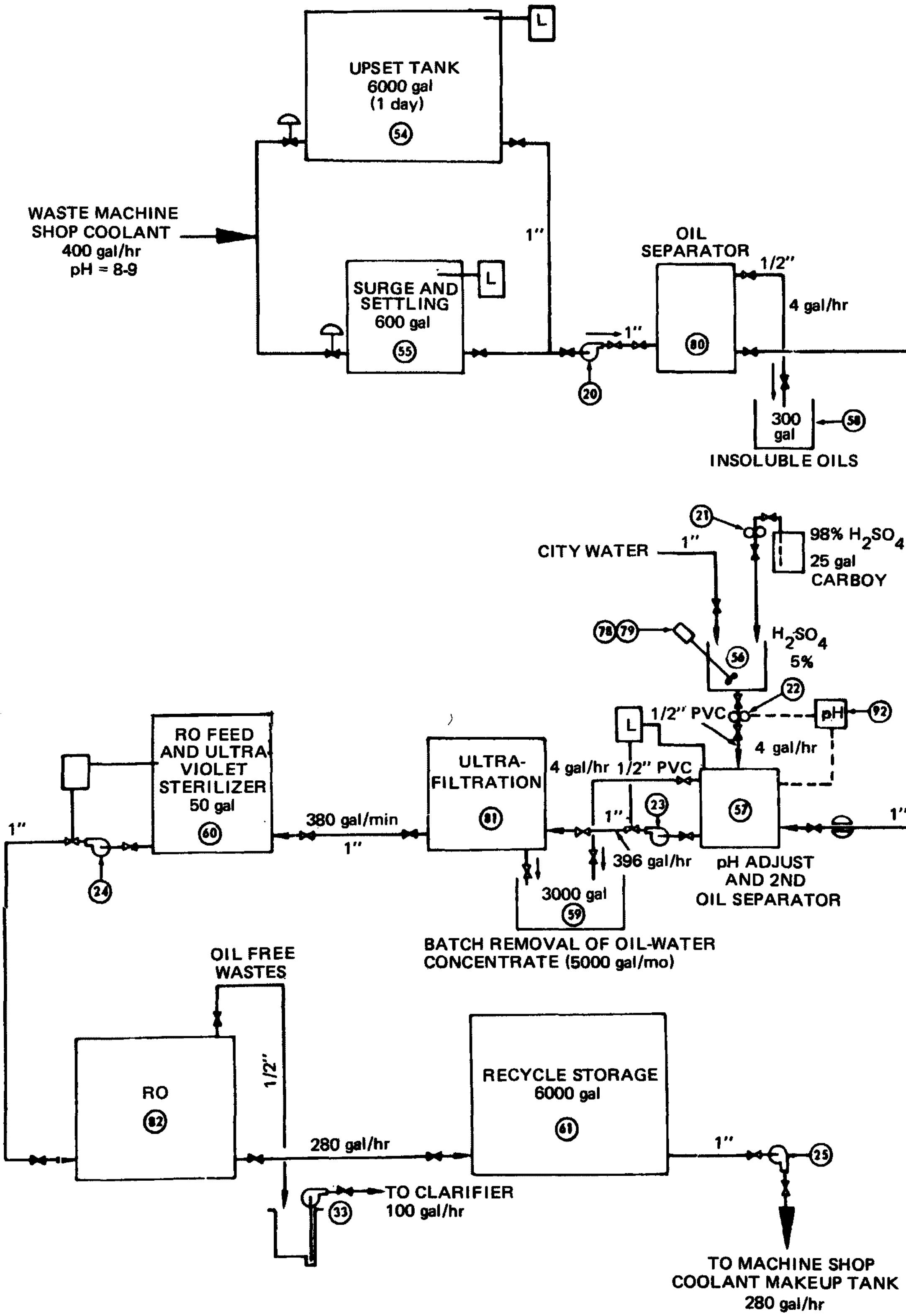


Figure F-6. Machine shop coolant water purification.

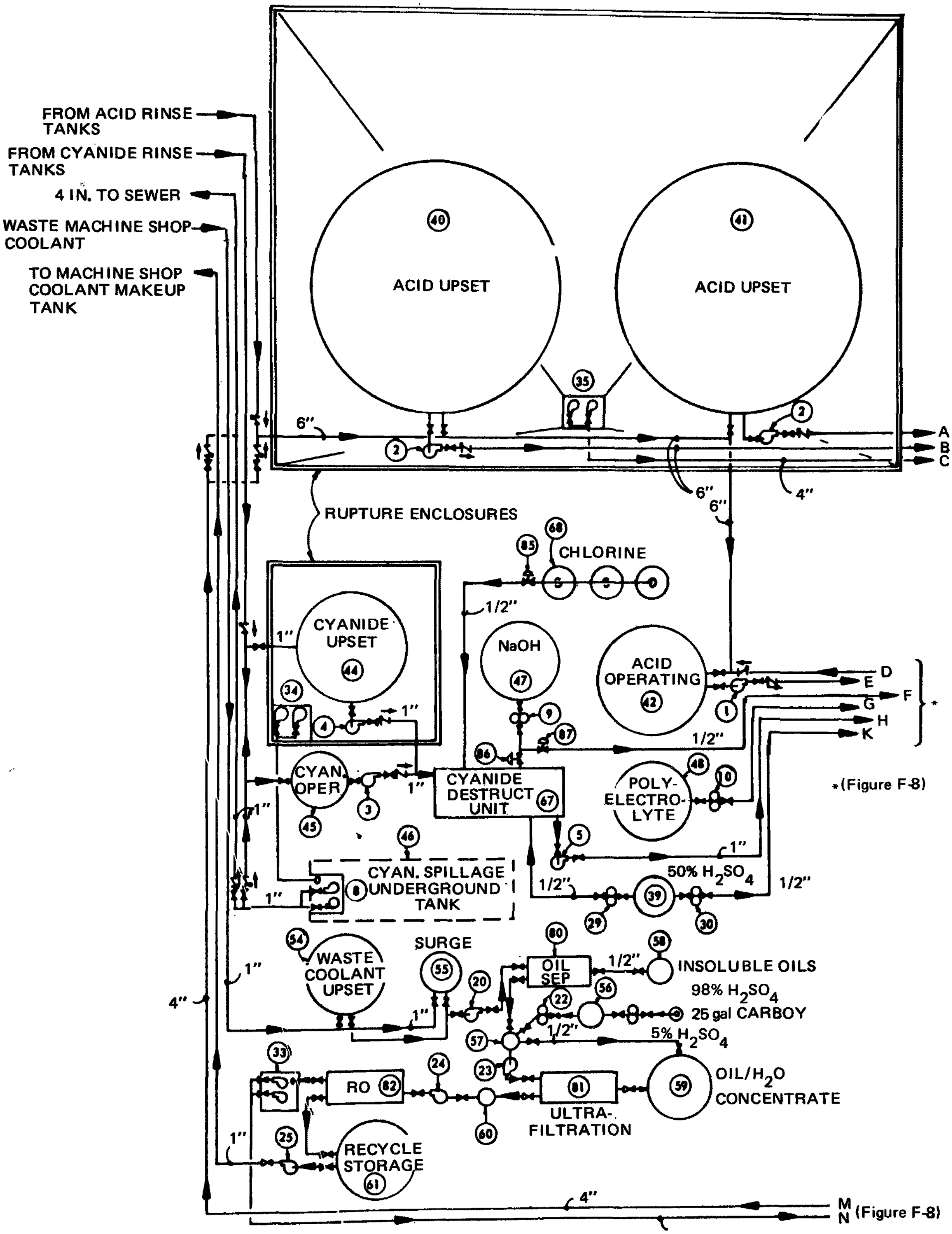


Figure F-7. Plant layout, water recycle system.

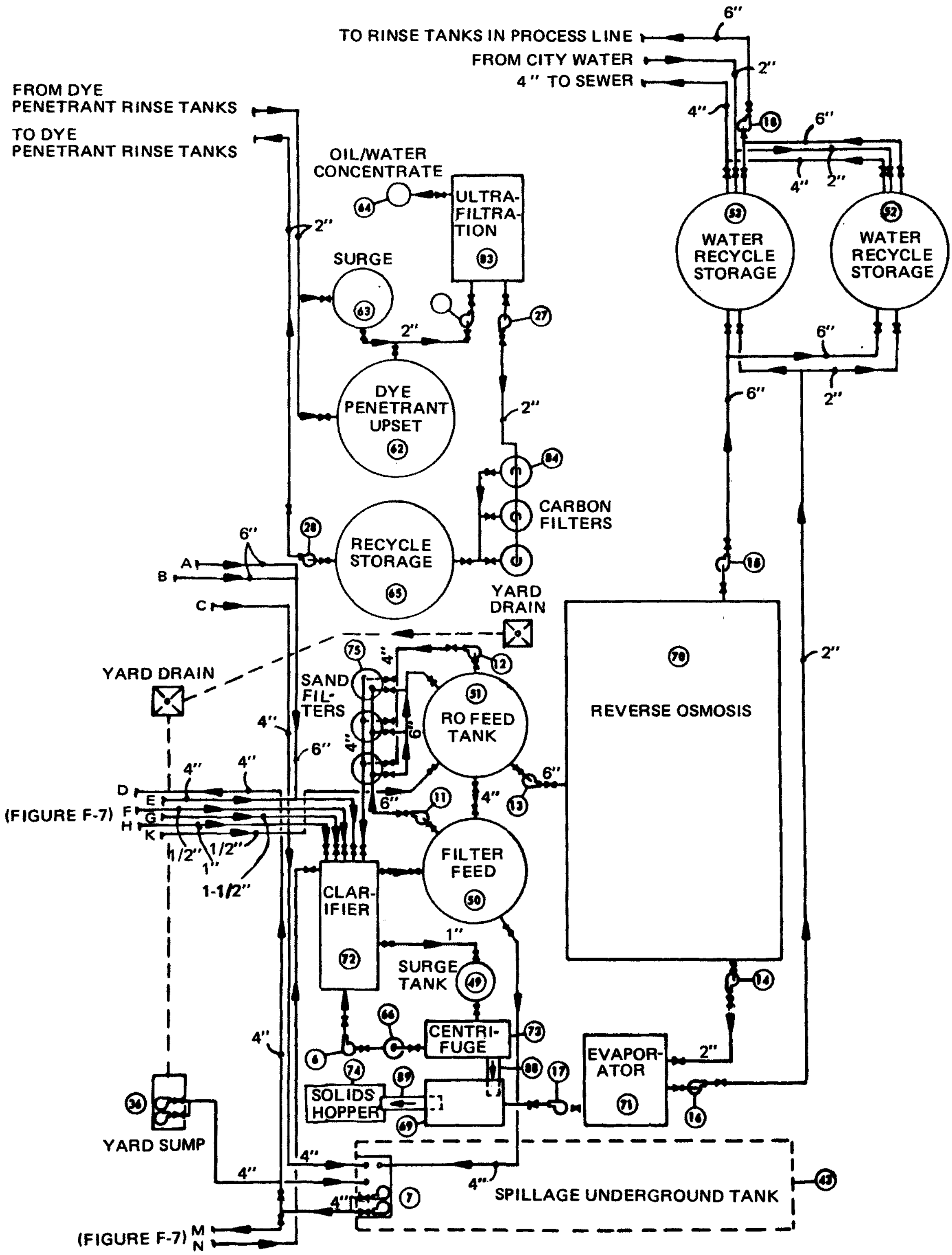


Figure F-8. Plant layout, water recycle system.

APPENDIX G

OPERATING ECONOMICS OF A FULL-SCALE PLANT–CALCULATIONS

Equipment and Installation Amortization Costs

Interest rate	=	8%
Amortization period	=	12 years
Periodic payment, from annuity tables, reference (2) p. 53	=	0.132695
Payment per day	=	0.13295/350
	=	3.79129 E-04

Hence:

1.	Chemical process rinse water equipment	=	$2,145,923 x 3.79129 E-04
		=	$813.58/day
2.	Dye penetrant rinse water equipment	=	$225,006 x 3.79129 E-04
		=	$85.30/day
3.	Machine shop coolant equipment	=	$163,320 x 3.79129 E-04
		=	$61.92/day
4.	Cyanide rinse water equipment	=	$112,751 x 3.79129 E-04
		=	$42.75/day

Building and Utilities Amortization Costs

Interest rate	=	8%
Amortization period	=	15 years
Periodic payment, from annuity tables, ref (2)	=	0.116830
Payment per day	=	0.116830/350
	=	3.33799 E-04

Hence:

1.	Chemical process rinse water building and utilities	=	$599,918 x 3.33799 E-04
		=	$200.25

2. Dye penetrant rinse water building and utilities = $37,148 x 3.33799 E-04
= $12.40

3. Machine shop coolant building and utilities = $45,658 x 3.33799 E-04
= $15.24

4. Cyanide rinse water building and utilities = $57,276 x 3.33799 E-04
= $19.12

Operating Costs

Man-hours per day = 16

Cost per day = 16 x $30
= $480

Hence:

1. Chemical process rinse water plant labor = $480 x 30%
= $144/day

2. Dye penetrant rinse water plant labor = $480 x 15%
= $77/day

3. Machine shop coolant plant labor = $480 x 40%
= $192/day

4. Cyanide process rinse plant labor = $480 x 15%
= $77/day

Total costs	Equipment plus installation cost amortiz. per day	Building and util. cost amortiz. per day	Total facility cost amortiz. per day	Operating cost per day
Chemical process rinse water	$813.58	$200.25	$1,013.83	$144.00
Dye penetrant rinse water	$ 85.30	$ 12.40	$ 97.70	$ 77.00
Machine shop coolant	$ 61.92	$ 15.24	$ 77.16	$192.00
Cyanide rinse water	$ 42.75	$ 19.12	$ 61.87	$ 77.00

APPENDIX H

COMPOSITION OF ALKALINE FLUSHING SOLUTION FOR ULTRAFILTRATION MEMBRANES

NaOH	70 grams
Proctor & Gamble's ERA*	200 milliliters
Formalin**	100 milliliters
Water	100 liters

The above solution, at 21°–38°C (70°–100°F), was circulated under approximately 200 kPa (30 lb/in.^{2}) pressure until an acceptable permeate flow rate was restored—normally between 1 and 6 hours.

* Heavy duty anionic and nonionic laundry surfactant

** 34% formaldehyde

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(Please read Instructions on the reverse before completing)

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		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Robinson, A. K. and Sekits, D. F.		8. PERFORMING ORGANIZATION REPORT NO. D6-42205-4
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16. ABSTRACT

The feasibility of recycling certain categories of water used in the manufacture of airplanes was demonstrated. Water in four categories was continuously recycled in 380-liter (100-gallon) treatment plants; chemical process rinse water, dye-penetrant crack-detection rinse water, electroplating process rinse water containing cyanides, and machine shop water-based coolant.

The estimated capital cost was $3.4 million for equipment to recycle the above categories of water in a typical, medium-sized airplane factory generating 1.5 Ml (0.4 x 10^6 gal)/day. Recycling costs were estimated to be: $0.94/kl ($3.57/1000 gal) for chemical process rinse water; $1.65/kl ($6.25/1000 gal) for dye penetrant rinse water; $4.36/kl ($16.50/1000 gal) for cyanide process rinse water; and $12.18/kl ($46.09/1000 gal) for machine shop coolant.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Circulation	Water Recovery Water Reuse	68D

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