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EFFECTIVE CONTROL OF SECONDARY WATER POLLUTION FROM FLUE GAS DESULFURIZATION SYSTEMS

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EFFECTIVE CONTROL OF SECONDARY WATER POLLUTION FROM FLUE GAS DESULFURIZATION SYSTEMS

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ABSTRACT

This report describes the demonstration tests conducted to substantiate the feasibility of using the vertical tube, falling-film, vapor compression evaporator to concentrate the waste water from a flue gas desulfurization (FGD) process. The test results show that the waste water from the Chiyoda FGD Process can be concentrated up to 140 times and with recovery of more than 99% of the waste stream as a high quality water (less than 10 ppm). Two series of tests were conducted, one with 0.095 m^3/day (25 gal/day) bench model evaporator and the other with 22.7 m^3/day (6000 gal/day) pilot size evaporator. Process conditions were identified and verified for scale free operation. Heat transfer coefficients of 2.84 to 4.26 kw/m^2 ^oF (500 to 750 BTU/hr ft^2 ^oF) were consistently achieved throughout the tests. A conceptual design and economic study of a full size treatment facility were conducted which showed that the capital cost will range from \$2300 to \$1350/m^3/D (\$8.71 to \$5.11/gpd) of waste depending on system capacity. The corresponding operating cost will vary from \$0.95 to \$0.65/m^3 (\$3.59 to \$2.46/1000 gal) of waste processed depending on the waste water composition. The operating cost of the FGD waste treatment process is significantly lower when credit is given for the high quality water recovered from the waste stream.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

B.P.R.	--	boiling point rise
BTU	--	British Thermal Units
Conc	--	concentrate
cm	--	centimeter
CW	--	cooling water
D	--	day
Dist	--	distillate
FGD	--	flue gas desulfurization
gal	--	gallon
g/l	--	grams per liter
gpd	--	gallons per day
gpm	--	gallons per minute
Hr	--	hour
HX	--	heat exchanger
J	--	Joules
kg	--	kilogram
kPa	--	kilo pascals
kWh	--	kilowatt-hour
l	--	liter
LC	--	level control
LRU	--	Laboratory Research Unit
m	--	meter
mg	--	milligram
mg/l	--	milligram per liter
μmhos/cm	--	micromhos per centimeter
ppm	--	parts per million
SS	--	Suspended Solids
Spec. Cond.	--	specific conductance
Sp. Gr.	--	specific gravity
TDS	--	Total Dissolved Solids
TS	--	Total Solids
Pas	--	Pascal Second

SYMBOLS

^{o}C	--	degrees centigrade
Ca^{++}	--	calcium ion
$CaSO_4$	--	calcium sulfate
Cl^-	--	chloride ion
F^-	--	fluoride ion
Fe^{+++}	--	ferric ion
HCO_3^-	--	bicarbonate ion
H_2SO_4	--	sulfuric acid
^{o}K	--	degrees Kelvin
Mg^{++}	--	magnesium ion
$MgSO_4$	--	magnesium sulfate
NO_3^-	--	nitrate ion
Na^+	--	sodium ion
Na_2SO_4	--	sodium sulfate
SO_2	--	sulfur dioxide gas
SO_3^-	--	sulfite ion
SO_4^{--}	--	sulfate ion
SiO_2	--	silica
ΔT	--	heat transfer delta temp.
U_o	--	overall heat transfer coefficient

SECTION 1

INTRODUCTION

The Clean Air Act of 1970 has provided increased impetus to programs directed to decreasing sulfur oxide (SO_x) emissions from new and existing power plants and other facilities. A major concern in installing a flue gas desulfurization process is the reduction or elimination of the secondary pollution of the water by SO_2 scrubbers. Demonstration that these pollutants can be removed from the scrubber waste stream by an available commercial process will allay that concern.

This report describes a program conducted for the Environmental Protection Agency (EPA) by Resources Conservation Co. (RCC) to demonstrate the practicability of using the RCC Brine Concentrator to significantly reduce the secondary water pollution resulting from flue gas desulfurization. The RCC Brine Concentrator is a vertical tube, falling-film, vapor compression evaporator, which has been developed to provide a highly energy efficient process for concentrating waste and blowdown waters. It is especially applicable to concentrating waste waters containing scale forming calcium sulfate and silica. Use of the unique RCC seed slurry process allows concentration of such waste waters far beyond the solubility limit of the normally scaling constituents without forming scale on the heat transfer surfaces. Currently, RCC has several brine concentrators operating or under construction in the Western United States and Canada. These installation represent the only commercial evaporators possessing the capability of concentrating these normally scaling waters without suffering scale formation.

An appropriate program to demonstrate the feasibility of the RCC Brine Concentrator for reducing the volume of waste water from flue gas desulfurization processes required on-site operation of the concentrator at an SO_2 scrubber installation. The Chiyoda "Thoroughbred 101" scrubber installed at

the Sholz Power Plant of Gulf Power Company in Sneads, Florida was chosen for the on-site testing because it was producing a continuous blowdown stream. The Chiyoda process removes sulfur dioxide from the flue gas via countercurrent scrubbing with weak sulfuric acid in a fixed bed absorber. The absorption of SO_2 by H_2O gives sulfurous acid (H_2SO_3) which is catalytically oxidized to H_2SO_4. The concentration of sulfuric acid in the scrubbing liquid is maintained constant by continuous withdrawal to the crystallizer. In the crystallizer this absorbent is partially neutralized by limestone to produce gypsum. There are two waste streams from the process. One is flyash bleed from the prescrubber, and the other is the scrubbing liquid bleed from the crystallizer for water balance and control of the chloride concentration in the scrubbing liquor. These two waste streams are combined, neutralized by limestone and discharged to the liquid waste pond. This combined neutralized waste water was the feed to the concentrator during the demonstration tests.

The demonstration program consisted of the following sequential tasks: 1) evaluation of existing chemical data on waste streams from the Chiyoda process, 2) glassware evaporation tests to confirm predicted precipitation levels and to establish operating conditions for bench model tests, 3) bench model tests to verify operating conditions for the on-site demonstration tests, 4) on-site tests to demonstrate the vapor compression evaporator's long-term performance in concentrating scrubber waste water, and 5) estimation of the capital and operating costs for a full-scale system.

The primary objective of this program was to demonstrate a way to reduce the volume of waste water from a desulfurization process to less than 4% of its initial volume. Test results have demonstrated the feasibility of concentrating the waste stream from the Chiyoda FGD Process up to 140 times and recovering more than 99% of the waste stream as a high quality water (less than 10 ppm TDS) for recycle back to the power plant.

SECTION 2

CONCLUSIONS

The following conclusions have been developed based on the results obtained in this demonstration program.

1) The test program has demonstrated the technical feasibility of using the RCC falling film, vapor compression evaporator system for control of secondary water pollution from the Chiyoda FGD Process.

2) The discharge of waste water from the Chiyoda FGD Process can be reduced to as little as 1% of initial volume with the remainder recovered as a high quality water (less than 10 ppm TDS), suitable for recycle to the process or other uses.

3) Long term, scale free operation of the RCC Brine Concentrator Process was demonstrated.

4) Formation of scale on the heat transfer surfaces of the evaporator was prevented by the use of the RCC seed slurry process.

5) No degradation of the heat transfer coefficient (U) due to fouling of the heat transfer surfaces was encountered during the demonstration tests.

6) The small amounts of foaming encountered during the test period will not adversely affect operation of the vapor compression evaporator.

7) The overall heat transfer-coefficient remainded unchanged for total solids concentrations in the evaporator up to 400 g/l.

8) Due to the feed being saturated with calcium sulfate and to its inverse solubility, scale inhibitor must be added to the waste water fed to the evaporator at a rate of 15 ppm to prevent fouling of the feed heat exchanger and deaerator.

9) At the very high concentration factors (140) attained during this demonstration program, the estimated energy consumption of a full size evapora-

tor will be 2.6 to 3.2 kWh/m^3 (98 to 121 kWh/1000 gal) of waste water con-concentrated. At current installations operating at lower concentration factors the energy consumption is 2.1 kWh/m^3 (80 kWh/1000 gal) of waste water concentrated.

10) The capital cost of a full size system for application in treatment of FGD process waste water for capacities between 600 to 3200 m^3/D will range from \$2300 to \$1350 m^3/D (\$8.71 to \$5.11/gpd). The corresponding operating cost will vary from \$0.95 to \$0.65/m^3 (\$3.59 to \$2.46/1000 gal) of waste processed depending on the waste water composition.

11) The operating cost of the FGD waste treatment process is significantly lower when credit is given for the high quality water recovered from the waste stream.

12) Standard materials of construction are considered to be available for fabrication of a RCC Brine Concentrator for use in this application.

SECTION 3

RECOMMENDATIONS

Since this program has successfully demonstrated treatment of wastewaters from the Chiyoda regenerable flue gas scrubber system at the Sholz powerplant in Sneads, Florida, it is recommended that the brine concentration system be evaluated for a lime-limestone non-regenerable scrubber system using forced oxidation (lime-limestone scrubbers are in more general commercial use at the present time). Recent research at EPA's laboratory in Research Triangle Park[1] indicates that forced oxidation by air sparging or injection can effectively increase the sludge solids content to upwards of 80% solids. This is equal to a reduction of sludge volume by 25 to 40% for lime-limestone scrubbers. However, since this tightening of the scrubber loop will result in considerable build-up of soluble dissolved solids including corrosive chlorides a separate blowdown stream will be required to control the level of these salts. Treatment of this blowdown stream by a brine concentrator, would allow effective control of chlorides in the scrubber loop and reduce the dissolved solids concentration in the sludge solids. It is estimated[1] that a 70% reduction of the chlorides and other dissolved solids concentration could be effected by blowdown and evaporation of 5% of the filtrate liquor. This compares with a blowdown requirement of about four times that amount if forced oxidation is not used to convert calcium sulfite to calcium sulfate. Since the sludge solids have been increased in solids to the extent that they would easily be land-filled and the soluble salts concentration have been reduced in the sludge liquid phase, the costs of sludge fixation may well be alleviated.

If this work was to be successful it would "make possible the combustion of high chloride, high sulfur coals without damage to the environment"[1].

1) Borgwardt, Robert H., Paper presented at FLUE GAS DESULFURIZATION SYMPOSIUM, EPA/IERL, Hollywood, Florida, 8-11 Nov.77.

SECTION 4

DEMONSTRATION TEST PROGRAM

The purpose of this test program was to demonstrate the technical feasibility of using a falling film, vapor compression evaporator to eliminate secondary water pollution from flue gas desulfurization processes. Data were obtained to permit calculations for capital and operating costs, energy requirements and other critical criteria needed for design of a full-size treatment process.

The test program was conducted in four segments: 1) Evaluation of available chemical data on Chiyoda waste streams, 2) Laboratory glassware concentration tests, 3) Bench model evaporator testing, and 4) On-site demonstration tests.

TEST EQUIPMENT

Bench Model Evaporator

The bench model testing was conducted using the Resources Conservation Company (RCC) 0.095 m^3/D (25 gal/day) vertical plate, falling film, laboratory evaporator. A photograph and process flow diagram of the unit is presented in Figures 1 and 2, respectively. The Bench Model Evaporator was selected for initial evaporator testing since it provides small scale yet realistic simulation of a full size evaporator. The fluid film which is formed on the vertical heat transfer panel has essentially the same flow characteristics as the vertical tubes used in commercial RCC evaporators and thus gives heat transfer and process data applicable to the commercial plant. A detailed description of the Bench Model Evaporator is given in Appendix A.

Laboratory Research Unit

The on-site demonstration tests were conducted with the RCC Laboratory Research Unit (LRU). The LRU is a 22.7 m^3/D (6000 gal/day), vertical tube,

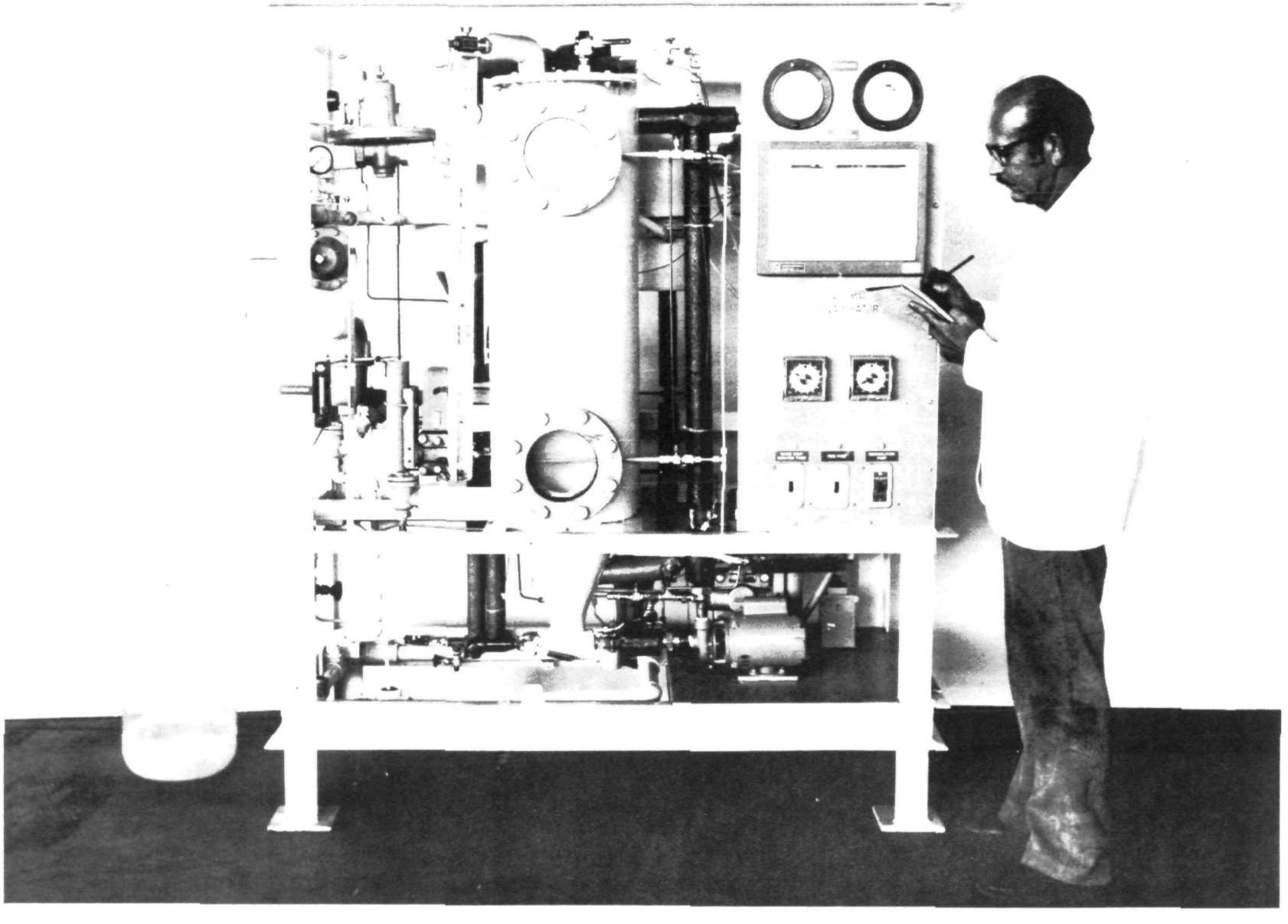

Figure 1. Bench Model Evaporator

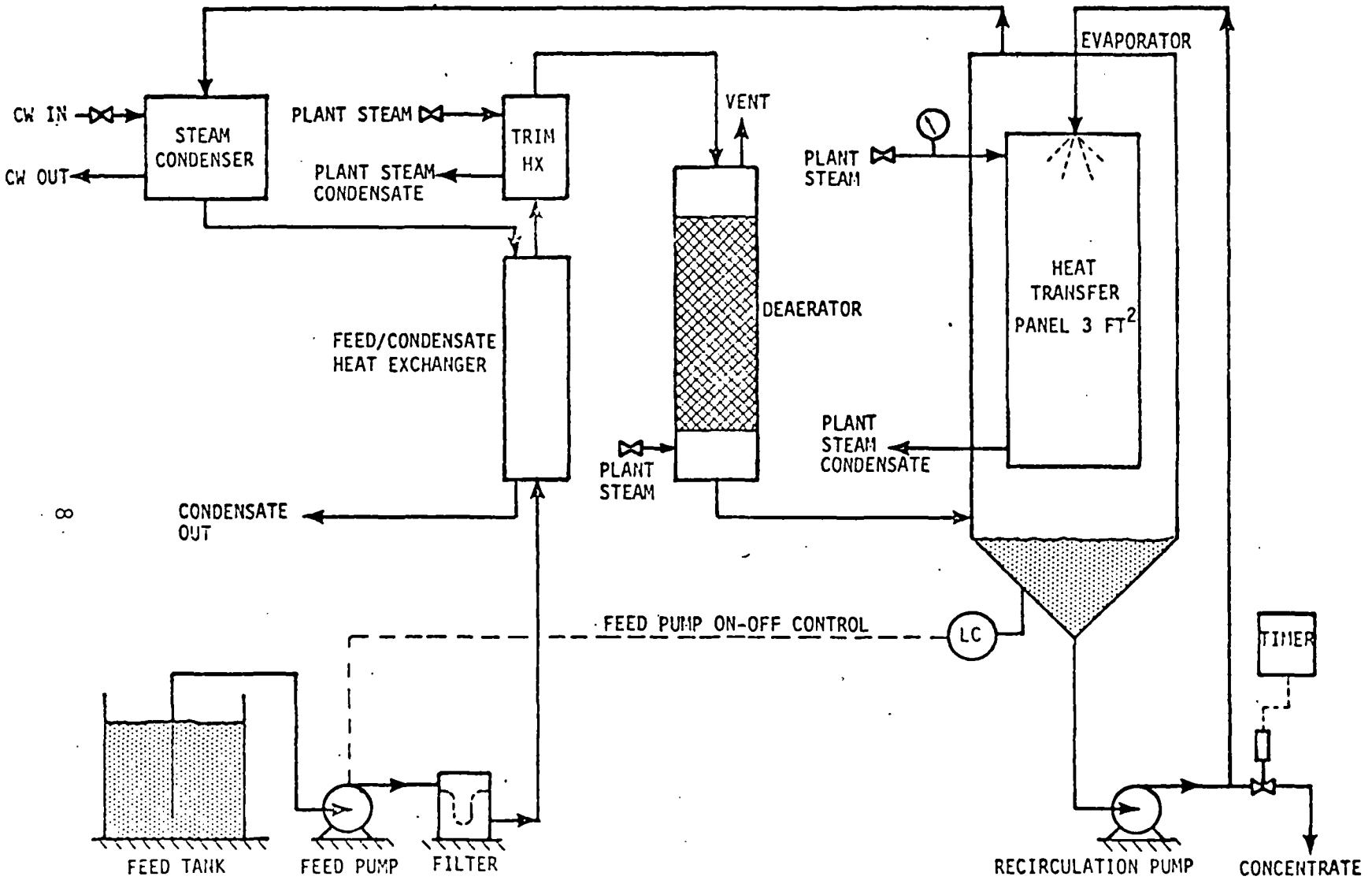

FIGURE 2: PROCESS FLOW DIAGRAM FOR BENCH MODEL EVAPORATOR

falling film, vapor compression, pilot evaporator designed to simulate the operation of a commercial size RCC evaporator. A photograph of the LRU is shown in Figure 3. The basic process flow diagram of the LRU is shown in Figure 4. A detailed description of the LRU is presented in Appendix A.

The neutralized Chiyoda waste water was piped to the evaporator through a filter, flow meter, heat exchangers and deaerator. The feed enters the sump at about its atmospheric boiling temperature. Evaporation occurs at slightly above atmospheric pressure as the concentrated waste is recirculated down the inside of the condenser tubes in a thin film. The steam is collected and then compressed to raise its temperature of condensation slightly above the boiling point of the brine on the inside of the tubes, and causes more steam to be evaporated from the brine inside the tubes. The condensate is collected as product water and pumped back through the heat exchanger to recover its heat. The small concentrated slurry waste stream is taken from the recirculation line, and is discharged periodically through a timer operated control valve.

Scale control is accomplished by utilizing a seed slurry method which prevents scale deposition on metal surfaces by providing preferential sites within the waste brine for crystal growth. The seed slurry is established in the sump during startup by seeding the unconcentrated feed with calcium sulfate and is maintained during operation by the natural precipitation of salts from the concentrated brine. Chemical analyses of the calcium sulfate seed usually show the presence of other ions. Some of these ions are from the brine left on the precipitate when it is filtered because calcium sulfate is not sufficiently insoluble to permit washing the precipitate. However, other ions and salts may also co-precipitate by several mechanisms depending on the composition of the concentrated brine. Some of the possible mechanisms are; double and triple salt formation with calcium sulfate as one component; substitution of ions of similar size and charge in the calcium sulfate crystal lattice; interstitial accumulation in the crystal lattice; and adsorption on the surface of the crystals. Contamination of calcium sulfate seed to levels of the order of 10% of other salts has been observed occasionally with no adverse effect on scale control.

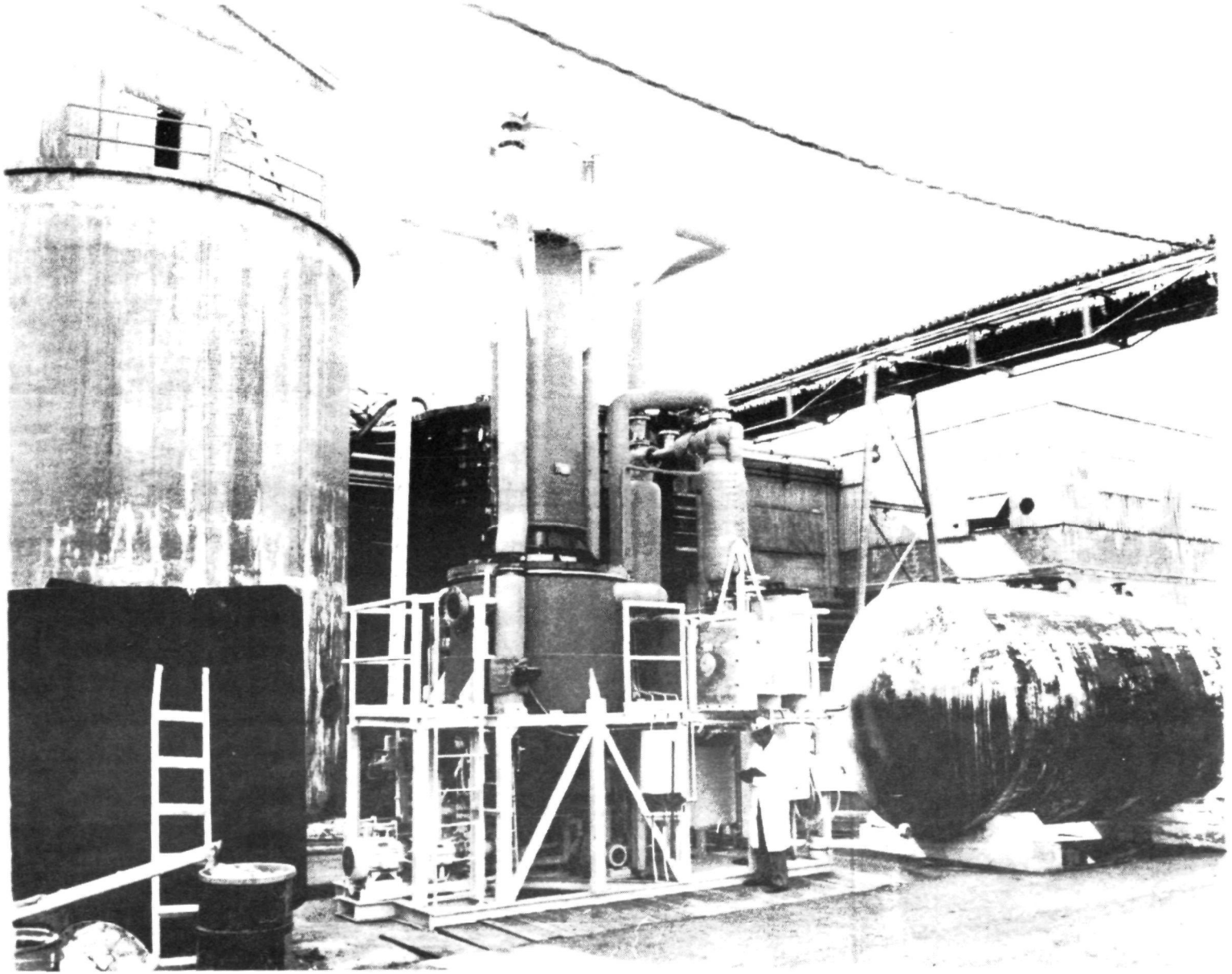

Figure 3. Laboratory Research Unit (LRU)

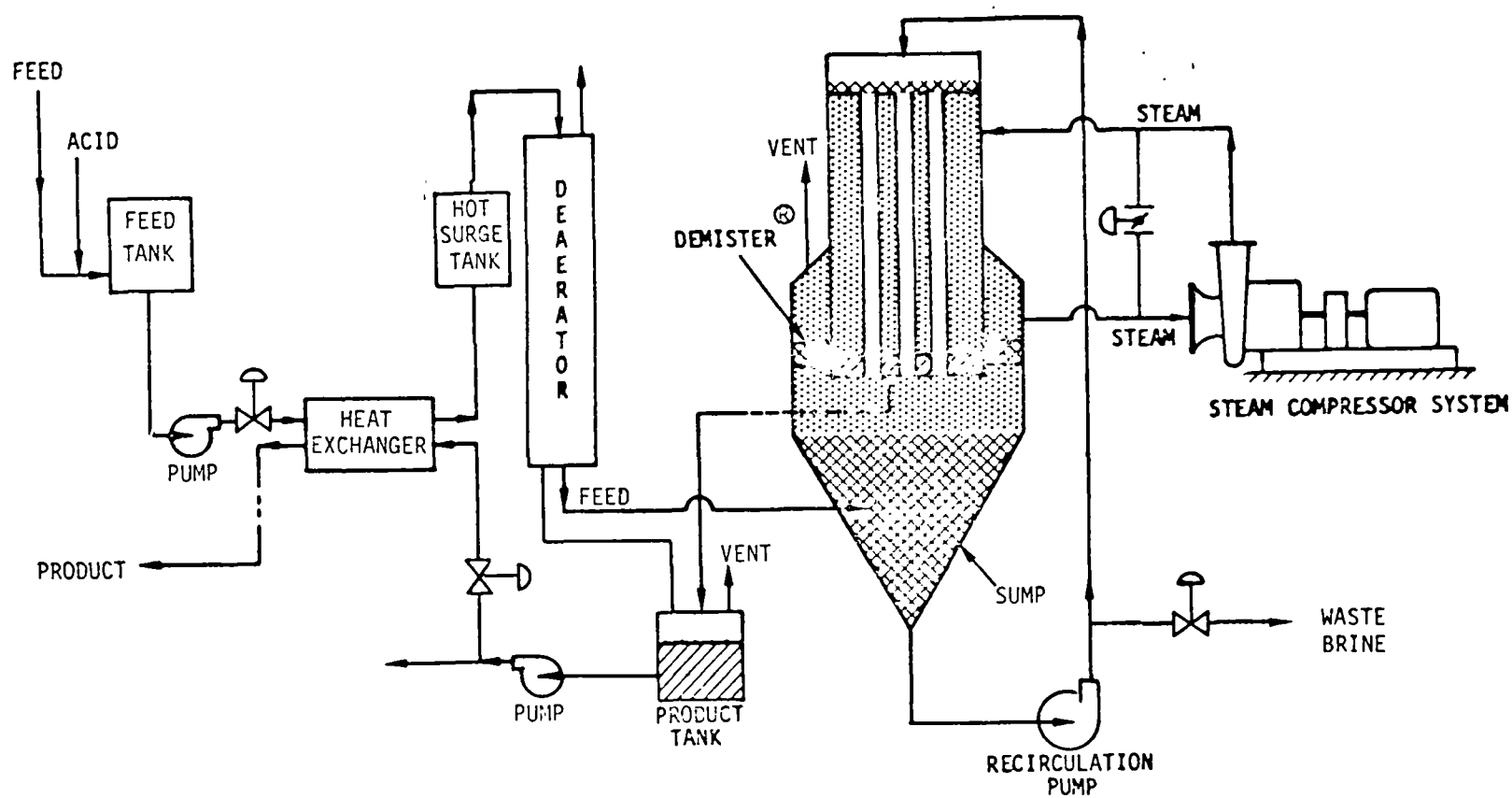

FIGURE 4: PROCESS FLOW DIAGRAM FOR LABORATORY RESEARCH UNIT (LRU)

RESULTS AND DISCUSSION

Literature Review and Glassware Tests

RCC obtained and evaluated the available chemical data on the waste stream from the Chiyoda Flue Gas Desulfurization Process. The purpose of this evaluation was to develop the procedure for the glassware testing and to obtain initial indications of evaporator performance when concentrating the scrubber waste water.

Available chemical data were received on the composition of wastes from the Chiyoda installation at Sneads, Florida. The data, all of which are presented in Appendix B, covered the time period from March 1975 thru May 1976 and included composition of limestone neutralized waste water which was the feed to the RCC evaporator (Table B1). The waste water is a mixture of the mother liquor purge (Table B2) and prescrubber blowdown (Table B3) which has been neutralized with limestone. Analysis of the data revealed that high concentration factors were possible with this waste because the low TDS and high ratio of calcium sulfate to other salts would yield a concentrate with a low boiling point rise and a high seed level.

Laboratory glassware tests were performed on a sample of the limestone neutralized waste water from the Chiyoda liquid waste pond at the Sneads, Florida facility.

The as received sample was analyzed for the chemical and physical properties. The analytical procedure used to determine the chemical properties of the waste water processed in this demonstration program are summarized in Table 1. The results of these analyses are presented in Table 2. The chemical composition of the sample was found to be similar to earlier waste compositions reported in the data received from Chiyoda.

In the glassware tests, the Chiyoda waste water sample was concentrated 77.5 times by volume resulting in a suspended solids level of 129,312 mg/l. The suspended solids contained 84.7% $CaSO_4$, the evaporation proceeded smoothly and the analysis of the dissolved solids (TDS 50,474 mg/l) indicated that further concentration was possible without significantly changing the composition

TABLE 1: Summary of Analytical Procedures*

Calcium	-	titration with standard EDTA solution
Magnesium	-	titration with standard EDTA solution
Chloride	-	titration with silver nitrate solution
Sulfate	-	precipitation with barium chloride
Bicarbonate	-	titration with standard acid
Nitrate	-	Brucine Method
Silica	-	colorimetric method with ammonium molybdate
Sulfite	-	titration with potassium iodide-potassium iodate
Fluoride	-	Alizarin visual method
Iron	-	colorimetric method with mercapto-acetic acid

*Further discussion of these procedures can be found in 'Standard Methods for the Examination of Water and Wastewater' Fourteenth Edition.

TABLE 2: Results of Glassware Analyses

PARAMETER	FEED	CONCENTRATE (77.5X)	DISTILLATE	% OF SALT REMOVED FROM SOLUTION
pH	7.00	6.10	6.88	
Specific Gravity at 60°F	1.003	1.042		
TDS at 220°F	3,200 mg/l	54,550 mg/l		
TDS at 900°F	2,800 "	33,650 "	0.25 mg/l	
Suspended Solids	11.8	129,312 "		
Sodium (Calc.)	148 mg/l	5,975 mg/l		47.9
Calcium	680 "	600 "		98.9
Magnesium	92 "	5,569 "		21.9
Chloride	40 "	3,099 "		0.0
Sulfate	2,000 "	20,756 "		86.6
Bicarbonate	122 "	73 "		99.2
Silica	4 "	100 "		67.7
Sulfite	2 "	2 "		98.7
Nitrate	189 "	14,300 "		2.3
Iron	0.16	0 "		100
Total (Calc.)	3,277.16 mg/l	50,474 mg/l		80.1
Total Organic Carbon		4 mg/l		
Total Inorganic Carbon		19 "		
Boiling Point		99.8°C @ 99.7 kPa		
Specific Heat		3.906×10^{3} J/kg °K		
Viscosity		0.4177×10^{-3} Pas		
Specific Conductance			5.854 micromhos/cm	

of the suspended solids.

The glassware results showed the Chiyoda waste to be of composition similar to brines presently being processed in commercial RCC evaporators. The waste is saturated with calcium sulfate and thus requires pretreatment with a small amount of scale inhibitor to prevent fouling of the feed heat exchanger and deaerator as the feed is heated prior to entering the evaporator. Based on chemical composition of the feed and the results of the glassware boildown, it was concluded that the waste could be concentrated up to about 100 times and still remain within process limits of the evaporator.

Bench Model Tests

The Bench Model Evaporator testing was conducted at the RCC Laboratory in Seattle, Washington between September 2 and September 16, 1976.

The purpose of the Bench Model Evaporator test was to verify glassware predictions and to establish the operating conditions for the on-site demonstration tests to be conducted with the LRU pilot evaporator. The Bench Model Evaporator was operated at two concentration levels, 37.5X and 128X. The results of the tests indicated that the feed can be concentrated at least 100X and a high quality distillate can be produced from the ponded Chiyoda waste. The Bench Model Evaporator test confirmed predictions made from the glassware test data.

At the beginning of the first bench model test the evaporator sump was filled with waste water at a pH of 6 and gypsum was added to provide the necessary seed level. After a period of heat soak, steam was then introduced into the heat transfer panel and a stable concentration of 37.5X was reached after about 3 days. The concentration was maintained for the remainder of the 8 day run. During the bench model testing the feed was acidified with sulfuric acid to aid in decarbonation. Scale inhibitor was also added at a rate of 15 ppm to prevent fouling of the heat exchanger and deaerator. Foaming of the circulating brine was encountered at the beginning of the test, but subsided as the sump concentration increased. No addition of an antifoaming agent was necessary.

The distillate was of excellent quality during the first run except when solids carry over was encountered due to the initial foaming. Physical and chemical properties of the feed, concentrate and distillate for the first run are presented in Table 3.

Operating data for the first concentration run are presented in Figures 5 and 6. The evaporator was operated at an average heat transfer delta T of 4.1^{o}C (7.3^{o}F). The heat transfer coefficient (U value) plotted in Figure 5 is seen to vary between 3.07 and 4.20 kW/m^{2} ^{o}K (540-740 BTU/hr ft^{2} ^{o}F). The boiling point rise (B.P.R.) was essentially constant throughout the test at about 0.56^{o}C (1.0^{o}F).

At completion of the run the evaporator was disassembled, inspected and cleaned. The heat transfer surfaces were found to be clean and in general the unit appeared "as new". A photograph of the heat transfer panel after the first run is presented in Figure 7. The white spots on the heat transfer panel is where seed has gathered in areas of pitting corrosion encountered in a previous test program.

The second concentration run was made following the same procedure except that the initial seed level was 140 g/l. A concentration factor of 128X was reached in approximately 5 days and was maintained for 4 days. Results of the analysis of the feed concentrate and distillate are presented in Table 4. The operating data pertaining to the second concentration run are presented in Figures 8 and 9. The evaporator was operated at an average heat transfer delta T of 3.9^{o}C (7.0^{o}F). The heat transfer coefficient (U value) plotted in Figure 8 varied from 3.29 to 4.26 kW/m^{2} ^{o}K (580-750 BTU/hr ft^{2} ^{o}F).

The evaporator was disassembled and inspected at the completion of this test. The heat transfer panel was slightly fouled with calcium sulfate as shown in Figure 10. The fouling was observed when the circulating brine flow was reduced resulting in incomplete wetting of the heat transfer panel. The reduced flow was caused by the increased viscosity and density of the brine at the abnormally high concentration factors attained

TABLE 3: Bench Model Evaporator - Run #1 Analyses

PARAMETER	FEED	CONCENTRATE (37.5X)	DISTILLATE	% OF SALT REMOVED FROM SOLUTION
pH	6.7	6.75	8.2	
Specific Gravity at 60°F	1.006	1.024		
TDS @ 220°F	3,190 mg/l	30,050 mg/l	2.67	
TDS @ 900°F	2,690 "	17,450 "		
Suspended Solids	0 "	89,732 "		
Sodium	138 mg/l	1,268 mg/l		75.5
Calcium	656 "	640 "		97.4
Magnesium	97 "	3,742 "		*
Chloride	43 "	1,937		*
Sulfate	1,939 "	10,125 "		86.1
Bicarbonate	110 "	146 "		96.5
Silica	4 "	14 "		90.7
Sulfite	2 "	2 "		97.3
Nitrate	174 "	7,436 "		**
Iron	0.16 "	0 "		100
Fluoride	18 "	2 "		99.7
TOTAL (Calc.)	3,181.16 mg/l	25,312 mg/l		78.8%
Total Organic Carbon	7 mg/l	30 mg/l		
Total Inorganic Carbon	20 "	20 "		
Boiling Point	372.6°K @ 99.6 kPa	372.9°K @ 99.6 kPa		
Specific Heat	---	3.91×10^{3} J/Kg °K		
Viscosity	---	0.41×10^{-3} Pas		
Specific Conductance			8.029 micromhos/cm	

* Inaccuracy of this determination is believed to be caused by the interference of heavy metals

** This discrepency is believed to be a result of experimental error in the analytical technique used to measure the nitrate concentration.

TABLE 4: Bench Model Evaporator - Run #2 Analyses

PARAMETER	FEED	CONCENTRATE (128X)	DISTILLATE	% OF SALT REMOVED FROM SOLUTION
pH	7.57	6.7	5.7	
Specific Gravity at 60°F	1.005	1.070		
TDS @ 220°F	3,210 mg/l	101,250 mg/l	5.0 mg/l	
TDS @ 900°F	2,680 "	57,650 "		
Suspended Solids	0 "	309,436 "		
Sodium (Calc.)	152 mg/l	2,859 mg/l		84.5
Calcium	664 "	720 "		99.2
Magnesium	83 "	13,851 "		*
Chloride	47 "	5,423 "		9.9
Sulfate	1,912 "	34,438 "		85.9
Bicarbonate	122 "	159 "		99.0
Silica	7 "	149 "		83.7
Sulfite	2 "	2 "		99.2
Nitrate	186 "	24,596 "		**
Iron	0.18 "	0 "		0
Fluoride	7 "	275 "		69.3
Total (Calc.)	3,182.18 mg/l	82,472 mg/l		79.8
Total Organic Carbon	1 mg/l	99 mg/l		
Total Inorganic Carbon	21 mg/l	15 mg/l		
Boiling Point	372.8°K @ 98.9 kPa	373.0°K @ 98.9 kPa		
Specific Heat	---	352×10^3 J/kg°K		
Viscosity	---	0.45×10^{-3} Pa s		
Specific Conductance			3.6295 micromhos/cm	

* Inaccuracy of this determination is believed to be caused by the interference of heavy metals in the measurement of magnesium concentration.

** This discrepency is believed to be a result of experimental error in the analytical technique used to measure the nitrate concentration.

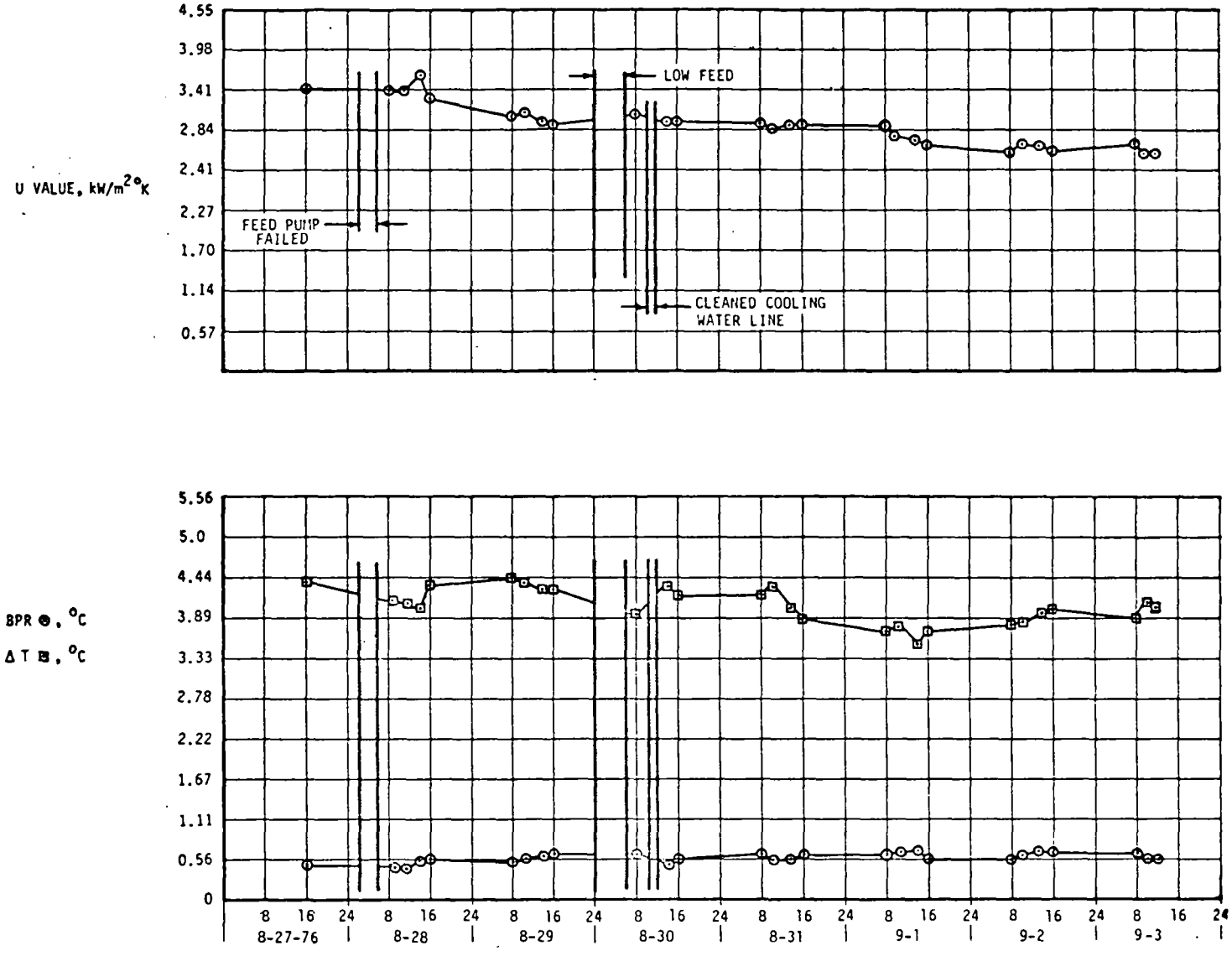

FIGURE 5: BENCH MODEL TEST RESULTS - RUN #1
(Heat Transfer Data)

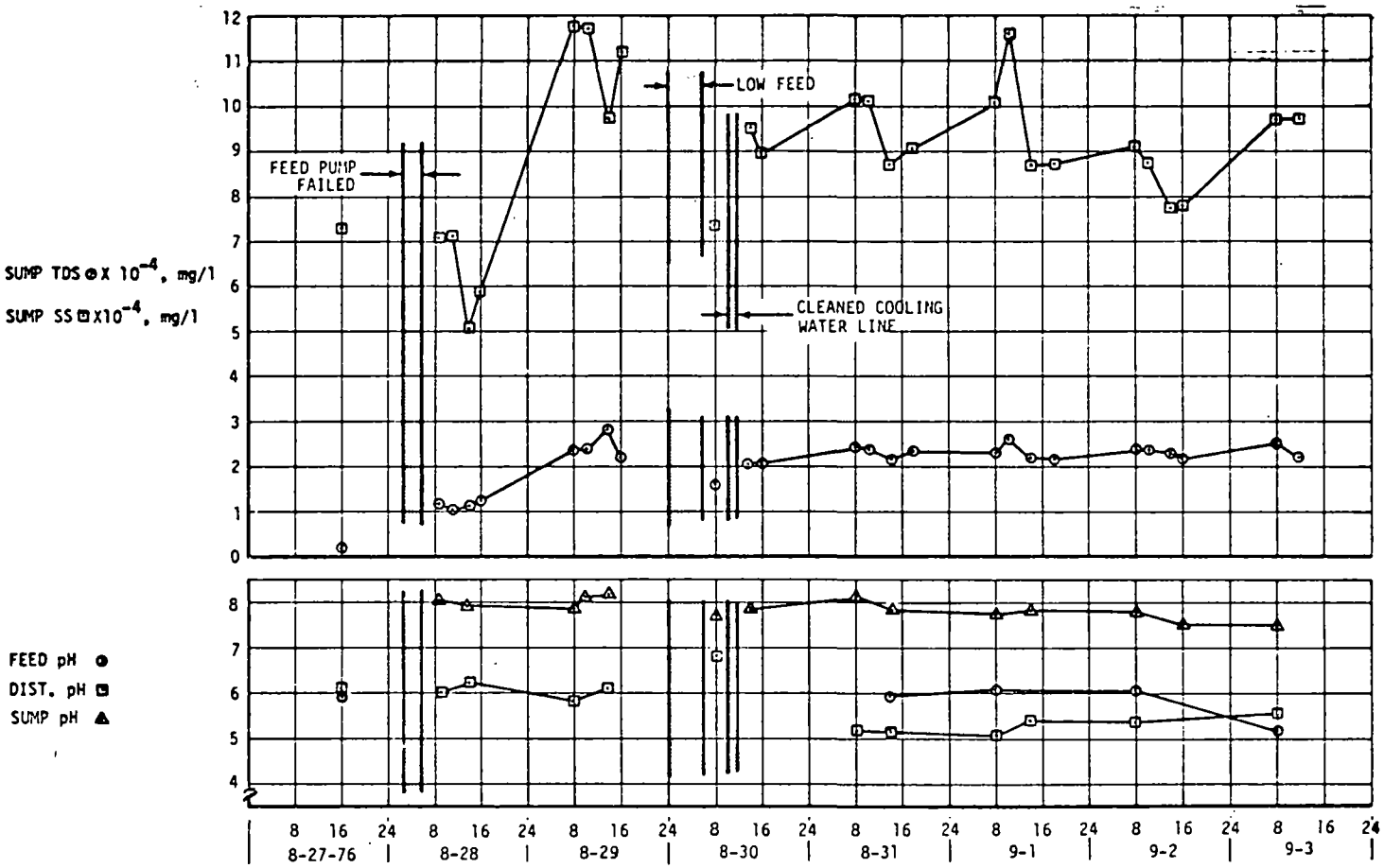

FIGURE 6 : BENCH MODEL TEST RESULTS - RUN #1
(Operating Data)

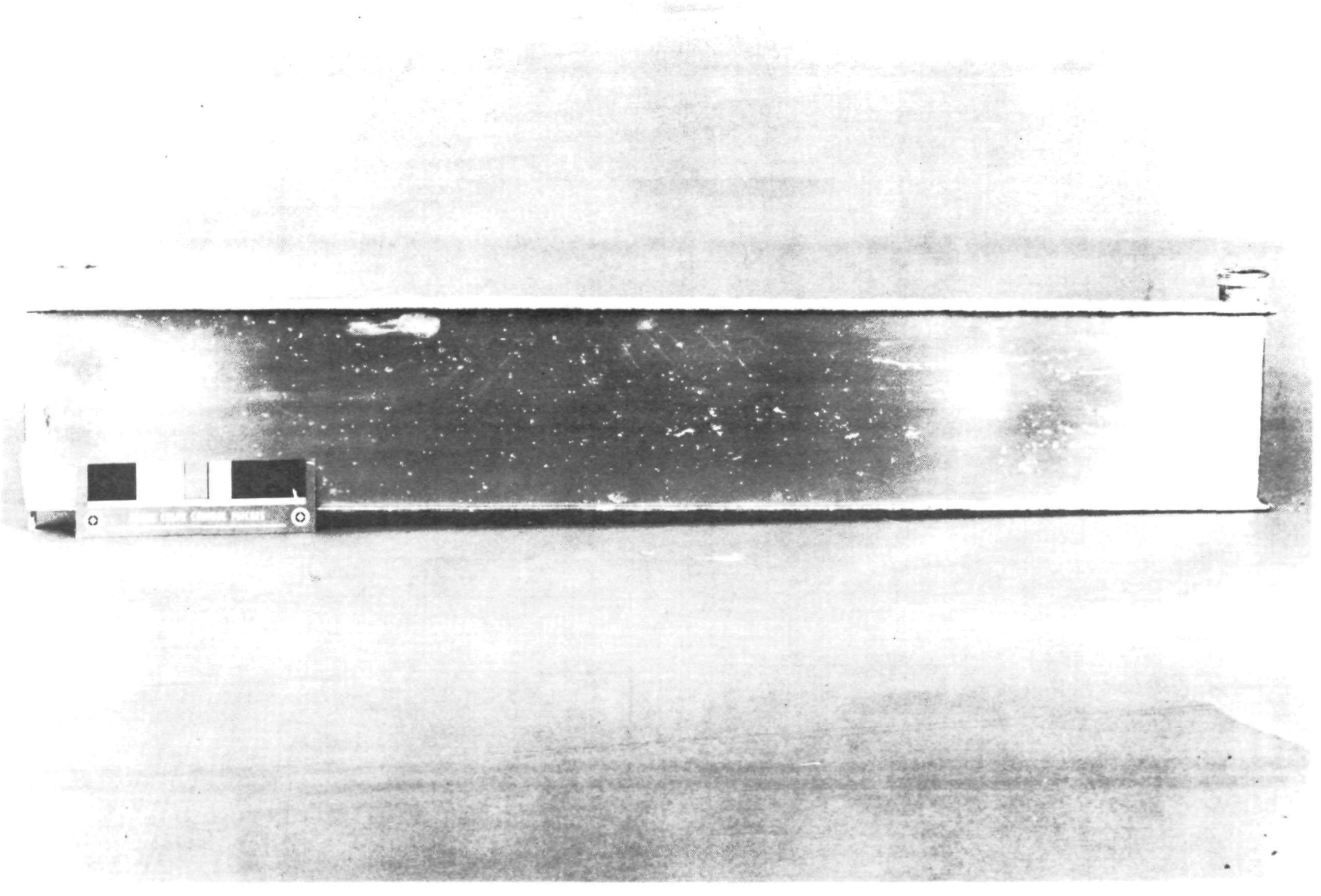

Figure 7. Heat Transfer Panel After Run Number 1

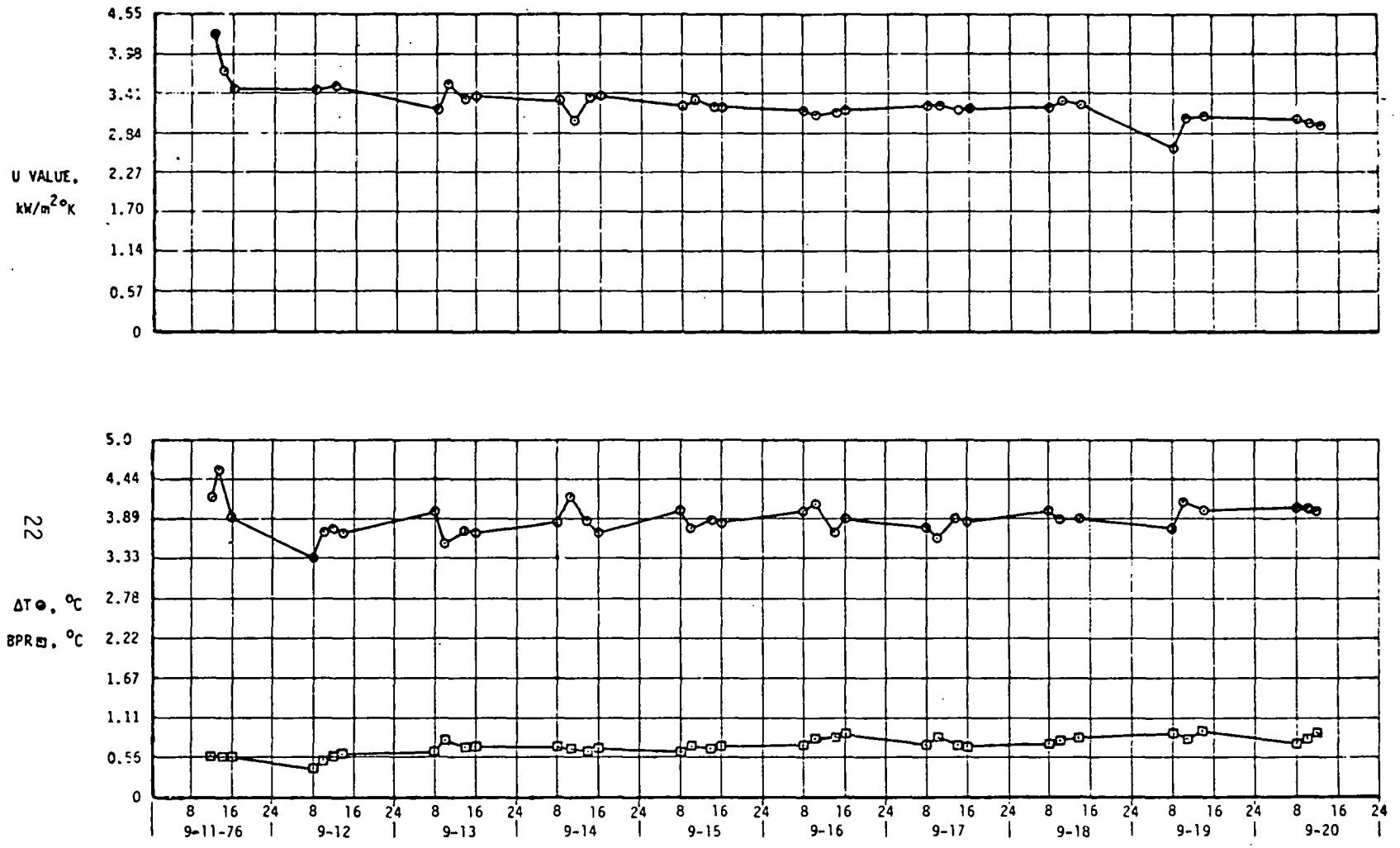

FIGURE 8: BENCH MODEL TEST RESULT - RUN #2
(Heat Transfer Data)

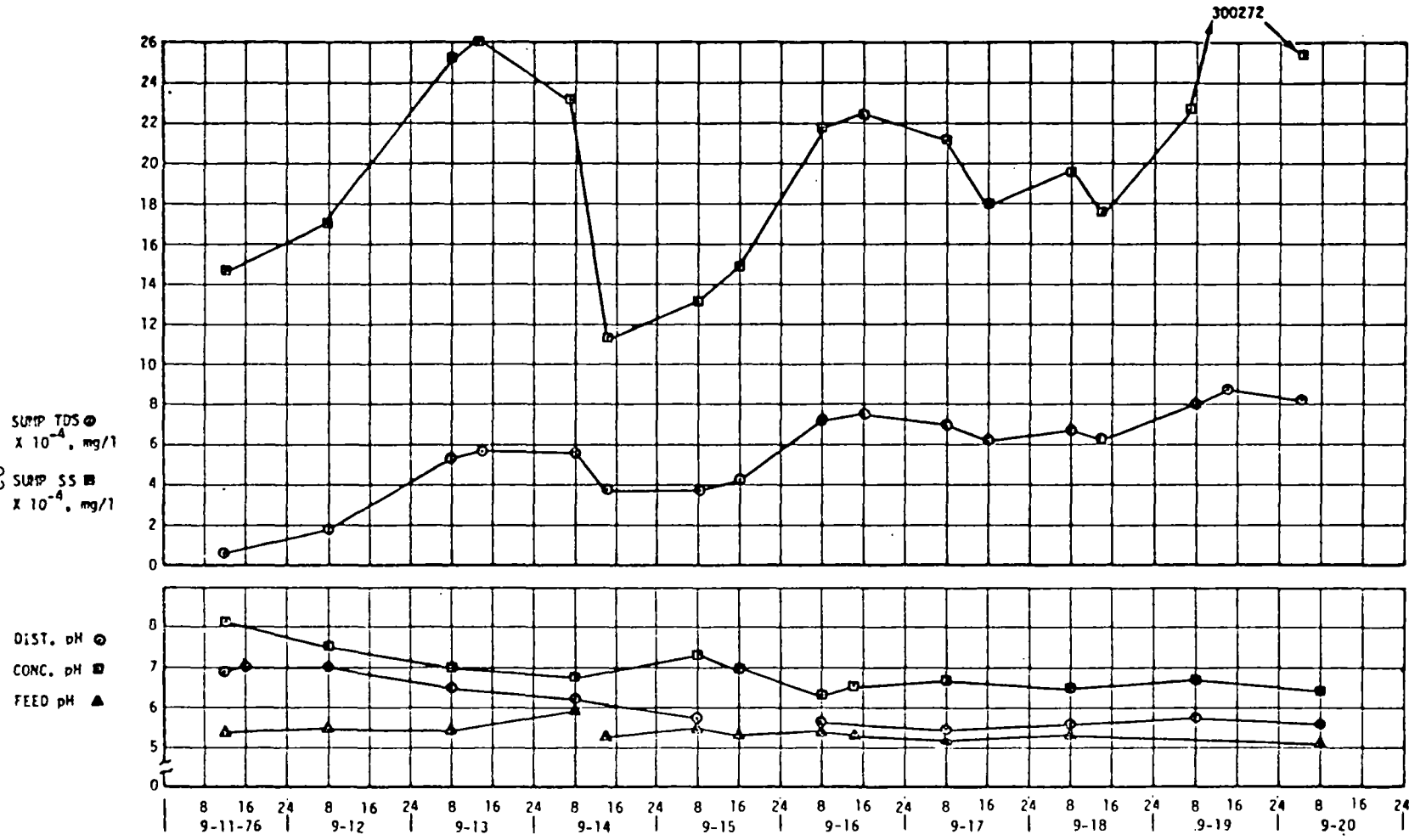

FIGURE 9: BENCH MODEL TEST RESULTS - RUN #2
(Operating Data)

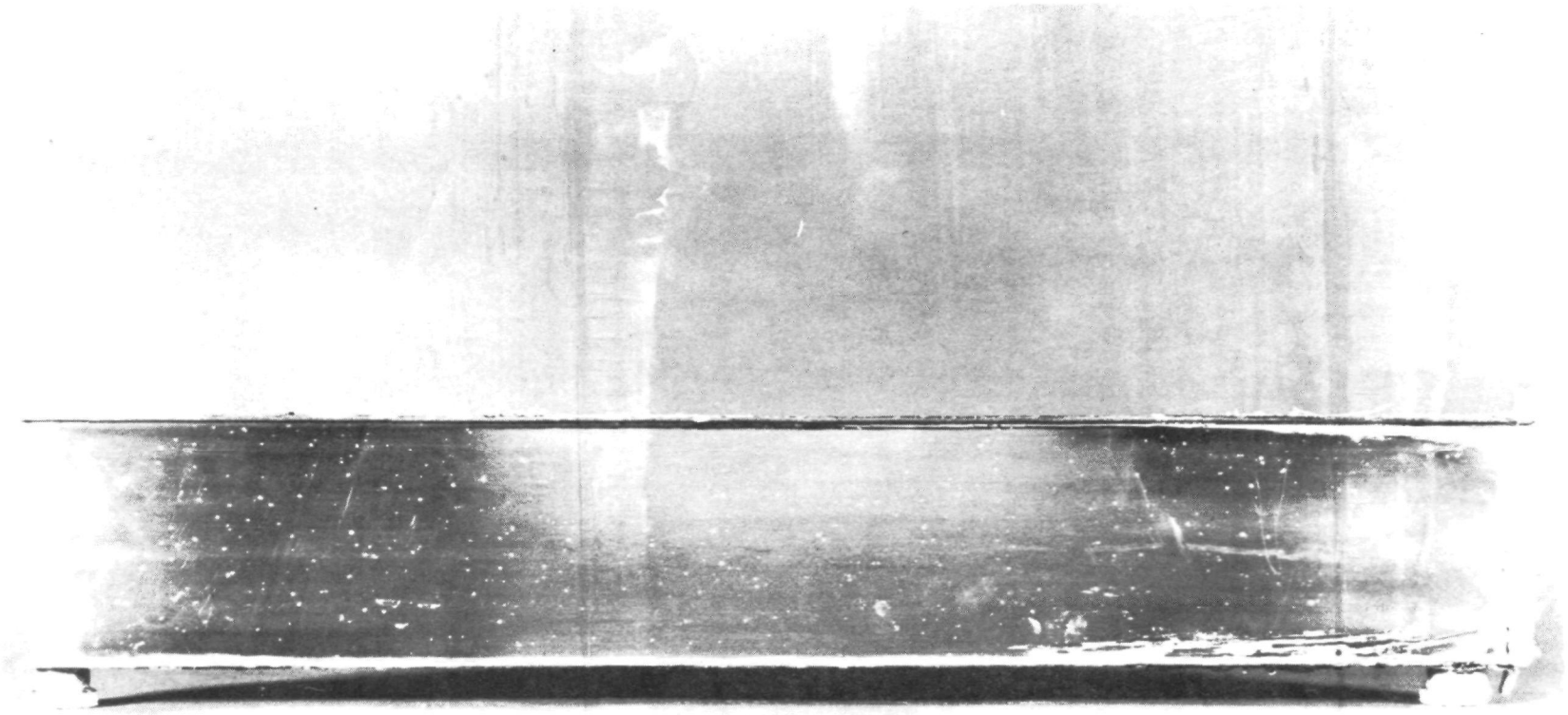

Figure 10. Heat Transfer After Run Number 2

during the test. The deposit observed is not expected to occur in commercial RCC evaporators because complete wetting of the tubular heat transfer surfaces is assured by equipment design and accurate control of the brine flow. There was a deposit of solids in the mist eliminator (Figure 11). The mist eliminator wash system in the commercial RCC evaporators would have removed this deposit; however, the bench model evaporator does not have this capability.

On-Site Demonstration Tests

The Laboratory Research Unit (LRU) pilot evaporator was installed on-site at the Sneads, Florida facility and took its feed from the Chiyoda liquid waste pond containing the neutralized waste from the Chiyoda FGD Process. The pilot unit was operated 60 days to insure successful demonstration of the technical objectives and obtain sufficient data to support operating and capital cost estimates for a full scale system. The primary objective of this test was to demonstrate the long term performance of the RCC falling film, vapor compression evaporator when concentrating the Chiyoda FGD Process waste water.

Results of the on-site demonstration tests indicate that the waste water volumes can be reduced to less than 1% of the present volume and a high quality distillate would be produced from the ponded Chiyoda waste water.

Prior to start-up, an analysis of the liquid pond indicated that the composition had changed significantly from the feed used in the bench model evaporator tests. This change in pond composition was caused by the incorrect use of dolomitic limestone for neutralization. After the use of dolomitic limestone was discontinued, the pond was drained and refilled with fresh waste water. Analyses of the refilled pond indicated that the composition was still different from the bench model evaporator test feed. Therefore, the initial operating conditions for the LRU were modified and the concentration factor estimated from the bench model test data (115X) had to be revised to approximately 70X.

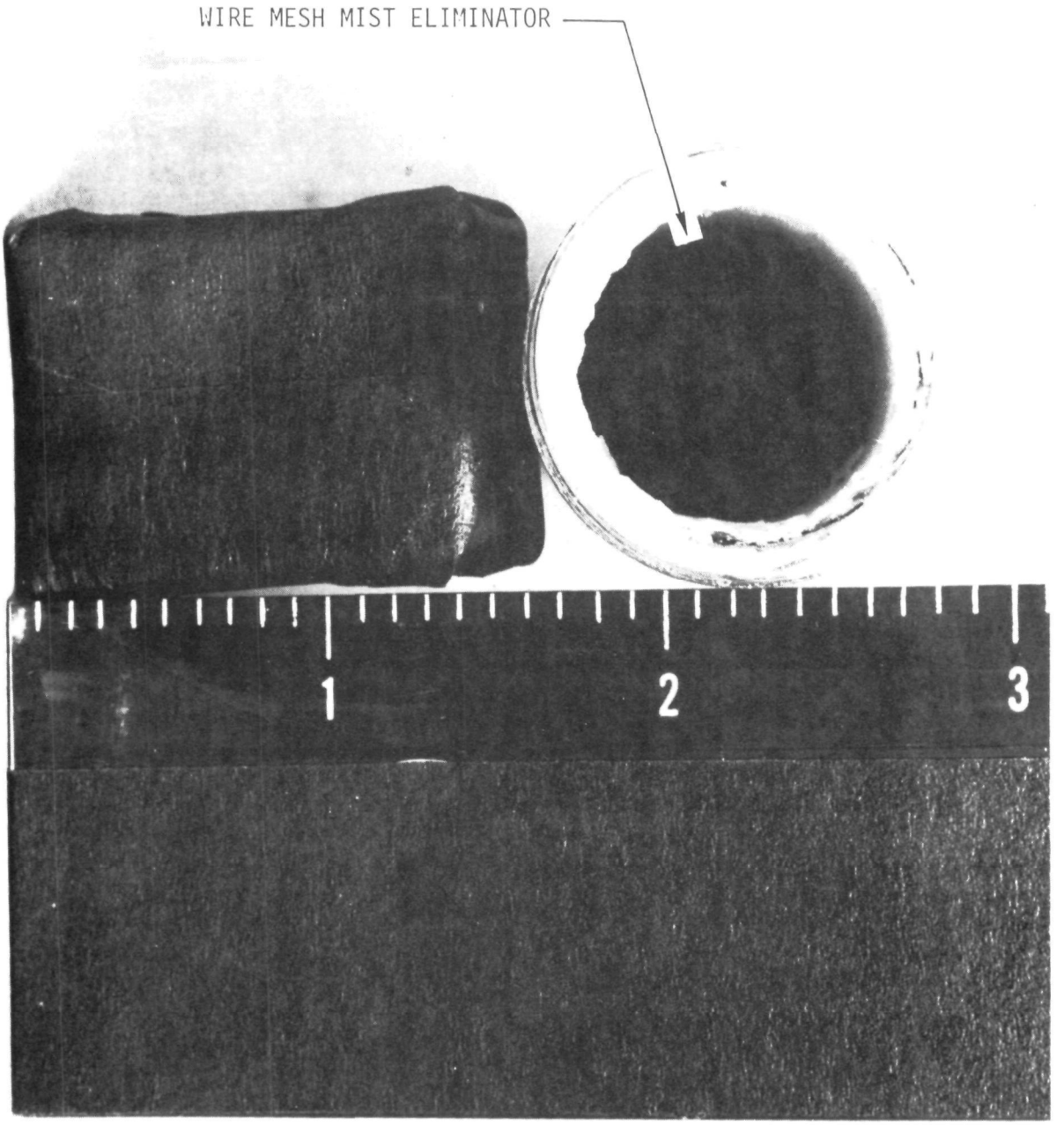

Figure 11. Mist Eliminator After Run Number 2

On startup, the LRU was seeded and the concentration level was increased to a concentration factor of about 70X. This concentration level was maintained for about 33 days to establish stable operation. Then the suspended solids level in the sump was increased slowly to about 250 g/l. At this suspended solids level, analysis of the solids indicated that the precipitating species included the double salt, Vanhoffite ($3Na_2SO_4 \cdot MgSO_4$). Although no immediate problems were encountered, the concentration factor was reduced because the long term effects of double salt formation are unknown. The concentration factors attained during the on-site demonstration are presented in Figure 12. The concentration factors are also presented in tabular form in Appendix C.

The feed to the evaporator was analyzed daily for total solids (TS) and a complete chemical analysis was performed weekly. Results of these analyses are presented in Figure 13 and Table 5, respectively. The analyses indicated that the feed is saturated with $CaSO_4$. The important chemical constituents in the feed were calcium sulfate ($CaSO_4$), silica (SiO_2), and bicarbonate ion (HCO_3^-). The calcium sulfate and silica are potential hard scale formers and require a scale control process when the feed is concentrated in the evaporator. The presence of the bicarbonate ion requires that acid pretreatment be used to permit deaeration and decarbonation in the deaerator for removal of non-condensible gases. During the test period the feed was acidified with sulfuric acid (H_2SO_4) in the feed tank where a scale inhibitor was also added. The pH of the feed was adjusted as necessary to produce a sump pH of 6.5 to 7.1. The feed was then preheated, deaerated and decarbonated prior to evaporation. When steady operating conditions were reached, the feed rate was approximately 265 cm^3/D (4.2 gpm).

The sump brine was analyzed several times daily for total dissolved solids (TDS) and suspended solids (SS). This data is presented in Figure 13. An analysis of the sump brine was performed each week during the test period. The results of these analyses are summarized in Table 6. The brine did exhibit a tendency to foam periodically during the test, but was

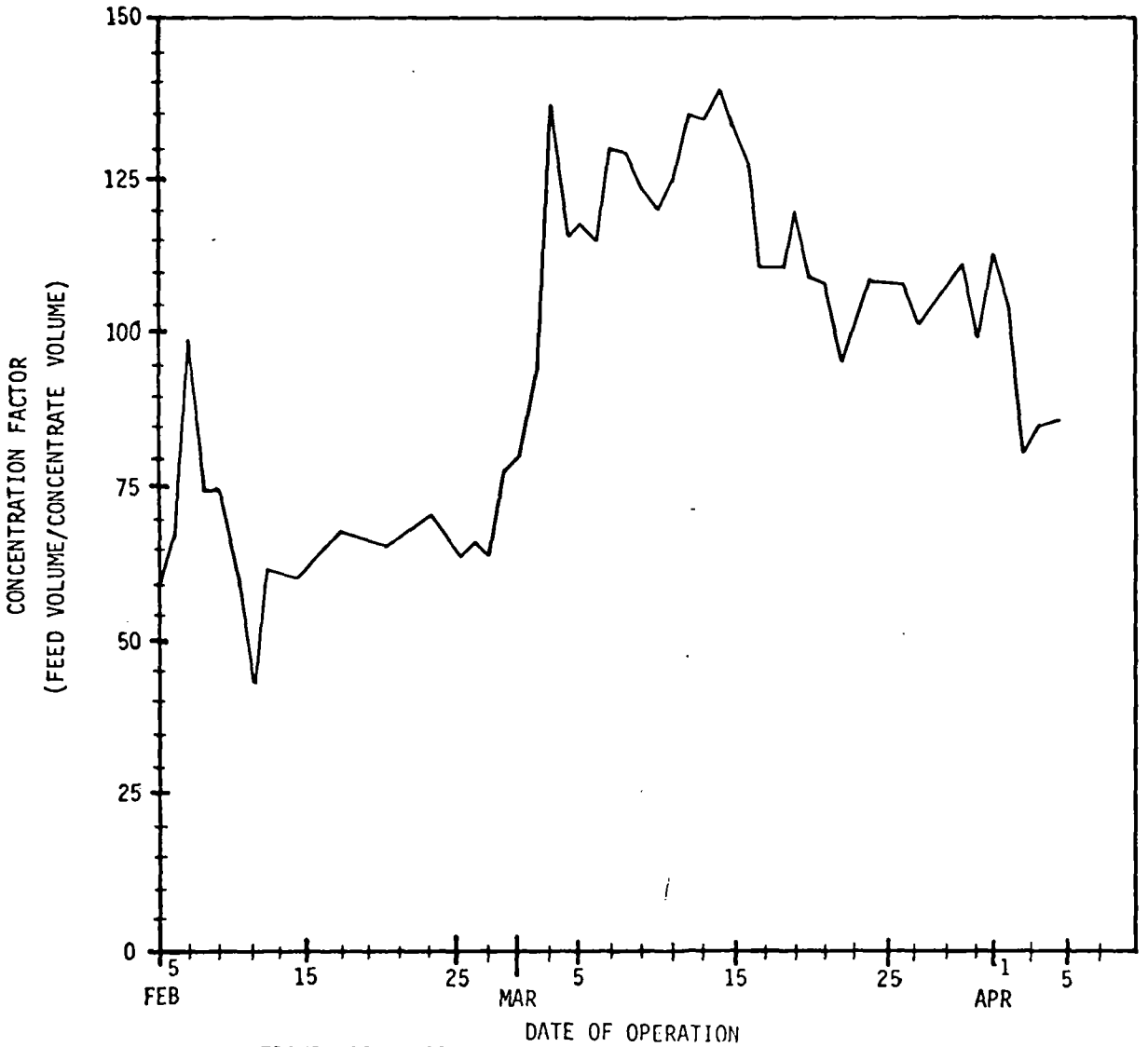

FIGURE 12: WASTE VOLUME REDUCTION DURING ON-SITE TEST

TABLE 5: Chemical and Physical Properties of Evaporator Feed

SAMPLE NO. DATE	1769 1/30	1771 1/31	1797 2/3	1807 2/7	1816 2/9	1820 2/11	1839 2/15	1850 2/18	1899 2/25	1917 3/4	1970 3/11	1997 3/18	2026 3/26
pH	7.45	7.35	7.90	7.59	6.95	7.3	7.00	6.45	6.38	6.5	7.2	6.15	6.4
SP. GR.	1.006	1.006	1.006	1.004	1.006	1.008	1.010	1.007	1.005	1.007	1.005	1.007	1.007
TDS (200°F)	4,700	4,830	4,920	4,360	4,520	4,440	4,270	4,350	4,060	3,990	4,100	3,790	4,300
TDS (900°F)	3,830	3,990	4,020	3,820	3,680	3,600	3,450	3,510	3,350	3,270	3,280	3,140	3 310
SS (mg/l)	10	10	11	12	12	12	8	10	12	TR.	0	0	0
Na (calc)	528	407	426	376	197	581	122	345	111	334	332	195	1,485
Ca (mg/l)	280	320	560	480	560	440	580	600	580	560	600	400	480
Mg "	316	316	316	292	292	170	243	231	207	122	170	194	292
Cl "	91	91	76	91	73	73	85	86	30	76	67	79	66
SO_4 "	2,835	2,754	3,330	2,900	2,750	2,800	2,450	2,900	2,349	2,430	2,390	2,106	3.645
HCO_3 "	85	110	73	85	73	49	49	67	61	49	85	37	49
SiO_2 "	12	12	14	14	17	15	15	14	16	15	14	9	9
Fe "	0.11	0.09	0	0.13	0	0.37	0.26	0.42	0	0.21	0.24	0.18	0.32
NO_3 "	277	256	256	256	256	256	246	256	277	256	328	389	410
F "	25	19	18	9	9	18	16	17	14	18	13	8	12
SO_3 "	0	0	0	0	0	0	0	0	0	0	0.5	1	4.5

TABLE 6: Chemical and Physical Properties of Sump Concentrate

SAMPLE NO. DATE	1770 1/30	1772 1/31	1798 2/3	1808 2/7	1816 2/9	1821 2/11	1840 2/15	1851 2/18	1900 2/25	1918 3/4	1971 3/11	1998 3/18	2027 3/26
Conc. Factor*	26	37	52	80	72	77	73	57	64	77	94	111	76
pH	4.95	4.93	6.30	6.70	6.70	6.60	6.70	6.75	6.95	6.59	6.45	6.40	6.88
Sp. Gr.	1.022	1.053	1.093	1.127	1.121	1.119	1.115	1.098	1.081	1.094	1.114	1.115	1.108
TDS (220°F)	20,880	41,040	119,500	166,750	166,200	150,650	142,550	133,200	113,000	129,550	162,300	164,700	153,150
TDS (900°F)	15,130	30,150	87,800	121,300	114,100	107,450	102,100	90,050	73,650	78,600	99,600	101,350	84,500
SS	102,930	137,628	136,332	182,040	157,170	192,030	175,998	116,846	147,126	178,992	222,638	254,856	214,874
B.P. (°C) @ kPa	99.8 99.8	99.9 99.8	100.6 100.3	101.1 100.3	101.0 99.9	100.8 99.9	100.2 99.5	100.2 99.4	100.3 100.3	100.0 99.5	100.0 99.3	99.9 99.4	99.8 98.4
Na (calc)	216	194	233	233	3,004	4,838	1,872	1,872	1,588	1,701	11,989	12,256	6,820
Ca (mg/l)	560	1,000	500	550	500	480	550	500	480	800	800	750	1,000
Mg "	2,381	4,374	18,529	21,080	22,478	20,048	19,258	19,470	13,498	14,197	19,562	18,377	19,076
Cl "	498	1,012	3,776	4,834	4,834	5,136	4,836	4,924	4,909	2,266	6,646	7,250	7,175
SO_4 "	10,530	21,465	70,000	78,750	90,000	83,750	75,000	75,574	51,250	58,663	65,813	57,713	55,688
HCO_3 "	37	61	98	171	122	98	98	134	134	134	159	195	207
SiO_2 "	125	200	325	79	81	82	86	87	72	79	77	26	37
F "			200	284	284	208		210	152	256	248	244	220
NO_3 "			19,680	29,725	27,470	28,495		26,445	24,395	31,160	37,517	41,410	33,825
SO_3 "			0					0	0	0	0	0	0
Fe "			0					0	1	0	0	0	0

* Based on Total Solids

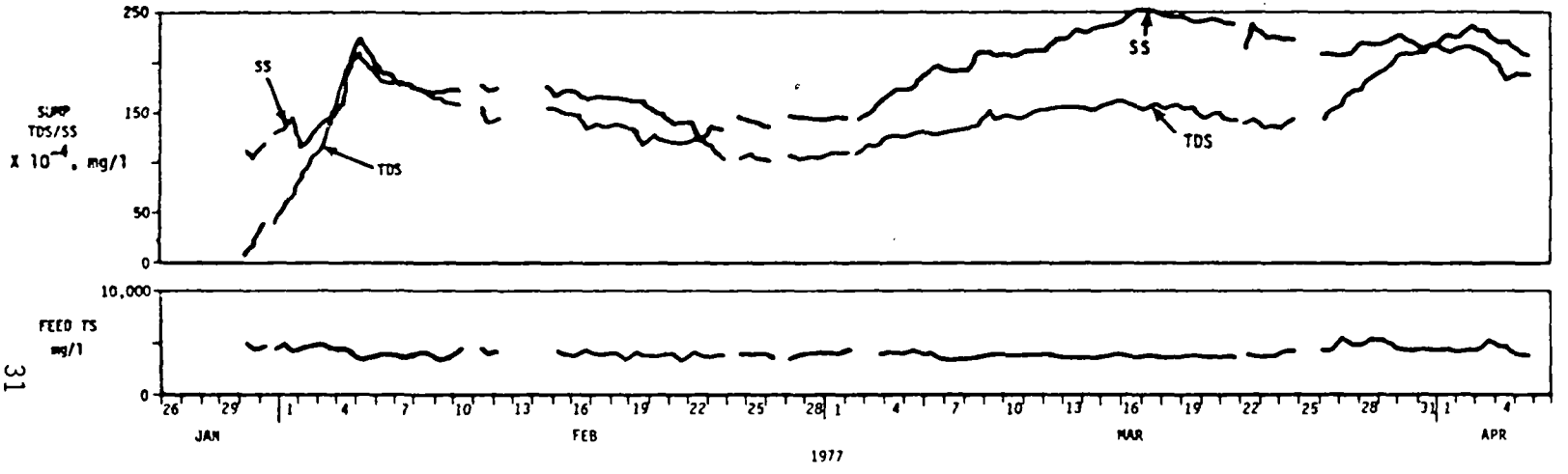

FIGURE 13: ON-SITE DEMONSTRATION TEST OPERATING DATA

easily eliminated with the intermittent use of an antifoaming agent. The distillate produced during the test was of excellent quality being generally in the range of 0.25 to 9.33 mg/l TDS. The specific conductance of the distillate remained below 16 micromhos/cm throughout the test program. Results of the distillate analyses are presented in Table 7.

The heat transfer data obtained during the on site tests is presented in Figure 14. The evaporator was operated at an average heat transfer delta T of 1.7^{o}C (3.0^{o}F). The heat transfer coefficient (U) varied from 3.29 to 5.11 kW/m^{2} ^{o}K (580 to 900 BTU/hr ft^{2} ^{o}F) and averaged about 4.15 kW/m^{2} ^{o}K (730 BTU/hr ft^{2} ^{o}F). The boiling point rise (B.P.R.) was between 0.8^{o}C (1.5^{o}F) and 1.8^{o}C (3.3^{o}F) throughout the testing.

Inspection of the evaporator at the completion of the test revealed a deposit on the evaporator sump walls and on the exterior of the inlet brine nozzles in the floodbox. The deposit was a result of the equipment shutdown procedure and was not caused by insufficient action of the scale control mechanism. The heat transfer tubes contained no detectable deposit.

TABLE 7: Properties of the Product Water From Evaporator

SAMPLE NO. DATE	pH	Spec. Cond. (μmhos/cm)	TDS @ 220°F mg/l
1822 2/11	8.00	9.529	3.70
1852 2/18	5.78	16.14	2.67
1901 2/25	7.20	5.417	4.33
1919 3/4	7.60	13.182	9.33
1972 3/11	7.60	11.770	3.33
1999 3/18	6.88	5.859	3.33
2028 3/26	5.70	5.650	0.25
2043 4/1	6.02	4.794	4.24

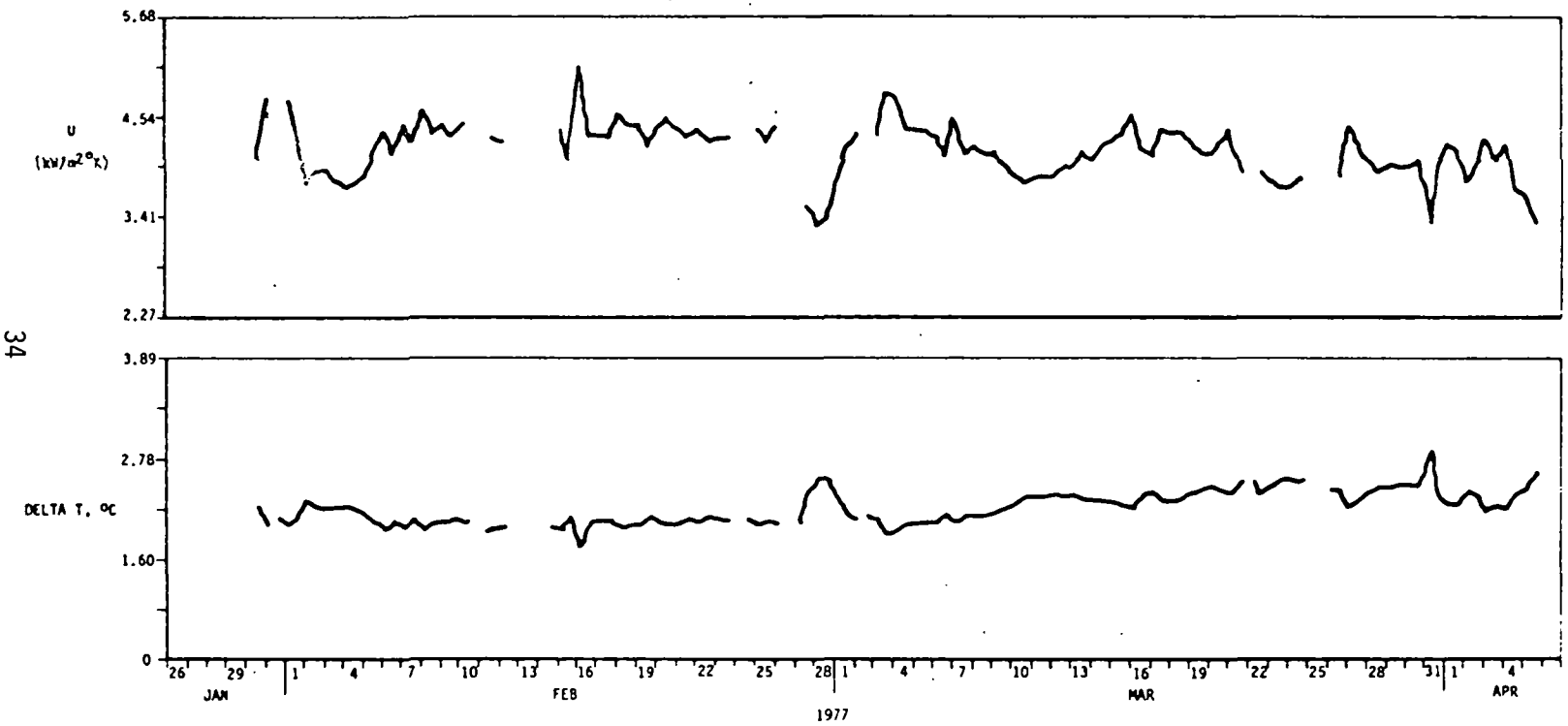

FIGURE 14: ON-SITE DEMONSTRATION TEST HEAT TRANSFER DATA

SECTION 5

DESIGN CONDITIONS FOR FULL SCALE SYSTEMS

The following design conditions for a process to concentrate the waste water from Chiyoda Flue Gas Scrubber have been established. These conditions are based on the results of the demonstration test program, information obtained from Chiyoda regarding the composition of the waste stream from their process and Resources Conservation Co.'s previous experience concentrating similar waste streams.

Feed Chemistry

The composition of the Chiyoda FGD Process waste stream to be concentrated in the full scale evaporator is presented in Table 8. At the Sneads facility, Chiyoda diluted the acidic waste water 2 1/2 times prior to neutralization to facilitate pumping. Therefore, to calculate the composition of the waste stream presented in Table 8, the acidic waste water was neutralized with limestone and corrected for the supersaturation of $CaSO_4$. The composition of the acidic waste was based on the operating experience of Chiyoda at Sneads.

Pretreatment Requirements

The feed must be acidified with sulfuric acid to a pH of 6 to aid in bicarbonate removal. Scale inhibitor (i.e. Nalco 345) must be added to the feed at a rate of 15 ppm to prevent fouling of the heat exchanger and deaerator. Antifoam agent (i.e. Dow Corning DB110) may be required periodically to control foaming.

Overall Heat Transfer Coefficient (U)

The overall heat transfer coefficient used to size the evaporator will be 3.18 $kW/m^2\ {}^oK$ (560 $BTU/hr\ ft^2\ {}^oF$). This value is based on the results

of the demonstration test program, interpretation of the test data with the Dückler[2] correlations for heat transfer in vertical tubes and previous experience of RCC with similar waste streams.[3]

Heat Transfer Delta T

The evaporator will operate at a heat transfer delta T of up to $5^{o}C$ ($9^{o}F$).

Concentration Factor

The nominal waste streams composition presented in Table 8 will be concentrated 112X. The range of concentration possible will be 44X to 122X depending on the waste stream composition. The waste volume will be reduced to about 1% of its initial volume. The composition of the concentrated waste stream from the evaporator is given in Table 9.

Energy Consumption

The predicted energy consumption for concentrating the nominal composition waste is 26.7 kWh/m^3 (101 kWh/1000 gal). The energy consumption will be 24.3 to 29.3 kWh/m^3 (92 to 111 kWh/1000 gal) over the range of expected waste compositions.

Distillate Quality

Water recovered from the Chiyoda waste stream will be excellent quality (less than 10 ppm TDS). This is sufficient quality for boiler make up, which results in a definite savings in demineralizer regeneration time and chemicals.

2) Dückler, A. E., "Fluid Mechanics and Heat Transfer in Vertical Falling-Film Systems", Chemical Engineering Progress Symposium Series, Vol.56, No.30.

3) H. Herrigel, T. Fosberg, W. Stickney and C. Perry, "Operating Data of a Vertical Plane Surface, Falling Film Evaporator Using Slurry and High Concentration Feeds", OSW Report 14-30-2939, Office of Saline Water, October 1972.

TABLE 8: Composition of Neutralized Chiyoda Waste Stream

ANALYSIS	NOMINAL CONCENTRATION	RANGE
Sodium	345 mg/l	220 - 1250
Calcium	530 "	390 - 586
Magnesium	370 "	243 - 991
Chloride	585 "	100 - 1212
Sulfate	2337 "	2088 - 4596
Silica	18 "	5 - 26
Nitrate	750 "	435 - 1652
Fluoride	15 "	9 - 25
Sulfite	8 "	0 - 13
TDS (calc.)	4958 "	3586 - 10251

TABLE 9: Composition of Concentrated Waste Stream from Evaporator

ANALYSIS	NOMINAL CONCENTRATION	RANGE
Sodium	54744 mg/l	26766 - 57684
Calcium	494 "	329 - 543
Magnesium	41440 "	29646 - 43604
Chloride	53328 "	12200 - 65520
Sulfate	120661 "	113931 - 161886
Silica	200 "	200
Nitrate	84000 "	53070 - 90100
Fluoride	1680 "	1100 - 1830
Sulfite	896 "	0 - 1586
TDS (calc.)	352354	237242 -369636

SECTION 6

ECONOMICS

This section presents an estimate of the capital and operating costs for providing full scale treatment of the flue gas desulfurization waste stream. A schematic of the waste treatment process is presented in Figure 15. The design conditions given in the previous section was used to properly size the required process equipment.

The capital and operating costs are presented in a manner that permits an estimate to be calculated for a range of waste water flowrates to the waste treatment process. Capital costs for the waste treatment process are presented in Figure 16. The capital cost includes all process equipment and accessories installed at the site, but does not include cost of land and buildings. The operating costs of the waste treatment process are presented in Figure 17. The operating costs are presented for treating the range of waste stream compositions given in the previous section. The operating costs include power at 2¢/kWh, maintenance materials, operation and maintenance labor and pretreatment chemicals. The amortization of capital is not included in the operating costs.

The operating cost of the FGD waste treatment process is somewhat lower when credit is given for the high quality water recovered from the waste stream. When the reclaimed water is used for boiler makeup, the operating costs of the boiler water polishing ion exchange system is significantly reduced. For example, when reclaimed water (less than 10 ppm TDS) replaces well water (500 ppm TDS), the operating cost of a 378.5 m^3/D (100,000 gpd), 2 bed ion exchange system with degasifier is reduced about \$0.40 to \$0.46/m^3 (\$1.50 to \$1.75/1000 gal).

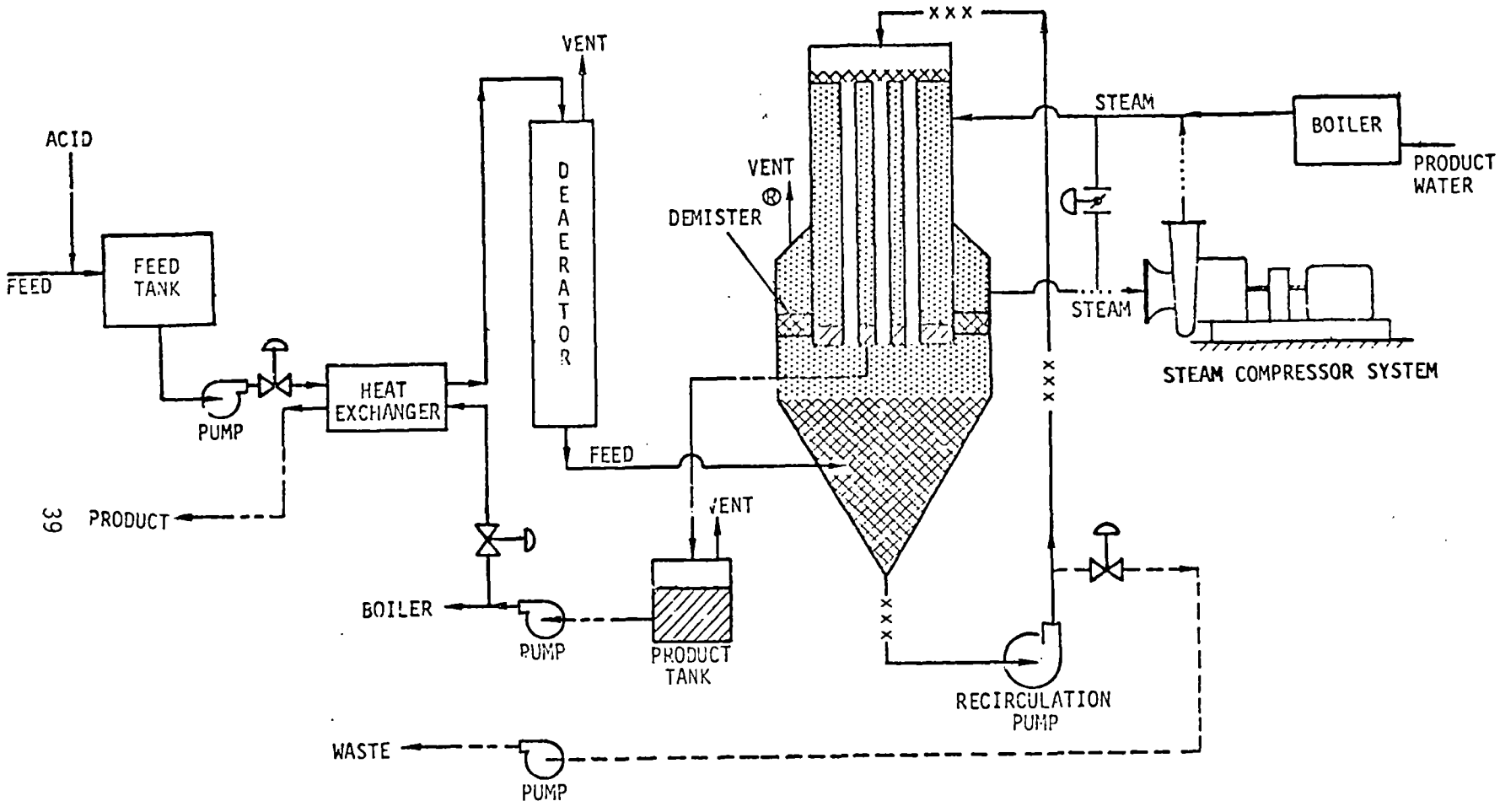

FIGURE 15: RCC BRINE CONCENTRATOR
PROCESS FLOW DIAGRAM - SCHEMATIC

PRODUCT
STEAM
FEED
RECIRCULATION BRINE
WASTE BRINE

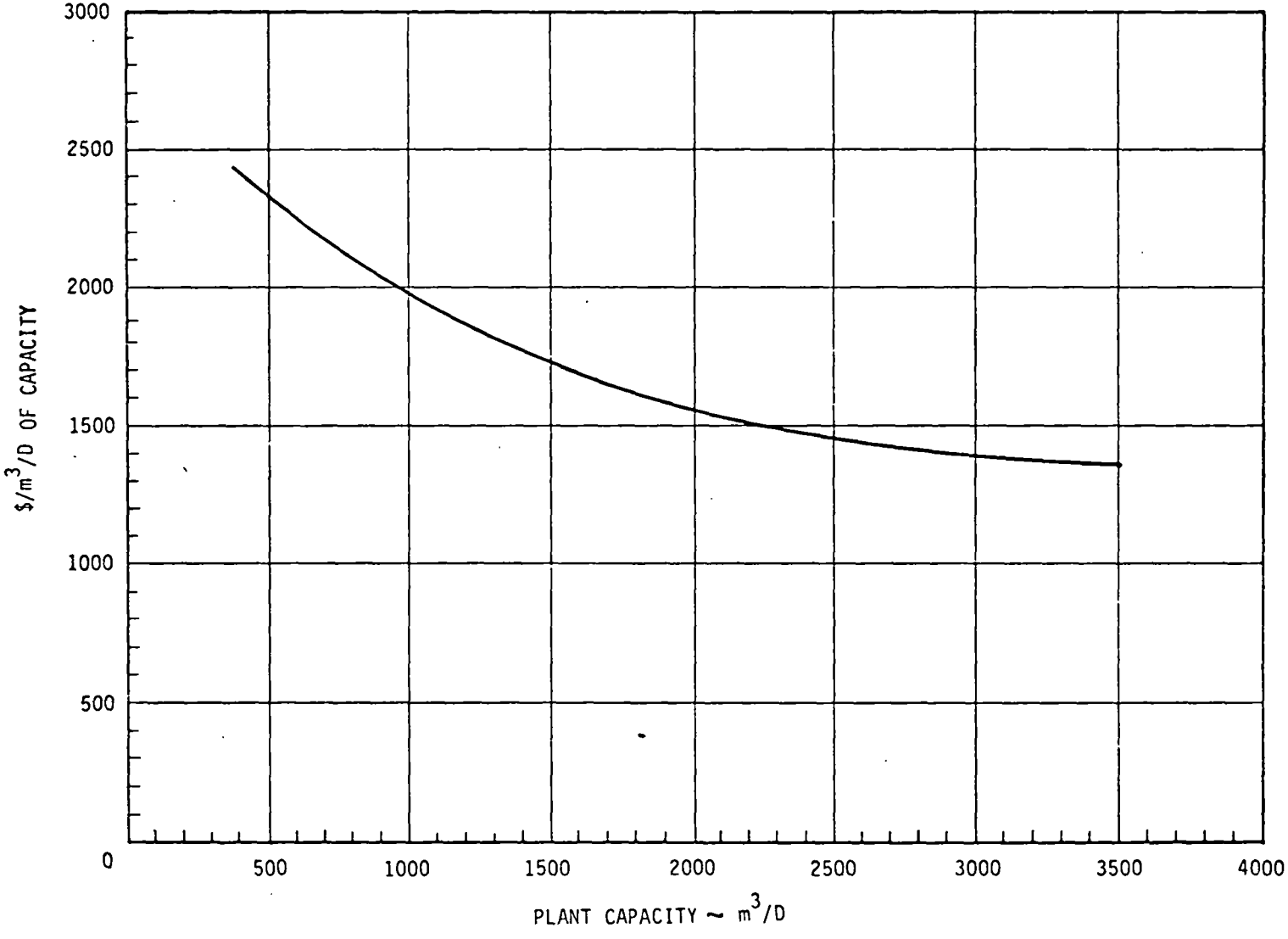

FIGURE 16: CAPITAL COST FOR WASTE TREATMENT SYSTEM

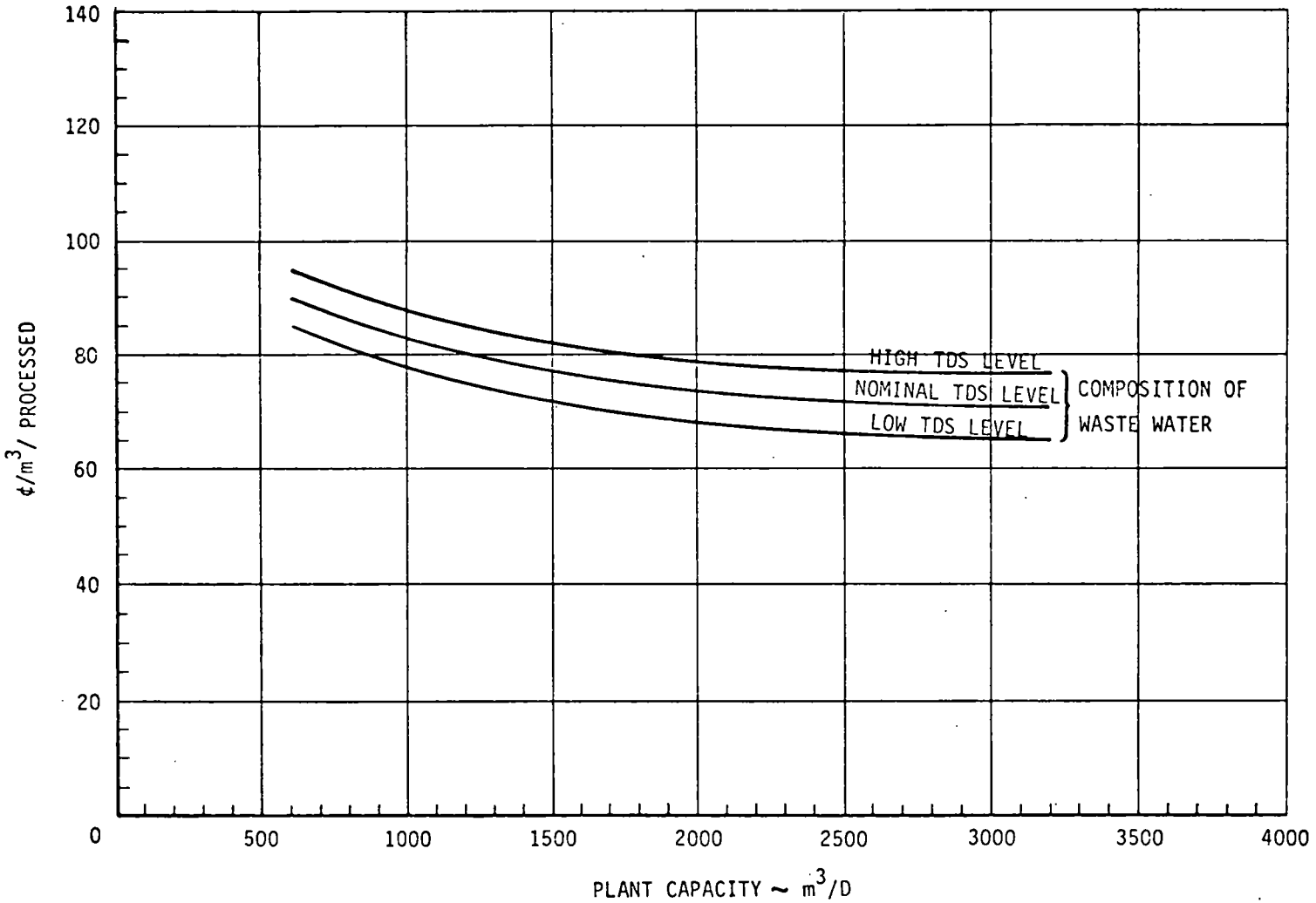

FIGURE 17 - OPERATING COST FOR WASTE TREATMENT SYSTEM

APPENDIX A: TEST EQUIPMENT

BENCH MODEL EVAPORATOR

The bench model testing was conducted using the RCC vertical flat plate, falling film, bench model test evaporator. Feed enters through a condensate/feed heat exchanger, steam heat exchanger and deaerator. Evaporation occurs as the concentrate flows in a film over the outer surfaces of a 15 cm wide x 92 cm high x 4 cm deep hollow panel which provides 0.186 m^2 of heat transfer surface area. The heat transfer surface thickness is 0.66 mm. Plant steam, fed to the inside of the panel through a pressure regulator, is used as the heat source for evaporation. The steam formed from evaporation of the concentrate is condensed and flows out of the system through the feed heat exchanger. View ports are provided for observation of the heat transfer panel during operation. The evaporator body, piping and heat transfer panel are constructed of Type 316 stainless steel.

Controls are provided for automatic operation of the unit. The control system consists of a level controller which provides on-off control of the feed pump. Also, a timer-operated valve is provided to control the discharge rate of concentrate and thereby maintain sump concentration.

Feed and evaporator temperatures are continuously monitored on a multipoint recorder. A calibrated thermometer is installed in the sump to measure the boiling point of the concentrate. Pressures are measured periodically with water manometers and gauges. Total dissolved solids are determined by weighing samples and drying at 104.4^{o}C (220°F).

The flat plate evaporator was selected for this test since the heat transfer surface is exposed for inspection during test operation. The fluid film which is formed on the flat surface has essentially the same flow characteristics as the vertical tubes used in RCC evaporator and thus gives heat transfer and process data applicable to the commercial plant.

LABORATORY RESEARCH UNIT

The on-site demonstration tests were conducted with the RCC Laboratory Research Unit (LRU). The LRU is a 22.7 m^3/D (6000 gal/D) vertical tube, falling film, vapor compression, pilot evaporator, designed to simulate the operation of a commercial size RCC unit. The LRU is fully instrumented to measure and record process data. Level and pressure controls permit automatic, unattended operation. Materials of construction include 304 stainless steel tubes, 316 stainless steel sump, titanium feed heat exchangers, and fiberglas and 316 stainless steel piping.

The waste to be processed is fed through feed filters to the feed tank. Sulfuric acid is added for bicarbonate ion removal. The feed tank provides a short residence time for complete acidification before the feed is pumped to the heat exchangers where its temperature is raised close to boiling. From there it is fed to an electrically heated hot surge tank where the feed is raised to slightly above its boiling temperature. The feed then enters the deaerator, flashes to remove non-condensibles and is then fed to the evaporator sump where it is concentrated.

The concentrated brine slurry in the sump is recirculated down the inside of the condenser tubes in a thin film with a small amount evaporated as steam. This steam is collected and then compressed to raise its temperature of condensation slightly above the boiling point of the brine on the inside of the tubes. The steam condenses on the outside of the tubes and causes more steam to be evaporated from the brine inside the tubes. The condensate is collected as product water and pumped back through the heat exchanger to recover its heat.

The small concentrated slurry waste stream is taken from the recirculation line and is discharged periodically through a timer operated control valve.

Scale control is accomplished by utilizing a seed slurry method which prevents scale deposition on metal surfaces by providing preferential sites within the waste brine for crystal growth.

APPENDIX B: CHIYODA WASTE WATER CHEMISTRY

TABLE B1 CHIYODA LIQUID PURGE SETTLING POND OVERFLOW ANALYSIS
DETERMINED CONCENTRATION (mg/l)

PARAMETER / DATE	7/17/75	8/25/75	9/29/75	10/27/75	11/18/75	12/22/75	1/26/76	2/23/76	3/29/76	4/26/76	5/26/76
TDS	4640	2000	3860	4670	4994	4338	8180		5640	4580	6730
TSS	6	6	393	9	88	238	826		19	17	7
pH (on site)	2.31	2.60	4.10	7.53	6.75	4.55	10.80		6.75	3.88	6.22
Temperature ^{o}C	20	26	16	24	21	18	18		18	20	24
Total Calcium as Ca	750	330	675	860	1100	726	614		996	370	426
Total Magnesium as Mg	140	39	83	182	144	246	90		300	142	172
Total Sodium as Na	64.0	58	65	34	50	28	2320		164	616	1270
Total Potassium as K	2.93	0.85	2.4	1.0	2.8	2.3	13		4.6	5.4	14
Total Hardness as $CaCO_3$	2670	1093	2055	2900	3360	2871	1920		3740	1542	1780
Total Phosphorus as P	0.036	<0.01	<0.01	<0.01	0.01	<0.01	0.014		0.015	0.026	0.020
Dissolved Silica as SiO_2	30.8	22	16	12	22	24	3.4	NO FLOW	20	20	15
Sulfate as SO_4	2750	1160	1910	2570	2460	2008	3590		2500	2600	3900
Sulfite as SO_3	<1	<1	<1	<1	<1	<1	22.4		<1	<1	0
Carbonate as $CaCO_3$	0	0	0	0	0	0	965		0	0	0
Bicarbonate as $CaCO_3$	0	0	3.3	38	8.1	0	566		25	0	9.5
Hydroxide as $CaCO_3$	0	0	0	0	0	0	0		0	0	0
Chloride as Cl	138	55	75	51	77	97	168		460	182	213

TABLE B1 CHIYODA LIQUID PURGE SETTLING POND OVERFLOW ANALYSIS (cont'd)
DETERMINED CONCENTRATION (mg/l)

PARAMETER / DATE	7/17/75	8/25/75	9/29/75	10/27/75	11/18/75	12/22/75	1/26/76	2/23/76	3/29/76	4/26/76	5/26/76
Total Aluminum as Al	4.16	3.5	2.1	0.88	3.4	4.8	0.88		2.1	3.4	1.7
Total Arsenic as As	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01
Boron as B	4.6	1.0	2.0	2.5	3.8	3.0	2.9		3.8	6.0	3.9
Total Cadmium as Cd	-	-	-	-	<0.01	<0.01	<0.01		<0.01	0.012	<0.01
Total Chromium as Cr	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01
Total Copper as Cu	0.06	0.16	0.076	0.064	0.14	0.30	0.11		0.044	0.24	0.083
Total Iron as Fe	109.0	50	7.9	2.5	0.54	8.6	6.8		0.90	7.1	0.45
Total Lead as Pb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01
Total Manganese as Mn	0.68	0.17	0.44	0.56	0.65	1.08	0.21	NO FLOW	1.2	0.77	0.74
Total Mercury as Mg	0.0068	0.0022	0.0014	<0.0002	<0.0002	0.0006	0.0018		<0.0002	<0.0020	0.0005
Total Nickel as Ni	0.10	0.020	0.10	0.020	0.042	0.15	0.078		0.16	0.16	0.067
Total Selenium as Se	0.083	0.016	0.033	0.036	0.070	0.13	0.58		0.10	0.045	0.026
Total Zinc as Zn	1.3	0.26	0.67	0.26	0.67	1.1	0.089		0.74	0.53	0.39
Oil and Grease	<1	<1	<1	<1	<1	<1	<1		<1	<1	<1
Nitrate as N	76	20	45	87	102	105	27		115	72	68
Chemical Oxygen Demand, (COD)	11	<1	4.4	<1	6	5.7	23		20	22	15

TABLE B1 CHIYODA LIQUID PURGE SETTLING POND OVERFLOW ANALYSIS (cont'd)
DETERMINED CONCENTRATION (mg/l)

PARAMETER / DATE	7/17/75	8/25/75	9/29/75	10/27/75	11/18/75	12/22/75	1/26/76	2/23/76	3/29/76	4/26/76	5/26/76
Carbon Dioxide as CO_2	970	466	50	25	28	62	0	NO FLOW	32	46	20
Total Acidity as $CaCO_3$	1080	432	51	0	20	64	0		0	61	21
Color as Pt. Co. Units (True)	6	13	13	3	0.5	3	2		0.5	1	0.5
Turbidity as NTU's	12	4.2	92	16	11	65	450		21	21	4.5
Fluoride as F	27	4.2	16	16	26	26	12.1		20	8.2	10

TABLE B2 CHIYODA PRESCRUBBER BLOWDOWN ANALYSIS

Date	H_2SO_4 %	Cl^- (ppm)	Total Fe (ppm)	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (ppm)	Specific Gravity
3/4/75		885.1								
3/5/75	0.09	3130.								
3/5/75	0.13	1547.								
3/5/75	0.06	1446.								
3/6/75	0.04	1284.						337.9		
3/6/75	0.05	1671.						261.		
3/7/75	0.06	2431.								
3/7/75		914.8								
3/8/75		470.6								
3/8/75		1198.								
3/9/75		1246.								
3/10/75	0.14	1166.						25.		
3/10/75	0.02	275.9						18.		
3/11/75	0.10	575.3						20.		
3/11/75	0.00	368.9						15.		
3/20/75		224.1	2.92		57.97					
3/27/75	0.08	465.4								
3/28/75	0.07	425.8		3.1	49.6					
3/30/75	0.07	501.9								
3/31/75	0.09	556.6								
4/1/75	0.08	734.								
4/1/75	0.11	991.6								
4/2/75	0.08	769.5								
4/3/75	0.08	628.6								
4/15/75	0.10	591.								
4/16/75	0.05	552.6								
4/17/75	0.03	449.			68.2					
4/18/75	0.08	586.0								
4/21/75	0.01	1061.			57.4			294.		
4/22/75	0.00	17.24								
4/23/75	0.00	22.31								
5/12/75	0.00	19.3								

End Start-up

TABLE B2 CHIYODA PRESCRUBBER BLOWDOWN ANALYSIS (cont'd)

Date	H_2SO_4 %	Cl^- (ppm)	Total Fe (ppm)	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (ppm)	Specific Gravity
Begin Test Schedule										
5/13/75	0.08	763.4								
5/14/75		573.8						1586.		
5/15/75	0.09	509.9								
5/17/75	0.21	1191.								
5/20/75		1239.								
5/21/75	0.22	1007.								
6/2/75	0.22	662.1								
6/3/75		255.5						509.		
6/4/75	0.00	35.49								
6/5/75		233.2				75.	24.7			
6/6/75	0.10	624.5						20.		
6/9/75	0.09	221.0		3.1	79.36					
6/10/75		185.5						71.		
6/11/75	0.20	599.2	18.5							
6/12/75		248.4				52.6				
6/13/75	0.08	579.9								
6/16/75	0.05	407.0								
6/17/75		675.1						5.		
6/18/75	0.06	321.3								
6/19/75		404.1				87.2				
6/20/75	0.08	1113.						2194.		
6/23/75	0.13	688.9		0.0	88.04					
6/24/75		859.4						17.	3944	
6/25/75	0.05	249.3								
6/26/75		231.6				54.2				
6/27/75	0.10	223.7								

TABLE B2 CHIYODA PRESCRUBBER BLOWDOWN ANALYSIS (cont'd)

Date	H_2SO_4 %	Cl^- (ppm)	Total Fe (ppm)	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (ppm)	Specific Gravity
7/2/75	0.05	400.1								
7/3/75	0.08	242.4								
7/7/75	0.06	53.22								
7/10/75	0.36	1251.								
7/11/75	0.25	916.5								
7/14/75	0.10	346.9		6.2	80.6					
7/15/75		417.9						16.	2388.	
7/16/75	0.10	481.9	Undetectable							
7/17/75		688.9				75.0	28.2			
7/18/75	0.10	615.0						0.	2784.	
7/21/75	0.03	463.2								
7/22/75		31.54								
7/23/75	0.19	675.1								
7/24/75		264.1				65.				
7/25/75	0.10	462.2								
7/28/75	0.00	46.32								
7/30/75	0.16	467.1								
7/31/75	0.07	260.2								
8/1/75	0.08	520.3								
9/16/75	0.15	187.2								
9/17/75	0.13	184.3								
9/18/75	0.13	173.4								
9/19/75	0.14	250.3								
9/22/75	0.12	208.9								
9/23/75		188.1						177.		
9/26/75	0.13	198.6						170.		
9/29/75	0.06	172.0								
9/30/75		136.8						148.		

TABLE B2 CHIYODA PRESCRUBBER BLOWDOWN ANALYSIS (cont'd)

Date	H_2SO_4 %	Cl^- (ppm)	Total Fe (ppm)	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (ppm)	Specific Gravity
10/1/75	0.07	183.4								
10/2/75		252.7								
10/3/75	0.08	240.4								
10/6/75	0.12	261.3								
10/7/75		267.9								
10/8/75	0.09	140.0								
10/9/75		178.6								
10/9/75	0.11									
10/14/75	0.03	165.3								
10/15/75	0.06	134.9								
10/16/75		161.5								
10/17/75	0.14	246.0								
10/20/75	0.21	342.0								
10/20/75	0.24	461.7								
10/21/75	0.08	184.3								
10/21/75	0.16	238.5								
10/22/75	0.09	249.9								
10/22/75	0.08	214.7								
10/23/75	0.08	237.5								
10/23/75	0.08	242.0								
10/24/75	0.10	225.6								
10/24/75	0.05	154.3								
10/27/75	0.10	174.5								
10/27/75	0.06	141.7								
10/28/75	0.07	176.5								
10/28/75	0.03	199.5								
10/29/75	0.05	244.9								
10/29/75	0.03	256.5								
10/30/75	0.09	260.3								
10/30/75	0.07	282.5								
10/31/75	0.06	333.6								

TABLE B2 CHIYODA PRESCRUBBER BLOWDOWN ANALYSIS (cont'd)

Date	H_2SO_4 %	Cl^- (ppm)	Total Fe (ppm)	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (ppm)	Specific Gravity
11/3/75	0.03	211.2								
11/4/75	0.06	288.3								
11/5/75	0.04	295.1								
11/6/75	0.04	319.2								
11/7/75	0.12	424.3								
11/10/75	0.06	198.6								0.994
11/11/75	0.18	485.0						28.		0.993
11/12/75	0.19	358.7								0.992
11/13/75	0.06	370.3								0.991
11/14/75		388.6								0.992
11/17/75	0.17	373.2								0.992
11/18/75	0.14	443.5								0.993
11/19/75		413.7								
11/20/75	0.14	310.5								
11/21/75	0.13	318.2								0.990
12/1/75	0.08	350.0								
12/2/75		281.6								
12/3/75	0.05	257.5								
12/4/75		163.9								
12/5/75	0.05	185.1								
12/8/75	0.04	157.2								
12/10/75	0.05	251.7								
12/11/75		405.0								
12/12/75	0.06	300.8								
12/15/75	0.15	489.8								
12/16/75	0.15	650.4								
12/16/75	0.15	650.4								
12/23/75	0.14	432.0								
12/30/75	0.07	498.5								

TABLE B2 CHIYODA PRESCRUBBER BLOWDOWN ANALYSIS (cont'd)

Date	H_2SO_4 %	Cl^- (ppm)	Total Fe (ppm)	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (ppm)	Specific Gravity
1/2/76	0.11	551.5								
1/5/76	0.07	481.1								
1/9/76	0.15	1161.								
1/12/76	0.12	580.5								
1/14/76	0.16	570.8								
1/19/76	0.09	340.4								
2/26/76	0.38	588.2								
2/27/76	0.36	986.4								
3/1/76	0.32	1164.								
3/2/76	0.11	568.9								
3/3/76	0.16	820.6								
3/5/76	0.24	1667.						0.0		
3/8/76	0.25	1465.								
3/10/76	0.22	898.7								
3/12/76	0.07	237.2								
3/15/76	0.14	815.7								
3/17/76	0.13	3216.								
3/22/76	0.08	333.6								
3/24/76	0.10	1850.								
3/26/76	0.09	343.3						0.0		
3/29/76	0.00	1813.								
3/31/76	0.06	2126.								
4/2/76	0.03	1475.						577.0		

TABLE B3 CHIYODA MOTHER LIQUOR ANALYSIS

Date	H_2SO_4 %	Cl^- (ppm)	Fe^{+++}	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (ppm)	Specific Gravity
3/3/75	2.1	85.2								
3/7/75	1.93	132.8	2416.							
3/7/75	1.9									
3/8/75	1.88									
3/8/75	1.74									
3/10/75	1.71	153.2	2425.							
3/10/75	1.65									
3/11/75	1.57									
3/11/75	1.52									
3/11/75	1.30									
3/12/75	1.08									
3/25/75	--	140.5	2450.							
3/28/75	1.26									
3/30/75	1.77									
3/31/75	1.79									
4/1/75	1.79									
4/1/75	1.66									
4/2/75	1.58									
4/3/75	1.83									
4/14/75	0.98	141.1			663.4					
4/15/75	0.47									
4/16/75	0.96									
4/17/75	1.04									
4/18/75	1.11									
4/21/75	1.21									
4/22/75	0.89									
4/23/75	0.85									
5/12/75	0.90									

End Start-Up

TABLE B3 CHIYODA MOTHER LIQUOR ANALYSIS (cont'd)

Date	H_2SO_4 %	Cl^- (ppm)	Fe^{+++}	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (ppm)	Specific Gravity
Begin Test Schedule										
5/13/75	0.96	136.3	1880.							
5/14/75	1.40					904.	381.			
5/15/75	1.10									
5/16/75	1.43	124.3				837.	380.			
5/19/75	1.19	112.9	1754.							
5/20/75	1.17									
5/21/75	1.09									
6/2/75	0.97	103.4	1554.							
6/3/75	0.78					743.	228.			
6/4/75	1.10									
6/5/75	0.45	88.41				870.	289.			
6/6/75	1.25		1539.							
6/9/75	1.58	86.58	1637.							
6/10/75	1.49					975.	564.			
6/11/75	1.29									
6/12/75	1.20	79.69				1110.	496.			
6/13/75	0.92		1800.							
6/16/75	0.59	79.83	2056.							
6/17/75	0.85					782.	661.			
6/18/75	1.22									
6/19/75	1.32	80.02				830.	755.			
6/20/75	1.18		2191.							
6/23/75	1.10	80.42	2277.							
6/24/75	1.14					870.	896.		31548.	
6/25/75	1.34									
6/26/75	1.33	78.45				875.	872.			
6/27/75	1.34		2351.							
7/2/75	1.10									

TABLE B3 CHIYODA MOTHER LIQUOR ANALYSIS (cont'd)

Date	H_2SO_4 %	Cl^- (ppm)	Fe^{+++}	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (ppm)	Specific Gravity
7/3/75	0.95									
7/7/75	1.10	74.11	2223.							
7/10/75	0.77									
7/11/75	1.51					708.	729.			
7/14/75	1.82	64.06	2183.							
7/15/75	2.44					860.	628.			
7/16/75	2.89									
7/17/75	3.13	74.50				1160.	610.			
7/18/75	2.91		2138.							
7/21/75	0.75	81.01	2149.							
7/22/75	0.39					1007.	779.			
7/23/75	0.67									
7/24/75	0.90	77.86				1000.	693.			
7/25/75	1.11		2384.							
7/28/75	2.55	48.49	2195.							
7/30/75	2.43									
7/31/75	2.66									
8/1/75	3.09									
8/6/75	3.25		1816.							
8/8/75			2435.							
9/15/75	1.74		2550.							
9/16/75	1.26									
9/17/75	1.70									
9/18/75	1.93									
9/19/75	2.31									
9/22/75	1.34		2114.							
9/23/75	1.92					884.	506.			
9/26/75	1.63		1977.							
9/29/75	1.37		1914.			890.	715.			
9/30/75	1.34									

TABLE B3 CHIYODA MOTHER LIQUOR ANALYSIS (cont'd)

Date	H_2SO_4 %	Cl^- (ppm)	Fe^{+++}	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (ppm)	Specific Gravity
10/1/75	1.31					812.	728.			
10/2/75	1.05									
10/3/75	0.90									
10/6/75	0.97		2074.			750.	830.			
10/7/75	0.99									
10/8/75	1.08					805.	911.			
10/9/75	1.07									
10/14/75	0.66									
10/15/75	0.72									
10/16/75	0.90					915.	672.			
10/17/75	0.95		2223.							
10/20/75	0.79		2258.							
10/21/75	0.87					865.				
10/22/75	0.78									
10/23/75	0.80					882.				
10/24/75	0.86									
10/27/75	1.03									
10/28/75	1.10					950.				
10/29/75	1.13									
10/30/75	1.03					905.				
10/31/75	0.99									
11/3/75	0.93									
11/4/75	0.89									
11/5/75	1.00									
11/6/75	0.96									
11/7/75	0.73									
11/10/75	1.29		2166.							1.021
11/11/75	1.45					1060.	481.			1.022
11/12/75	1.33									1.020
11/13/75	1.45									1.020

TABLE B3 CHIYODA MOTHER LIQUOR ANALYSIS (cont'd)

Date	H_2SO_4 %	Cl^- (ppm)	Fe^{+++}	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (ppm)	Specific Gravity
11/14/75	1.21					1004.	681.			1.020
11/17/75	1.17		2172.							1.020
11/18/75	1.31									
11/19/75	1.11					975.	570.			
11/20/75	1.20									1.019
11/21/75	1.04									
12/1/75	1.32	41.66	2212.							
12/2/75	1.66					1040.	760.			
12/3/75	1.58									
12/4/75	1.54					1040.	841.			
12/5/75	1.43		2532.							
12/8/75	1.19		2550.							
12/10/75	1.09									
12/11/75	1.09					922.	829.			
12/12/75	1.22		2212.							
12/15/75	1.03									
12.16/75	1.07									
12/23/75	1.84									
12/30/75	0.31									
1/2/76	0.25									
1/5/76	0.62									
1/9/76	0.45									
1/12/76	0.46									
1/14/76	0.41									
1/19/76	0.42									
2/26/76	0.43									
2/27/76	0.91									
3/1/76	0.79									
3/3/76	0.50									

TABLE B3 CHIYODA MOTHER LIQUOR ANALYSIS (cont'd)

Date	H_2SO_4 %	Cl^- (ppm)	Fe^{+++}	NH_4^+ (ppm)	NO_x^- (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Suspended Solids (ppm)	Total Dissolved Solids (PPM)	Specific Gravity
3/5/76	0.46									
3/8/76	0.06		1891.							
3/9/76	0.93		2435.							
3/10/76	0.73		2361.							
3/11/76	0.97		2493.							
3/12/76	0.63									
3/15/76	0.71									
3/16/76	0.49									
3/17/76	0.35									
3/18/76	0.28									
3/22/76	0.65									
3/23/76	0.33									
3/24/76	1.32									
3/25/76	0.99									
3/26/76	0.26									
3/29/76	0.39									
3/30/76	0.49									
3/31/76	0.65									
4/1/76	0.50									
4/2/76	1.09									

APPENDIX C

Waste Volume Reduction During On-Site Tests

DATE	CONCENTRATE RATE (gpm)	FEED RATE (gpm)	CONCENTRATION FACTOR (based on volume)
2/5/77	0.072	3.90	54
2/6/77	0.060	4.05	67
2/7/77	0.043	4.20	98
2/8/77	0.057	4.20	74
2/9/77	0.056	4.15	74
2/10/77	0.067	3.90	58
2/11/77	0.106	4.20	60
2/12/77	0.065	4.00	62
2/13/77	---	---	--
2/14/77	0.065	4.00	61
2/15/77	0.063	3.95	63
2/16/77	0.062	4.00	65
2/17/77	0.062	4.15	67
2/18/77	0.06	4.05	66
2/19/77	0.061	4.00	66
2/20/77	0.064	4.15	65
2/21/77	0.060	4.00	67
2/22/77	0.061	4.15	68
2/23/77	0.059	4.20	71
2/24/77	---	---	--
2/25/77	0.864	4.10	64
2/26/77	0.064	4.20	66
2/27/77	0.064	4.10	64
2/28/77	0.054	4.20	78
3/1/77	0.052	4.15	80
3/2/77	0.044	4.20	95
3/3/77	0.030	4.10	137

APPENDIX C
(cont'd)

DATE	CONCENTRATE RATE (gpm)	FEED RATE (gpm)	CONCENTRATION FACTOR (based on volume)
3/4/77	0.035	4.05	116
3/5/77	0.034	4.00	118
3/6/77	0.036	4.15	115
3/7/77	0.032	4.15	130
3/8/77	0.031	4.00	129
3/9/77	0.033	4.05	123
3/10/77	0.035	4.25	121
3/11/77	0.034	4.25	125
3/12/77	0.033	4.45	135
3/13/77	0.034	4.55	134
3/14/77	0.032	4.45	139
3/15/77	0.035	4.65	133
3/16/77	0.037	4.70	127
3/18/77	0.042	4.70	112
3/18/77	0.040	4.80	120
3/18/77	0.043	4.80	112
3/19/77	0.040	4.80	120
3/20/77	0.044	4.80	109
3/21/77	0.045	4.85	108
3/22/77	0.047	4.50	96
3/23/77	0.044	4.55	103
3/24/77	0.043	4.65	108
3/25/77	---	---	---
3/26/77	0.042	4.50	107
3/27/77	0.045	4.60	102
3/28/77	0.044	4.60	105
3/29/77	0.045	4.80	107

APPENDIX C
(cont'd)

DATE	CONCENTRATE RATE (gpm)	FEED RATE (gpm)	CONCENTRATION FACTOR (based on volume)
3/30/77	0.043	4.80	112
3/31/77	0.048	4.80	100
4/1/77	0.039	4.40	113
4/2/77	0.043	4.50	105
4/3/77	0.053	4.30	81
4/4/77	0.053	4.50	85
4/5/77	0.052	4.50	86

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

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4. TITLE AND SUBTITLE Effective Control of Secondary Water Pollution from Flue Gas Desulfurization Systems		5. REPORT DATE September 1977
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7. AUTHOR(S) Lanny D. Weimer		8. PERFORMING ORGANIZATION REPORT NO.
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15. SUPPLEMENTARY NOTES IERL-RTP project officer for this report is Fredrick A. Roberts, Environmental Research Laboratory, Corvallis OR 97330 (420-4715).

16. ABSTRACT The report describes tests to demonstrate the feasibility of using a vertical-tube, falling-film, vapor-compression evaporator to concentrate waste water from a flue gas desulfurization (FGD) process. Tests showed that waste water from the Chiyoda FGD process can be concentrated up to 140 times and with recovery of more than 99% of the waste stream as high quality water (< 10 ppm TDS). Two series of tests were conducted: one with a 25 gpd bench model evaporator; the other with a 6000 gpd pilot size evaporator. Process conditions were identified and verified for scale free operation. Heat transfer coefficients of 500-750 Btu/hr-sq ft-°F were consistently achieved throughout the tests. A conceptual design and economic study of a full size treatment facility showed that capital costs will range from $5110 to $8706/1000 gpd of waste water processed, depending on system capacity. Operating costs will vary from $2.46 to $3.60/1000 gal. of waste water processed, depending on system capacity and waste water composition. Some credit can be taken for savings on boiler makeup water treatment costs by providing the high quality distillate to that process.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Waste Water	Stationary Sources	
Water Treatment	Chiyoda Process	
Flue Gases		21B
Desulfurization		07A,07D
Distillation		13H

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