LBL-8558

DEVELOPMENT OF DIRECT CONTACT HEAT EXCHANGERS FOR GEOTHERMAL BRINES

Final Report for Eight (8) Month Period
October 4, 1977 - June 30, 1978

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

M. W. URBANEK
DSS Engineers, Inc.
Fort Lauderdale, Florida

Prepared for:

Lawrence Berkeley Laboratory
University of California
Berkeley, California

under LBL Purchase Orders 4366002, 3558102

The work was supported by the Division of Geothermal Energy of the U. S. Department of Energy under Contract No. W-7405-ENG-48.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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

DISCLAIMER

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

DEVELOPMENT OF DIRECT CONTACT HEAT EXCHANGERS

FINAL REPORT - 1978

TABLE OF CONTENTS

		Page
SECTION 1	SUMMARY, CONCLUSIONS & RECOMMENDATIONS	
	1.1 Summary	1
	1.2 Conclusions	6
	1.3 Recommendations	9
SECTION 2	INTRODUCTION	11
SECTION 3	DESCRIPTION OF DCHX LOOP COMPONENTS	
	3.1 General Process Description	13
	3.2 General Component Design Details	15
	3.2.1 Direct Contact Heat Exchanger	15
	3.2.2 Separator	18
	3.2.3 Condenser	20
	3.2.4 Hotwell	20
	3.2.5 Degassing Column	21
	3.2.6 Pumps	21
SECTION 4	HEAT TRANSFER EXPERIMENTS & CORRELATIONS	
	4.0 Introduction	24
	4.1 Increased Throughput of Brine & Isobutane	25
	4.2 Determine Relationship of Column Height to Thermal Performance	30
SECTION 5	SECOND TURBINE TEST - ENDURANCE RUN	
	5.1 Modifications & Preparation	39
	5.2 Hairpin Calibration	45
	5.3 Endurance Run	46
	5.4 Teardown Inspection Results	53
SECTION 6	DEGASSING COLUMN EXPERIMENTS	
	6.1 Introduction	58
	6.2 Equipment	59
	6.3 Operating Procedure for Degassing Column	62
	6.4 Sampling Technique	63
	6.5 Lab Analysis	65
	6.6 Results	70
	6.7 Discussion & Recommendations	84
	6.8 Isobutane Recovery	85
SECTION 7	BRINE CARRYOVER EXPERIMENTS	
	7.1 Theory	88
	7.2 Modifications & Additional Equipment Required	92
	7.3 Procedure	100
	7.4 Results & Discussion	104

TABLE OF CONTENTS (con't)

		Page
SECTION 8	ORNL CONDENSER TESTING	
	8.1 Introduction	109
	8.2 Condenser Description & Loop Modifications	111
	8.3 Proposed Test Procedure & Problems Encountered	113
REFERENCES		116
APPENDIX A	Column Diameter Correlations	117
APPENDIX B	Letan Kehat Model	118
APPENDIX C	Results of Degassing Column Experiments Conducted During January & February of 1977	120
APPENDIX D	Solubility of CO_2 in Fresh Water and Seawater	131

LIST OF FIGURES

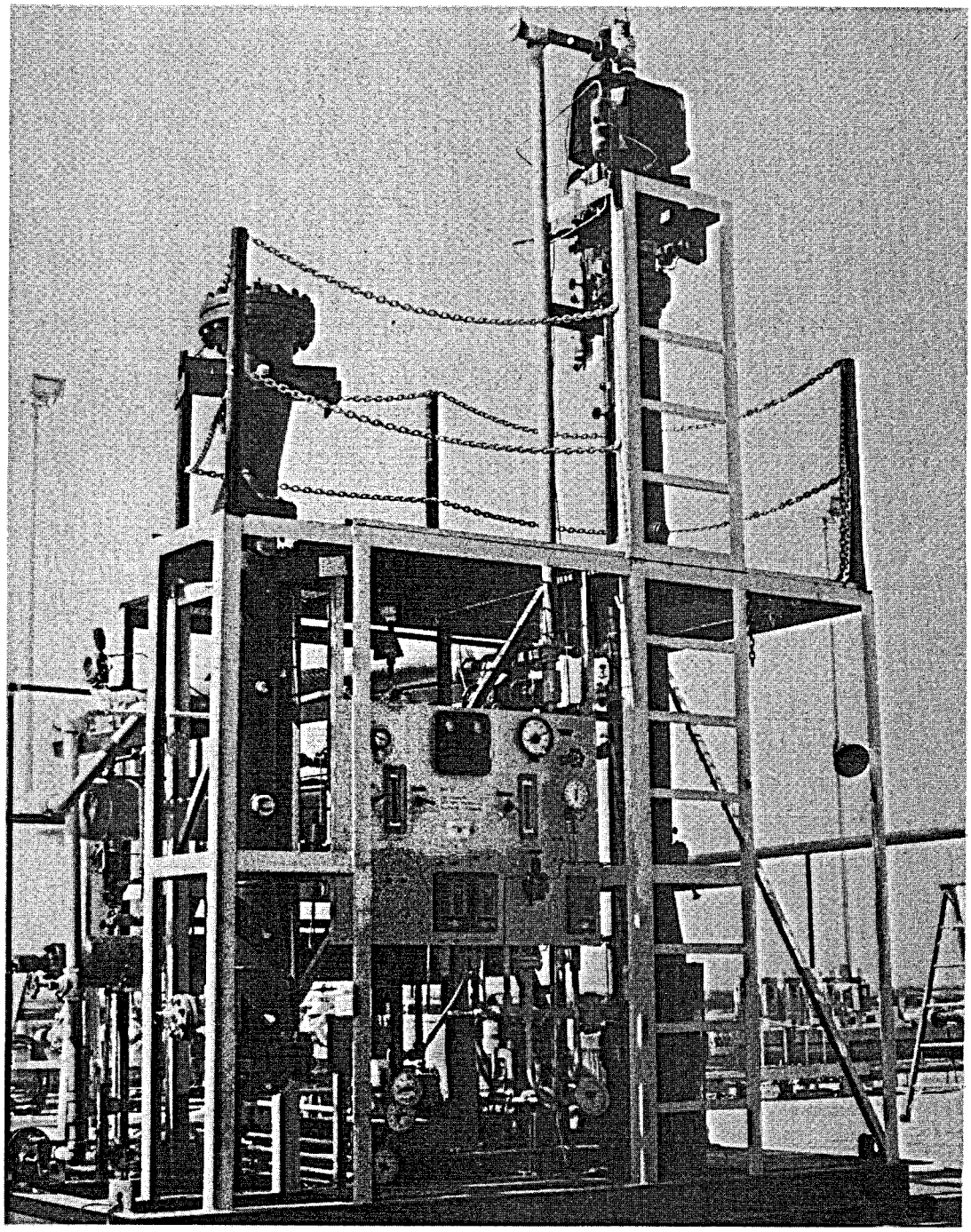
FIGURE NO.	DESCRIPTION	Page
3.1	DCHX Loop Components	14
3.2	Direct Contact Heat Exchanger	16
3.3	DCHX Boiler Upper Assembly	17
3.4	Separator Assembly	19
3.5	Hotwell Assembly	22
3.6	Degassing Column Assembly	22
4.1	Superficial Velocities of Isobutane & Brine at Flooding	29
4.2	Letan Kehat Model As Applied to Data of December 16, 1977	34
4.3	Diagramatic Representation of Letan Kehat Model Applied to Test 12 and Test 13	37
5.1	General Layout of DCHX	41
5.2	The DCHX Module Control Panel	41
5.3	Turbo-Generator Assembly	42
5.4	Knock-Out Drum	42
5.5	Solenoid Operated Control Valve	43
5.6	Differential Pressure Flow Meter	43
5.6A	P & I Diagram for DCHX Power Plant	44
5.7A	Isobutane Consumption VS Run Time	52
5.8	Post Endurance Run Teardown & Inspection	55
5.9	" " " " " "	55
5.10	" " " " " "	56
5.11	" " " " " "	56
6.1	P & I Diagram for Degassing Column & Sampling Train	61
6.2	Degassing Column Data Sheet (3 April 78)	64
6.3	Lab Setup Number 1 Used to Determine Residual CO_2	68
6.4	Lab Setup Number 2 Used to Determine Residual CO_2	69
6.5	Condenser Pressure Required to Condense Isobutane from A Mixture of Isobutane and CO_2	87
7.1	Superficial Velocity of Isobutane & Fresh Water - Sakiadis & Johnson Model	91
7.2	Dual Level Controller Installation	94
7.3	Dummy Turbine Nozzle Detail	96
7.4	Dummy Turbine Nozzle Assembly	97
7.5	Dummy Turbine Nozzle Assembly (Photograph)	97A
7.6	Location of "Dummy" Nozzle Assembly in Piping Circuit	97A
7.7 7.8	Conductivity Cell & Water Trap Installation	98
7.9	SARCO Water Trap (Photograph)	99
7.10	Hotwell Conductivity Probe Installation (Photograph)	99
7.11	Typical Printout of Conductivity VS Temperature During Calibration	102
7.12	Temperature Correction for Conductivity Probes	103
7.18 7.19 7.20 7.21	Photographs of "Dummy" Turbine Nozzle taken at Completion of Carryover Tests	108
8.1 8.2	Photographs of the ORNL Condensers	110

LIST OF FIGURES (con't)

FIGURE NO.	DESCRIPTION	Page
8.3	Photographs of the ORNL	
8.4	40 Tube Condenser Installed	112
8.5	Nozzle for Desuperheating in 2" Tee	114
C-1	P & I Diagram for Stripping Column and Isobutane Recovery	123

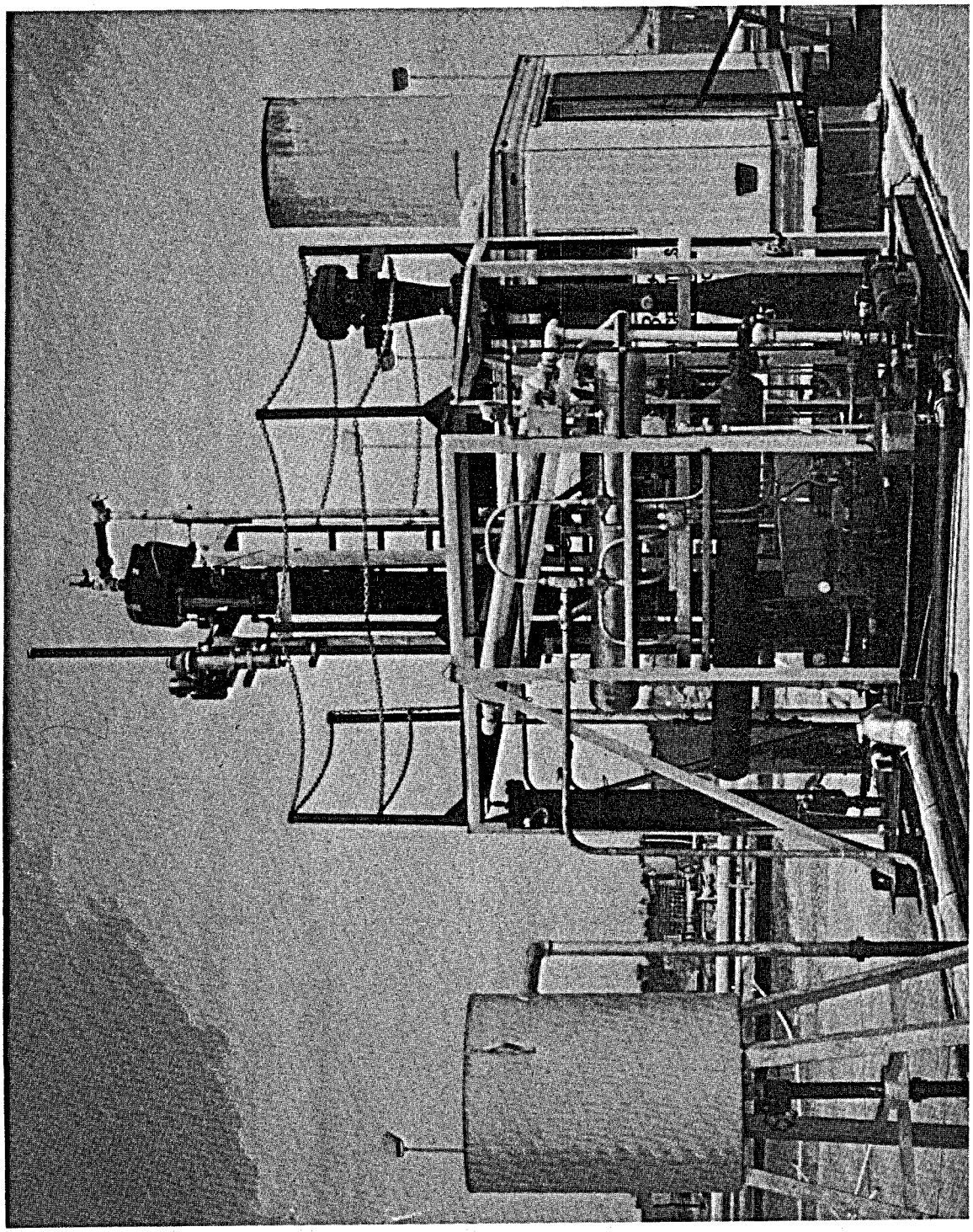
LIST OF TABLES

TABLE NO.	DESCRIPTION	Page
4.1	Heat Transfer Data for December 16, 1977	27
4.2	Letan Kehat Model-Sensitivity of Values for M and m	33
4.3	Heat Transfer Data for Test 12 (6/14/78) & Test 13 (6/14/78)	36
5.1	Hairpin Calibration - 2nd Turbine Test	47
5.2	2nd Turbine Endurance Test - Performance Data	49-50
5.3	2nd Turbine Test - Downtime Analysis	51
6.1	Summary of Degassing Column Operating Data	71
6.2	Degassing Column Brine Samples - Liquid Phase Carbonate Analysis Results	72
6.3	Degassing Column Samples - Laboratory Analysis Results	74
6.4	Mass Balances of Carbonates & Isobutane About the Degassing Column	75
6.5	Determination of Theoretical Solubilities of C_4H_{10} in Degassing Column Effluent Brine	77
6.6	Determination of Theoretical Solubility of C_4H_{10}	78
6.7	Theoretical Solubility of C_4H_{10} in Degassing Column Exit Brine VS Measured Concentration	79
6.8	Measured CO_2 and Carbonates (as CO_2) of Degassing Column Brine Samples	81
6.9	Comparison of Theoretical Solubilities & Measured Carbonate Content of the Degassing Column Effluent Brine	82
7.1	Carryover Data Summary - Measured Flow & Salinity Values	105
7.2	Carryover Data Summary - Calculated Values	106



DIRECT CONTACT HEAT EXCHANGER
AT
EAST MESA GEOTHERMAL COMPONENT
TEST FACILITY

XBB 791-587



DIRECT CONTACT HEAT EXCHANGER
AT
EAST MESA GEOTHERMAL TEST FACILITY

BBC 791-586

SECTION 1

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SECTION 1

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1.1 Summary

A series of experiments during a period of eight months was conducted with the existing Direct Contact Heat Exchanger (DCHX) Loop in order to better understand the thermal and hydraulic characteristics of the equipment. Modifications were made to the equipment which were designed to improve heat transfer and reduce the cost of the heat exchangers. Additional changes were made to the equipment to conduct turbine experiments, condenser experiments, and carryover tests. Further studies of the amounts of dissolved isobutane in the geothermal brine and methods of recovering this dissolved isobutane were also made.

The experimental unit is a skid mounted package containing a complete binary cycle loop and direct contact heat exchanger (DCHX). The equipment is based on a process which exchanges heat from geothermal brine to isobutane thereby vaporizing the isobutane and then expanding the isobutane through a turbine to produce power. The heat exchanger is an experimental direct contact unit that contacts isobutane with geothermal brine without metallic heat transfer surface. The skid mounted unit was built by DSS Engineers, Inc., in January 1977 and was operated successfully during its initial tests with geothermal brine at the East Mesa Geothermal Test Facility from March 1977 to July 1977. From July to October, 1977, the unit was operated with a small axial inflow turbine and generator to produce electricity. This was the first electricity to be generated by a geothermal binary cycle in the United States.

This report covers experimental studies performed from October 1977 through June 30, 1978. The following is a summary of this work.

1. The average volumetric heat transfer coefficient for the liquid-liquid heat exchange portion of the exchanger was increased from 5500 to approximately 7300 BTU/HR-F-ft^3 by increasing the brine flow from 5.5 to 6.6 gpm

and simultaneously the isobutane flow from 10 to 11.9 gpm. These are the upper flow limits that can be achieved using the existing pumps. For the boiling section, the volumetric heat transfer coefficient increased from 6,500 to 10,200 BTU/HR-F-ft^3 with the increased flow rates. The boiling and preheating coefficients are based on heights calculated using the Letan Kehat theoretical model.[7] The total height for both preheating and boiling was, however, measured directly.

2. The two most generally accepted correlations between flow rate of the phases in a spray column at the "flooding point" are: 1) the Minard-Johnson model and 2) the Sakiadis-Johnson model.[9] Both models were tested against operating data that should have been at or very near flooding as predicted by the models. However, "flooding", as indicated by "sniff testing" the effluent brine for the presence of C_4H_{10}, was never observed.

3. Tests were conducted to experimentally verify the exact height of the individual preheating and boiling sections of the direct contact heat exchanger as predicted by the Letan Kehat model. These tests hypothetically called for lowering the apparent level in the column (while maintaining constant continuous and dispersed phase flows) and comparing measured temperatures with temperatures predicted by the model. The initial attempts (November and December experiments) were unsuccessful because steady operating conditions of the column were never obtained for low operating levels.

Further attempts at verifying the model were made by fitting selected data obtained during the "carryover experiments" (conducted in May and June) to the model. The observed data was in good agreement with the model only after changing the value of a model constant (M) from .83 (suggested by Letan Kehat) to .70. The two test conditions compared were, however, for a relatively small difference in boiler operating level; i.e., 11 inches.

Only end point temperatures and two intermediate temperature points could be checked against the theoretical predicted temperature profile.

The theoretical profiles obtained using the Letan Kehat model result in a 2 F "pinch point" temperature. The actual data indicated an 11 F pinch point.

4. A 200 hour turbine endurance run was successfully completed demonstrating the production of electricity from a geothermal source using isobutane vapor generated by a direct contact heat exchanger. The test program was patterned after the "First" 500 hour endurance run[2] conducted in the summer of 1977. Basically the test loop consisted of the same components used for the first turbine test with modifications necessary to gain more accurate data and better evaluate turbine scaling problems.

Calibration tests were first completed for subcritical and supercritical turbine inlet cycle conditions using isobutane vapor generated in a "hairpin" surface type heat exchanger.

During the endurance run the DCHX loop accumulated a total of 203.9 hours and the turbo-generator accumulated 200 hours running time. The total downtime for the run was 14.8 hours. The overall on-stream factor was 93.2% The largest single cause for shutdown was for transferring from one brine supply well to another. The normal average isobutane consumption for the run was 2.24 lbs/hr. This is approximately.095% ($^{wt}/_{wt}$) of the total isobutane being circulated. Approximately 1.2 lb/hr of this isobutane can <u>theoretically</u> be accounted for as leaving the system solubilized in the effluent brine (386 ppm C_4H_{10} theoretically contained in brine at operating conditions of temperature and pressure).

At the conclusion of the endurance run the direct contact heat exchanger

was dismantled and inspected. The internal surfaces showed no unusual scale deposits. Teardown of the turbine assembly revealed scaling of the turbine nozzle as in the first turbine test.

5. A degassifier was operated to determine the quantity of dissolved isobutane that could be stripped from the brine leaving the heat exchanger. In additon, data was collected to construct a carbonate mass balance about the degassifier column.

The amount of dissolved isobutane in the degassing column brine outlet stream typically ranged between 10.8 and 12.4 ppm. The theoretical C_4H_{10} solubility, as estimated from work completed by Hellstrom", for these tests ranged between 8.4 and 13.2 ppm.

The mass balance results for isobutane and carbonates taken about the degassifier showed good closure. The mass flows for isobutane balance agree quite well with all but one of the balances agreeing within 5%. The flows for carbonates expressed as CO_2 are also in good agreement; the deviation between input and output CO_2 flows on all but one test was less than 10%.

Attempts were made at correlating the measured CO_2 and carbonate content of the inlet and outlet brine streams of the degassing column with published solubility data for the systems: 1) CO_2 in sea water[12] and 2) CO_2 in fresh water . As expected, there is not good agreement between the meausured values and the theoretical solubilities. THe main problem encountered was differentiating between free CO_2 and CO_2 as carbonate in the brine.

The degassing column was operated at an average C_4H_{10} volatilization efficiency of 98%, the composition of the degassing column vapors being primarily C_4H_{10} , Co_2 and H_2O. The mole fraction of these gases for each of the tests are presented in the text.

6. Recommendations are presented for future attempts at determining the amount of CO_2 and isobutane solubilized in the brine. These include: 1) larger samples of both gas and liquid, 2) a more accurate method of measuring gas flow rates, 3) more accurate pressure and temperature readings and 4) a method for differentiating between free CO_2 and CO_2 present as carbonate in the brine.

7. A brief discussion of the possible method for recovering isobutane from the degassing column vapor using compression and refrigeration is included in section 6.

8. Because of the turbine scaling problems experienced during both the first and second turbine endurance runs, a series of experiments were completed to: a) quantify and qualify the brine mist or entrainment carryover in the isobutane vapor stream; b) characterize this carryover as a function of the main DCHX operating variables and c) investigate means to minimize this carryover.

Several modifications to the basic DCHX loop were required before these experiments could be conducted. These included:

a) installation of dual level controllers on the boiler and a new boiler inlet; b) installation of a simulation turbine nozzle assembly; c) conductivity cells and water trap installations to quantify and qualify blowdown effluent and; d) additional instrumentation and miscellaneous piping changes.

Eighteen "carryover" tests were conducted in an attempt to correlate knockout drum and hotwell blowdown with isobutane flow rate, brine flow rate, boiler level and superheat. No definite correlations between boiler operating level and the amount or salinity of the water content of the isobutane vapor stream are apparent. The only significant result is that high knock-

out drum water blowdown rates are complimented with high salinity content.

No correlation between the partial pressure or degrees superheat of the isobutane and weight fraction water content of the vapor phase was evident.

The theoretical water vapor content of the vapor stream[14] from the boiler was compared to the actual measured values. The measured values were all higher than theoretical.

The measured salinity of the hotwell blowdown ranged from 237 ppm to over 1000 ppm. Theoretically, this blowdown should have a very low or negligible salinity. This can be explained by acknowledging the premise that ammonium bicarbonate may be formed on cooling in the condenser.

The "dummy" nozzle was removed from the circuit after being in service intermittently for approximately 120 hours. The surfaces of the nozzle were found to be free of any significant scale deposits.

9. As part of a heat transfer development program initiated by Oak Ridge National Laboratory, a series of condenser performance tests were planned using isobutane vapor generated by the DCHX. The basic loop was modified to facilitate these tests. The installation of a 40 tube stainless steel vertical shell-and-tube condenser was completed. However, because of numerous mechanical, design and operational problems, neither calibration nor test data could be sufficiently obtained within the time frame of the contract.

1.2 Conclusions

The work completed during the eight month experimental program outlined in this report, further demonstrates that the direct contact heat exchanger isobutane loop coupled with a suitable turbo-generator is a feasible method of producing electricity from a moderate temperature geothermal source.

The overall conclusion is that although there are no apparent major technical obstacles to the development of commercial direct contact heat exchange systems, there are still some design and optimization studies that should be completed before the concept can be reliably used in geothermal applications. Also, various aspects of the system, such as working fluid recovery, are dependent on the physical and chemical nature of the resource, and must be developed accordingly.

A summary of other conclusions is as follows:

a. The heat transfer coefficients for the liquid-liquid heat exchange portion of the exchanger as well as the boiling section increase with increased mass flow rates of the continuous and dispersed phases.

b. "Flooding" of the heat exchanger was never achieved. Therefore, the maximum heat transfer coefficients that may be obtained are still unknown.

c. It appears that a modified Letan Kehat model may be used to estimate the height of the preheating and boiling sections in the direct contact heat exchanger. Further modifications of the model are required before it may be used to estimate the temperature profiles associated with the DCHX. Additional experiments are required before the model can be considered reliable.

d. Stable long-term operation of a direct contact heat exchanger coupled with a turbo-generator using isobutane as the heat transfer media can be achieved.

e. Inspection of the direct contact heat exchanger components and turbine internals concluding the 200 hour endurance run verified the results of the first endurance run; i.e., 1) no unusual scaling occurred in the direct contact unit, 2) turbine efficiency was affected by scale buildup on the turbine wheel, nozzles and exhaust housing.

f. Approximately twice as much isobutane was consumed or lost during the endurance run as theoretically can be accounted for as leaving the system solubilized in the effluent brine. Numerous leaks were recorded during the run that contribute to these losses.

g. The amount of isobutane in the brine stream exiting the separator consistently ranged between 175 and 210 ppm. A degassifier column was designed and operated such that only approximately 5% of this isobutane or 10 ppm remains with the column effluent brine. This is close to the average theoretical solubility of 81 ppm. The overall degassing column efficiency averages 98%. Separation of the isobutane from the vapors exiting the degassifier remains a problem. Work on a recovery system is required.

h. Isobutane and total CO_2 content of the various liquid phase and gas phase streams about the loop can be accurately determined using a gas chromatograph and proper sample collection and testing techniques.

i. Differentiating between free CO_2 and CO_2 present as carbonate and bicarbonate in the brine requires further developmental work.

J. Further work is required to understand the mechanism of carryover and salinity of the DCHX vapors.

k. The average salinity of the hotwell blowdown effluent under <u>normal</u> DCHX operation (no evidence of system upset) ranged between 300 and 450 ppm. This can be attributed to the formation of ammonium bicarbonate in the condenser on cooling.

l. The relationship between flow rate, dispersed phase drop size and column diameter for the DCHX is still not known. The mathematical models used to predict these in spray column applications, namely, the Minard-Johnson model and the Sakiadis-Johnson model, have not been verified by the DCHX operating data. However, sufficient operating data is not available to discredit these models.

1.3 Recommendations

The following recommendations are offered as follow up considerations to the work completed to date.

Further heat transfer experiments should be conducted to test the mathematical models of 1) Letan-Kehat, 2) Sakiadis-Johnson and 3) Minard-Johnson or, if necessary, to generate a new model that could be used specifically for design of direct contact heat exchanger. These experiments would require major modifications to the existing equipment train.

Additional experiments are required to determine the overall effect that the free CO_2 content of the brine has on performance of the direct contact heat exchanger, condenser, and isobutane recovery system. These experiments would consist of: 1) developmental laboratory work to determine the best procedures for identifying the amount of free CO_2 in the brine, 2) laboratory experiments conducted under controlled conditions to verify these procedures, 3) operation of the DCHX-isobutane loop with controlled or measured content of free CO_2 in the brine for performance evaluation.

An isobutane recovery system should be developed, evaluated technically and economically, sized and built to accommodate the existing loop and finally operated as part of the binary cycle loop for performance evaluation.

Recent studies have shown that other working fluids, particularly isopentane, may be better with geothermal fluid at some temperatures. Advantages in using isopentane instead of isobutane include lower working pressures, lower working fluid losses and higher effectiveness with geothermal fluid in certain temperature ranges. Based on this, it is recommended that additional studies and tests be performed using isopentane in the DCHX circuit to ob-

tain actual design and operating data such that a detailed economic comparison of the two cycles can be made.

SECTION 2

INTRODUCTION

SECTION 2

INTRODUCTION

In July 1977, DSS Engineers, Inc., was contracted by Lawrence Berkeley Laboratory (via subcontract with Barber-Nichols Engineering) to provide the use of the Direct Contact Heat Exchanger Isobutane Loop for a turbine experiment. The objectives of that test were: (1) to demonstrate the workability of a complete binary isobutane power cycle: (2) obtain generating experience and (3) identify potential problem areas.

After some piping changes and installation of additional instrumentation and safety devices necessary to connect the turbine to the DCHX loop were made, the turbine was calibrated in both subcritical and supercritical modes of operation. The calibration was accomplished using isobutane vapor generated in a "hairpin" surface type exchanger. The turbine was then run for 500 hours using isobutane vapor generated by the DCHX.

During this "endurance" run the turbine efficiency changed from an initial 49% to 39% as a result of scale formation in the turbine nozzle. After analyzing the scale, it was theorized that brine was being carried over as a mist with the isobutane vapor forming silica scale on the expansion cone section of the turbine nozzle.

In October of 1977, DSS Engineers was awarded a second contract with Lawrence Berkeley Laboratory (Purchase Order 3558102) to conduct a series of follow-up tests over a three month period. The main objectives of these tests were to operate the DCHX and collect data necessary to accomplish the following:

(1) Evaluate heat tranfer performance of the boiler; (2) correlate the volumetric coefficients with isobutane hold-up and/or flow rate in a given tower cross section; (3) determine relationship of column height to thermal performance; (4) evaluate the isobutane removal efficiency of a degassing column, and (5) design a 250 KW direct contact heat exchanger/binary cycle power plant.

Based on the results of the first turbine test as well as the limited success in collecting data in the restricted time frame of the second contract, it was recommended that the test program be continued.

Accordingly, in February of 1978, DSS Engineers was awarded a three month contract by LBL to operate the DCHX Isobutane Loop in support of a second turbine test. This test was to be performed with a demister vessel located between the DCHX loop and the turbine in an effort to minimize liquid mist carryover. During this endurance run, degassing column experiments were to be conducted to verify the isobutane loss fraction and characterize the degassing column performance. Immediately following this run, the contract was extended to cover testing through June 1978. The objectives of the additional work were: 1) to operate the DCHX Isobutane Loop in support of a series of condenser tests performed by Oak Ridge National Laboratories; and, 2) to quantify and qualify brine carryover in the isobutane vapor stream during this operation; and, 3) obtain data to differentiate between boiler and preheater areas.

This report summarizes the procedures and presents the results of the tests performed during the period.

SECTION 3

DESCRIPTION OF DCHX LOOP

SECTION 3

DESCRIPTION OF DIRECT CONTACT HEAT EXCHANGER LOOP COMPONENTS

3.1 General Process Description

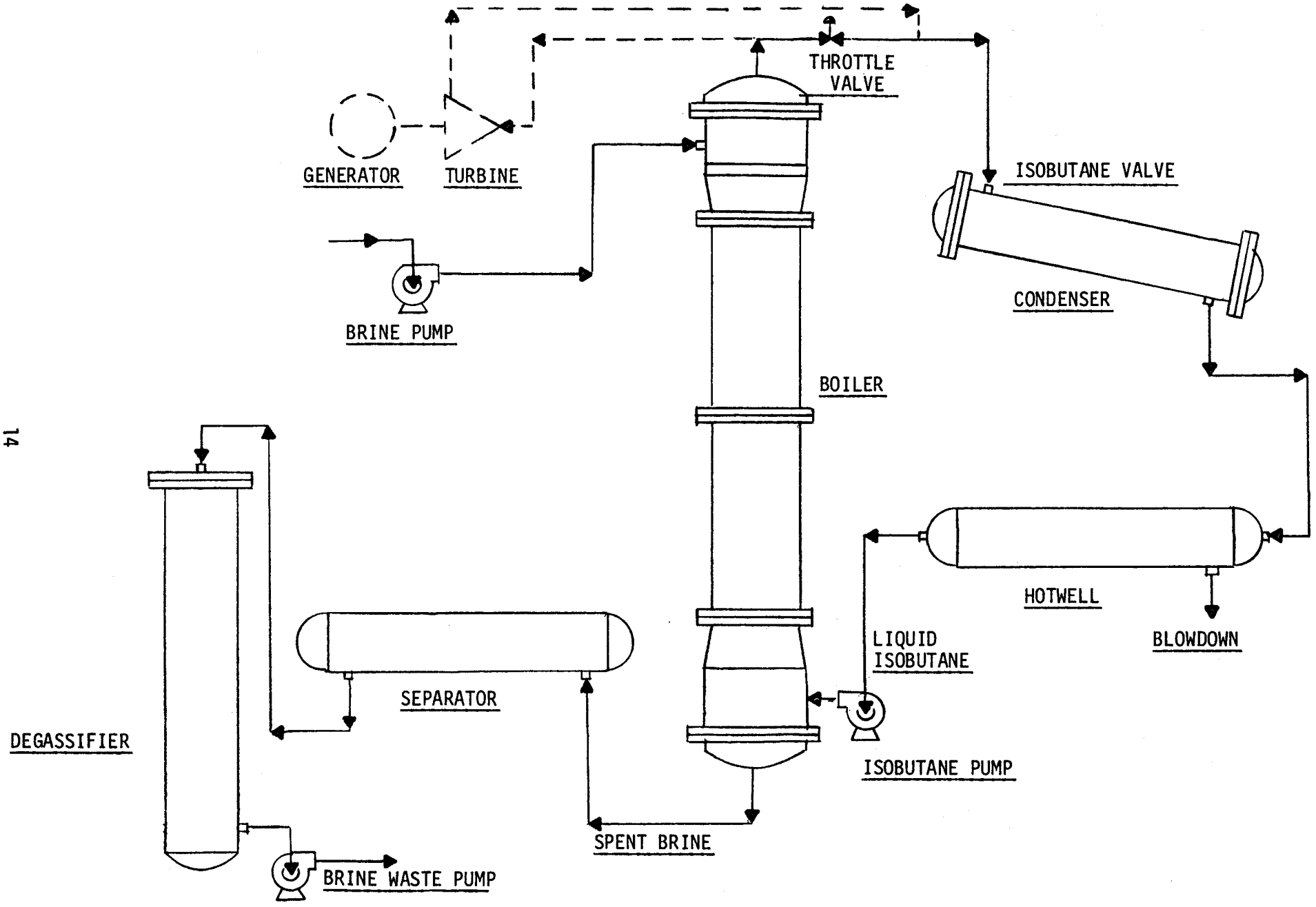
The test unit provides for the continuous circulation, contact and separation of brine and isobutane. Heat from geothermal brine is transferred to the isobutane in a single direct contact heat exchanger; a combination of a preheater and boiler. Other major components are the separator, condenser, hot well, degassifier (stripper) and the three circulating pumps. The general relationship of these components is illustrated in Figure 3-1. Photographs of the module are shown on pages i and ii.

Isobutane liquid is pumped from the hotwell to the direct contact heat exchanger where it is heated and vaporized by counter current contact with brine. The isobutane vapor and a small amount of water vapor is then throttled to the condensing pressure through a turbine or a valve in lieu of expansion in a turbine. The vapor is condensed and the isobutane liquid returns to the hotwell to repeat the cycle. Water condensate in the hotwell is continuously drained off.

Hot brine is pumped from the geothermal supply to the direct contact heat exchanger where heat is extracted from it to heat and vaporize the isobutane. The cooled brine leaving the heat exchanger enters the separator where any small, entrained isobutane drops are coalesced and settle out. The high pressure brine is then reduced to atmospheric pressure and dumped into an open tank where any remaining dissolved isobutane in the brine is flashed out. Finally the brine is sent to the reinjection system.

FIGURE 3-1

DCHX LOOP COMPONENTS



3.2 General Component Design Details

All test vessels were fabricated of carbon steel to Section VIII, Division 1 of the ASME Boiler and pressure Vessel Code. Plate, standard weight pipe (sch.40) and welding fittings were used for the shells. Nozzles were either schedule 80 pipe with 300# flanges or 3000# screwed couplings. Overpressure protection was provided by safety valves installed behind stainless steel rupture disks. The condenser was a standard off-the-shelf item with brass shell and tubes, and a cast iron water box. Piping was predominately carbon steel hydraulic tubing to facilitate bending and minimize the number of joints. "Swagelok" type fittings were used extensively to allow frequent disassembly and modification of the piping system.

3.2.1 Direct Contact Heat Exchanger

The Preheater and boiler are combined into one single column having an overall height of about thirteen feet. The distance between the isobutane distributor at the bottom and the brine distributor at the top is ten feet four inches. The straight section of column is 9 feet in length with an inside diameter of 6 inches. At both ends a conical section with an included angle of 20 degrees flares to a ten inch diameter. The transition at the bottom results in a gradually decreasing downward velocity of the brine and the enlarged diameter at the bottom allows sufficient area in the annulus between the isobutane distributor and the wall to reduce the brine velocity in the straight section. At the top of the column the ten inch diameter provides a large area for mist eliminators. The column is shown schematically in Figure 3-2 and in detail in Figure 3-3.

DIRECT CONTACT HEAT EXCHANGER

FIGURE 3-2

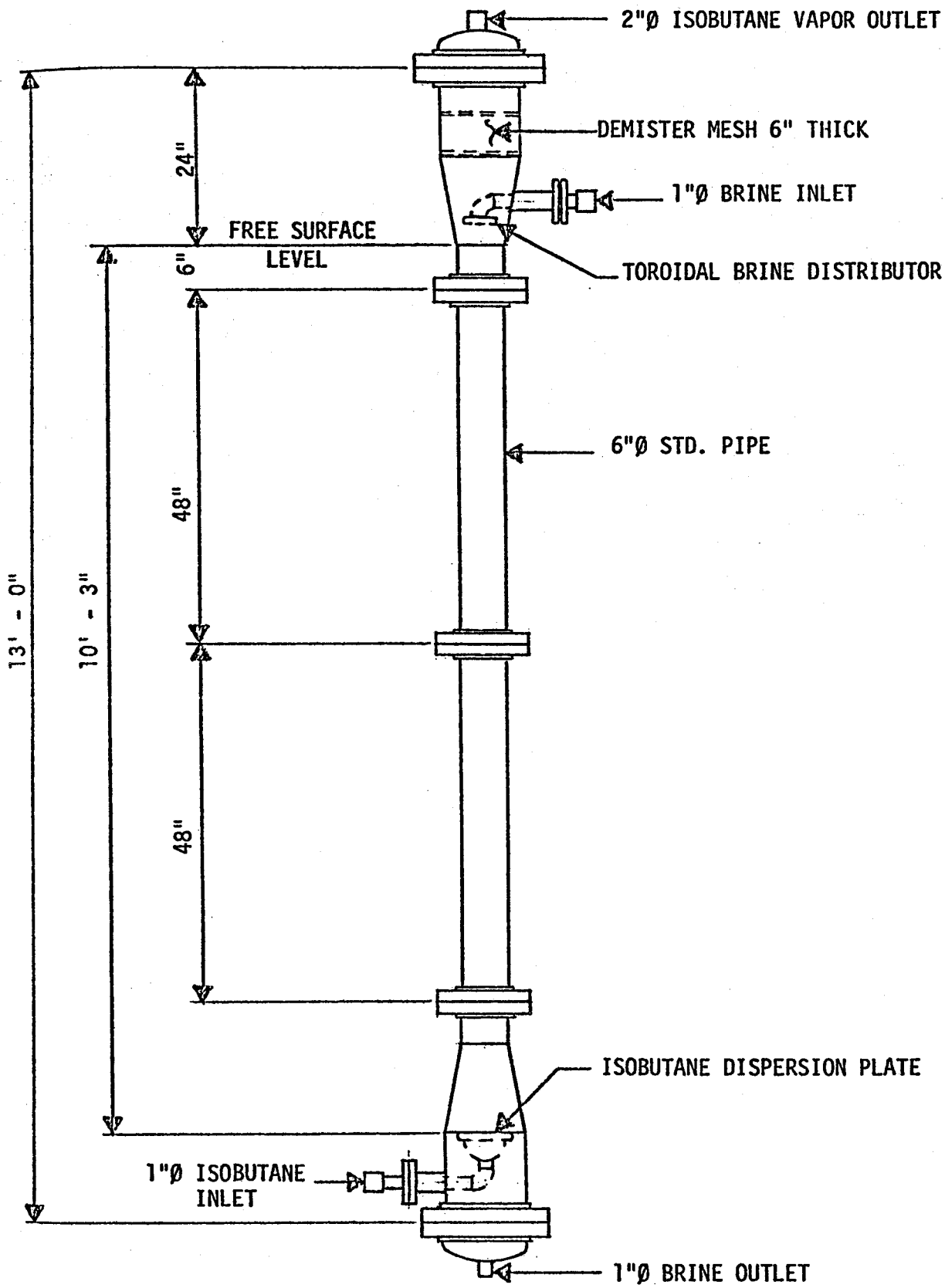
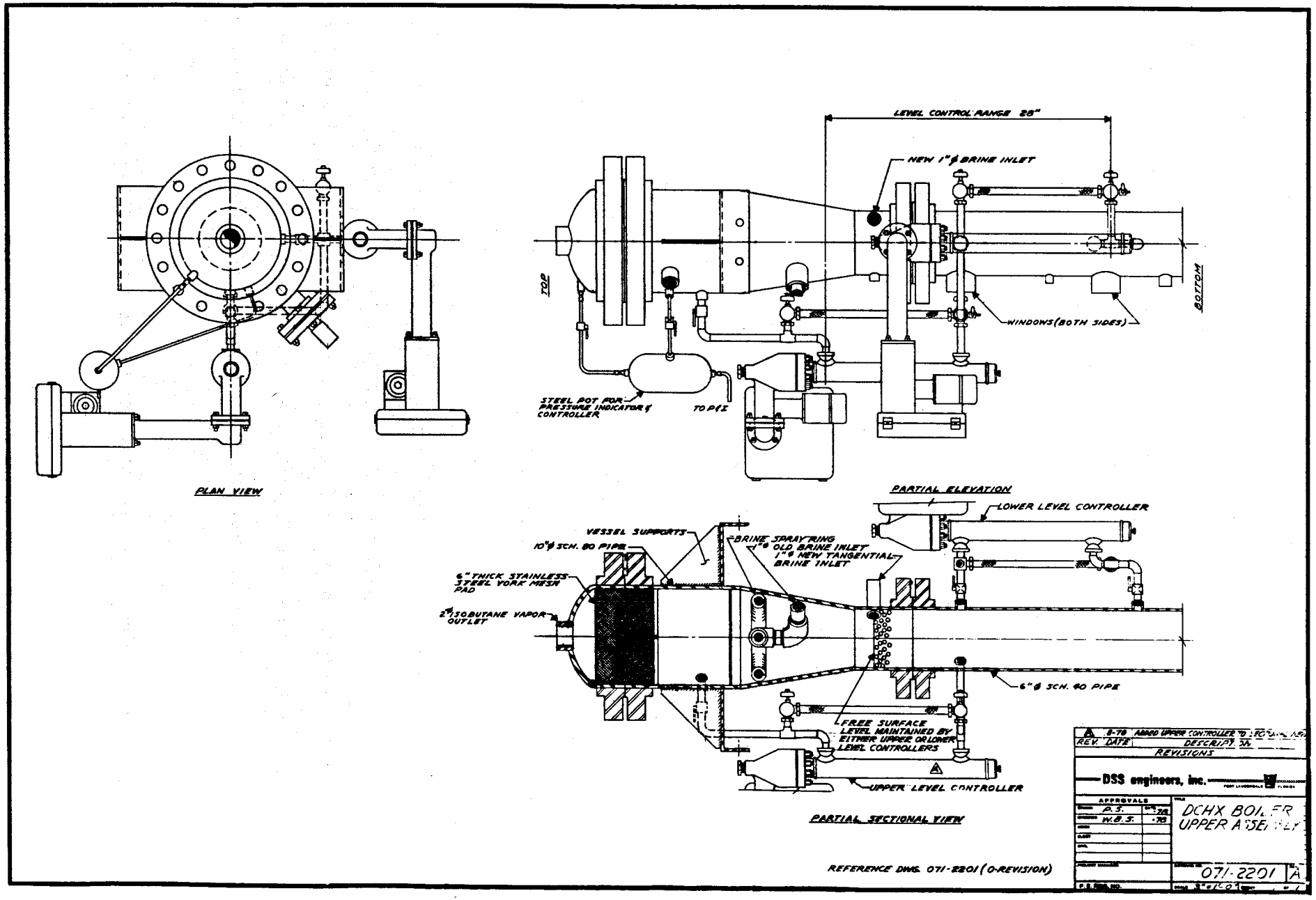


FIG. 3-3


PLAN VIEW
LEVEL CONTROL RANGE 28"
NEW 1"ϕ BRINE INLET
TOP
BOTTOM
WINDOWS (BOTH SIDES)
STEEL POT FOR PRESSURE INDICATOR & CONTROLLER
TO P&I
PARTIAL ELEVATION
LOWER LEVEL CONTROLLER
VESSEL SUPPORTS
10"ϕ SCH. 80 PIPE
BRINE SPRAY RING
1"ϕ OLD BRINE INLET
1"ϕ NEW TANGENTIAL BRINE INLET
6" THICK STAINLESS STEEL YORK MESH PAD
2" ISOBUTANE VAPOR OUTLET
6"ϕ SCH. 40 PIPE
FREE SURFACE LEVEL MAINTAINED BY EITHER UPPER OR LOWER LEVEL CONTROLLERS
UPPER LEVEL CONTROLLER
PARTIAL SECTIONAL VIEW
REFERENCE DWG. 071-2201 (0-REVISION)
REV. DATE
REVISIONS
DSS engineers, inc.
APPROVALS
P.S.
W.B.S.
DCHX BOILER UPPER ASSEMBLY
071-2201
A

Isobutane is introduced near the bottom of the column by a plate containing 390 drilled holes 0.060 inch in diameter. Type 316 Stainless Steel, 1/8 inch thick was used for the plate. On the bottom face of the plate the edges of the holes were beveled while the upper face of the plate was ground to ensure sharp edges. After machining, the surface of the plate was slightly oxidized to make it more olephobic (less wettable by isobutane) by pickling in concentrated nitric acid.

Brine is introduced through a perforated distribution ring near the top of the column. The isobutane vapor leaving the top of the column must pass through a knit stainless steel wire mesh demister pad six inches deep which minimizes carryover of either liquid isobutane or brine.

The construction of the column incorporates five pairs of flanges to facilitate inspection and make experimental modifications. Numerous connections are provided on the shell of the column for vents,drains and instrumentation including three thermowells, one pressure gage connection, two manometer taps, four high-pressure windows (or "bulls-eyes") for viewing the dispersion, and three pairs of gage glass connections.

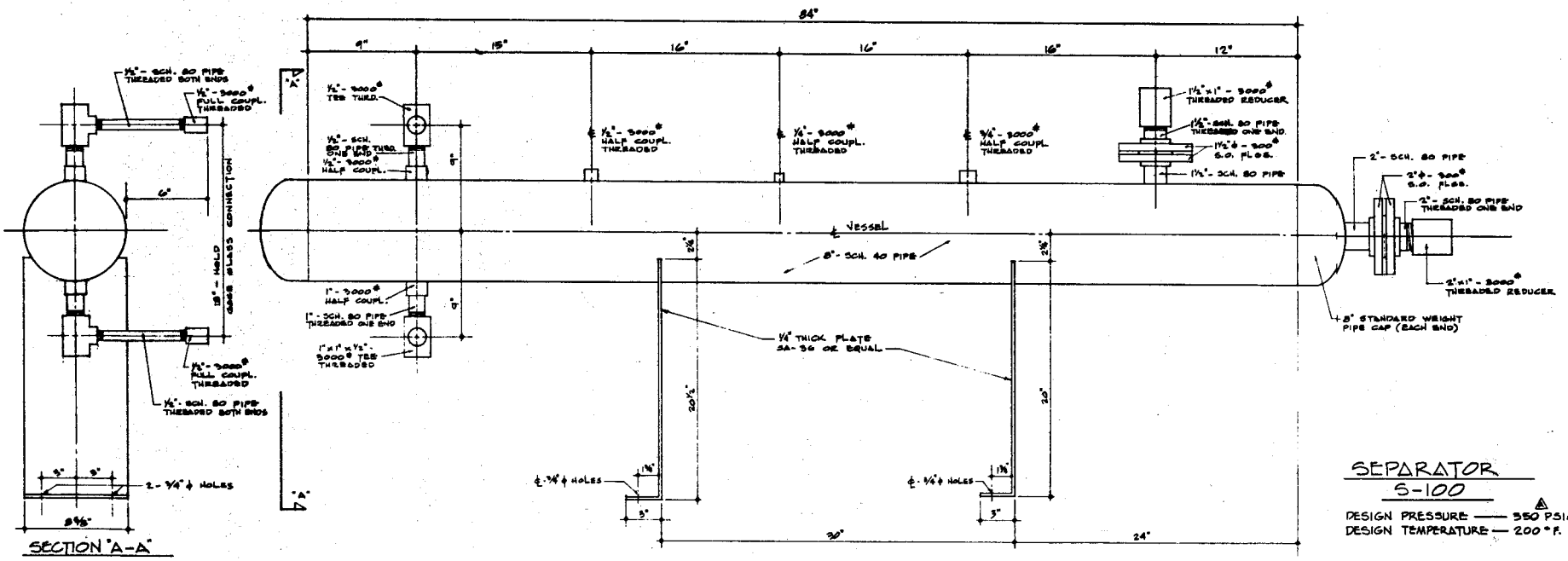
3.2.2 Separator

Brine leaving the direct contact heat exchanger enters the separator which is a horizontal settler with a coalescer at the inlet end. The vessel is seven feet long and eight inches in diameter, providing a retention time of 3.7 minutes for the brine. It is installed with its longitudinal axis tilted up one degree from the horizontal toward the outlet end. The separator is shown as Figure 3-4.

The coalescer, which fills the entire cross section of the separator at

FIGURE 3-4

SEPARATOR ASSEMBLY



SEPARATOR
S-100

DESIGN PRESSURE —— 350 PSIA
DESIGN TEMPERATURE — 200 °F.

DBB ENGINEERS, Inc.

APPROVALS		
DRAWN	DK	7-15
CHECKED	DJ MORIN	7/15
SUPV.	DJ MORIN	7/15

TITLE: PRESSURE VESSELS FOR DIRECT CONTACT TEST UNIT

DRAWING NO. 051-2203 C

SCALE 3" = 1'-0"

the inlet end, consists of a knit mesh of stainless steel wire and glass fiber. Its function is to entrap and hold the small isobutane drops entrained in the brine stream so that they can coalesce with other small drops and form drops large enough to rise to the surface. Besides recovering small quantities of dispersed liquid isobutane (as opposed to dissolved isobutane) from the brine discharge stream during normal operating conditions, the separator also provides volume to cope with the large amounts of isobutane entrained in the brine during upset conditions. Isobutane liquid collected is periodically vented to the hotwell which is always at a lower pressure than the separator when the test unit is in operation.

3.2.3 Condenser

Isobutane vapor, after throttling through a valve or expanding through the turbine, is condensed on the shell side of a conventional shell-and-tube heat exchanger by cooling water flowing through a single pass of tubes. The unit is installed with its longitudinal axis tilted up twenty degrees from the horizontal. The inlet of isobutane vapor is at the upper end of this unit and the outlet of condensate is at the lower end. The cooling water flows counter current with respect to the isobutane flow. The condensate outlet and a vent line are connected to the hotwell in such a way that a liquid level is maintained in the bottom of the condenser to sub-cool isobutane liquid. The total heat transfer area for this condenser is 120 sq. ft.

3.2.4 Hotwell

The hotwell serves as a receiver for condensed isobutane from which the isobutane pump takes suction. As test unit operating conditions change, the amounts of isobutane in the direct contact heat exchanger varies. The hotwell provides the inventory to cope with these operating changes as well as losses through leakage. Instrumentation on the hotwell includes temperature and

pressure indication and one gage glass. The vessel is six feet long and 10-5/8 inches in diameter. It is installed with its longitudinal axis tilted up one inch from the horizontal toward the suction line of pump. Therefore, the water condensate in the hotwell may be drained off at the lower end of the vessel. The hotwell is shown in detail as Figure 3-5.

3.2.5 Degassing Column (Stripping Column)

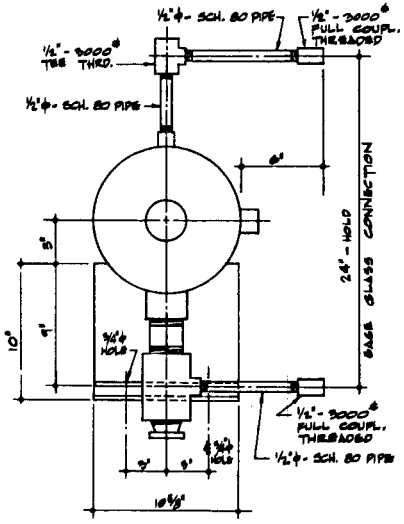
The high-pressure brine leaving the separator still containes dissolved isobutane. A stripping column was installed in order to flash out the isobutane by reducing the pressure. This vessel is 6 ft. in height and 6 5/8 inches in diameter. The top of the vessel is sealed with a blind flange for accessibility. Before the isobutane vapor leaves the outlet at the top, it passes through a knit mesh demister. The brine exits at the bottom of the vessel to the reinjection system. Instrumentation on the stripping column includes temperature and pressure indication, gas rotameter and two gage glasses. The stripping column is shown as Figure 3-6.

3.2.6 Pumps

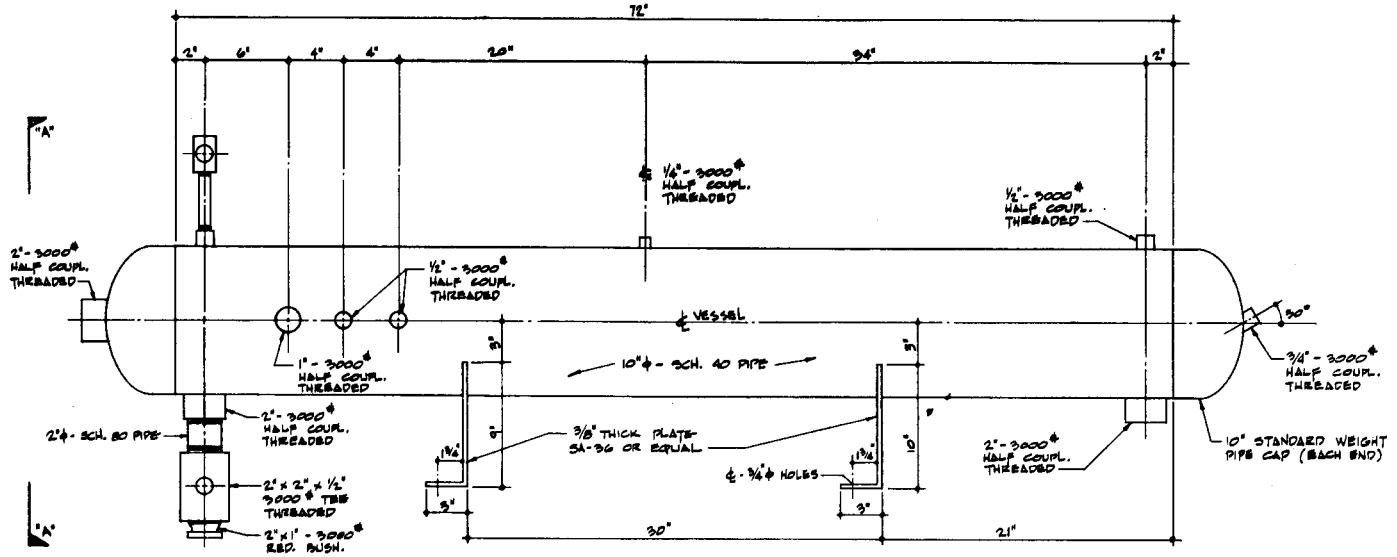
The isobutane is circulated by a four cylinder John Bean outside packed plunger pump (Model T-04102) rated at 10 GPM capacity. The brine pump is an outside packed triplex plunger pump (John Bean Model M-0910) with a rated capacity of 7 GPM. Both pumps are equipped with a nitrogen filled accumulator on the discharge side used to reduce pressure pulsation. Flow rate is controlled by a valve on a bypass line from the discharge to suction side to prevent overpressure damage to the pump or test unit.

FIGURE 3-5

HOTWELL ASSEMBLY



SECTION "A-A"

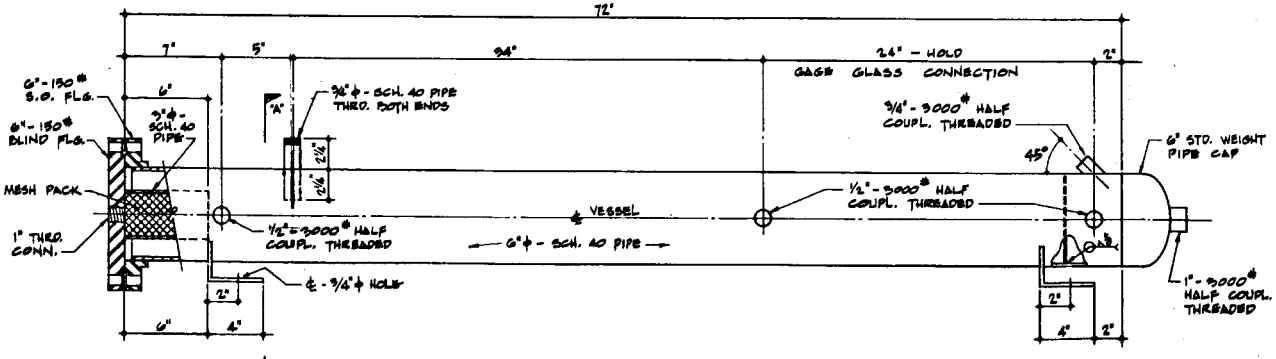


HOTWELL V-100A

DESIGN PRESSURE ——— 220 PSIA
DESIGN TEMPERATURE ——— 185°F.

NOTE

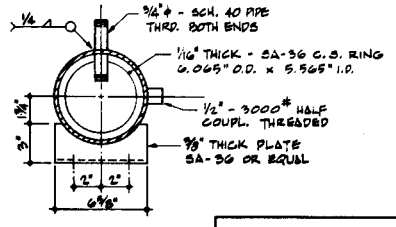
WELD DETAILS AND NOTES ON DRAWING 051-2201 APPLY TO FABRICATION OF VESSELS ON THIS DRAWING.



MESH PACK
DYNNET STYLE NO. 0440, 7.5# WIRE, TYPE 316 S.S. OR EQUAL.

STRIPPING COLUMN SC-101

DESIGN PRESSURE ——— 65 PSIA
DESIGN TEMPERATURE ——— 200°F.



SECTION "A-A"

FIGURE 3-6

DEGASSING COLUMN ASSEMBLY

DSS ENGINEERS, Inc.
FORT LAUDERDALE, FLORIDA

APPROVALS	
DRAWN	DK 8-7-76
CHECKED	
ISSUED	
CLIENT	
CODE	
PROJECT MANAGER	
P.E. REG. NO.	

TITLE: PRESSURE VESSELS FOR DIRECT CONTACT TEST UNIT

ENGINEER NO. 051-2208

SCALE 3/8" = 1'-0"

Pumping requirements for the isobutane are especially demanding because of the combination of low available net positive suction head and high discharge head in a single pump. Isobutane liquid also has extremely low density and viscosity, placing further restrictions on the type of pump which can be used.

A third pump is required to pump the effluent brine from the stripping or degassing column to the reinjection system. The pump used is a four cylinder outside packed plunger pump similar to the isobutane circulating pump mentioned above.

SECTION 4

HEAT TRANSFER

SECTION 4

HEAT TRANSFER EXPERIMENTS AND CORRELATIONS

4.0 INTRODUCTION

The initial DCHX-Isobutane heat transfer experiments conducted at Wrightsville Beach, N. C.[1] utilized a separate preheater and boiler so that the performance of each could be evaluated separately. The diameter of the preheater used was sized at 6 inches ID using the Minard-Johnson[8] relationship. The preheater height was set at 6 feet by selecting a volumetric heat transfer coefficient (U_V) of 5000 BTU/HR- F-Ft^3. This coefficient was based on the findings of a preliminary literature review. The boiler was sized by setting the diameter at 6 inches ID and assuming a volumetric heat transfer coefficient of 10,000 BTU/HR- F-ft^3.

The experimental unit operated at Wrightsville Beach with no major problems. The volumetric heat transfer coefficient obtained in the preheater varied predominately with the volumetric isobutane holdup and ranged up to 4000 BTU/HR- F-ft^3. The boiling heat transfer coefficients were measured to be as high as 17,000 BTU/HR- F-ft^3. These values were obtained with an overall isobutane through put averaging 10 gpm.

As follow up to the original work, the data obtained at Wrightsville Beach was reduced and fitted to the theoretical sizing models of (1) Minard Johnson[8], (2) Sakiadis-Johnson[9], and (3) Letan-Kehat[7]. It appeared that the experimental results were in good agreement with the theoretical models.

A major improvement of the heat exchanger was developed by the combination of the preheater and boiler into a single continuous column. At East Mesa, this new direct contact heat exchanger was demonstrated successfully on geothermal brine under a follow up ERDA contract. The volumetric heat transfer coefficients of the assumed preheater section ranged up to 5,500 BTU/HR- F-ft^3. and of the boiler section to 6,500 BTU/HR- F-ft^3.

In an effort to increase these volumetric heat transfer coefficients, DSS was contracted by LBL to operate the DCHX-Isobutane Loop. The tests were performed in November and December of 1977 using geothermal brine from well 6-2 at East Mesa. The object of the experiments was to increase the coefficients by: 1) increasing the mass flow of the two fluids, keeping the volume constant and 2) varying the working height of the column keeping the mass flow constant.

This section of the report summarizes the heat transfer correlations obtained under the LBL contract.

4.1 Increased Throughput of Brine and Isobutane

Heat transfer performance of direct contact heat exchangers is often expressed as a volumetric coefficient. (Btu/hr - F - Cu.ft.). Previous experiments have shown a correlation of volumetric coefficient with isobutane holdup and/or flow rate in a given tower cross-section. The theoretical limit to the fluid flow is of course the flooding point of the tower. For a fixed flow rate of the continuous phase (brine), as the flow rate of the dispersed phase is increased, the slowly rising droplets increase in concentration within the column to a point where more dispersed

phase cannot be forced through the column. Any additional increase in the flow rate of the dispersed phase results in the entrainment of droplets by the continuous phase at the bottom of the column with subsequent loss of working fluid. The situation is referred to as a flooded column. Since heat transfer increases with higher and higher dispersed phase flow rates we would like to operate the heat exchanger just short of the flooding rate.

Both isobutane and brine streams are circulated by high pressure plunger pumps. These pumps are positive displacement types and their flow capacity is a function of cylinder volume and pump speed. Fixed speed motors drive these pumps by means of a vee belt drive and the flow is controlled by varying the amount of fluid flowing through a by-pass valve, which returns fluid from the pump discharge back to the pump suction.

During the previous test program these pumps were putting out their maximum capacity and yet the heat exchanger was easily handling this flow and was apparently able to accept even higher flows. At this point the indicated brine flow was 5.5 GPM and the isobutane flow was 10 GPM.

The calculated heat transfer coefficients (U_V) were 5,500 BTU/HR- F-ft^3. for the assumed preheater section and 6,500 BTU/HR F-ft^3. for the boiler.

To increase the flow rates, new sheaves were installed on the pumps and motors to increase the speed by 20%. The corresponding indicated flow rates were then 11.9 GPM for the isobutane and 6.6 GPM for the brine.

A heat balance was constructed about the preheater and boiler using data obtained on 12/16/77; considered as a "typical" run. Table 4-1 gives a summary of the operating data and heat balance results. The calculated

TABLE 4-1
TYPICAL RESULTS*

Indicated C_4H_{10} Flow (GPM)		11.9
Corrected C_4H_{10} Flow (GPM)		10.8
C_4H_{10} Flow (LB/HR)		3026
Indicated Brine Flow (GPM)		6.7
Corrected Brine Flow (GPM)		7.9
Brine Flow (Lb/Hr)		3065
Brine Inlet Temp (F)		323
C_4H_{10} Inlet Temp (F)		71
Brine Outlet Temp (F)		145
Boiler Vapor Outlet Temp (F)		225
Boiler Pressure (PSIA)		318.7
Water Carryover (Lb/Hr)		43
Water Vapor Pressure (psia)		16.2
C_4H_{10} Sat. Pressure (psia)		302.5
C_4H_{10} Boiling Temp. (F)		217
Q - Preheat (Btu/Hr)	Liquid-Liquid	302049
LMTD (F) (preheat)	Liquid-Liquid	34.1
H (ft) (Letan Kehat)	Liquid-Liquid	6.1
U_V (Btu/Hr - F - Cu ft)	Liquid-Liquid	7284
Q Boiling(Btu/Hr)	Boiling	327053
LMTD - (F) (boiling)	Boiling	40.8
H (ft)(Total - boiling)	Boiling	4
U_V (Btu/Hr F Cu ft)	Boiling	10200
C_4H_{10} Inlet (Lb/ft^3)		34.8
brine inlet (lb/ft^3)		56.5
** Q - radiation loss (Btu/Hr - ft^2- F)		3.58
Brine Inlet Temp to Preheater (F)		229

* December 16, 1977 time 1805

** Experimentally measured by flowing only brine through column and recording inlet and outlet temps.

heat transfer coefficients for these higher mass flow rates are 7284 BTU/HR- F-ft^3 and 10,200 BTU/HR- F-ft^3 for the preheat section and boiler respectively. These are significantly higher as expected.

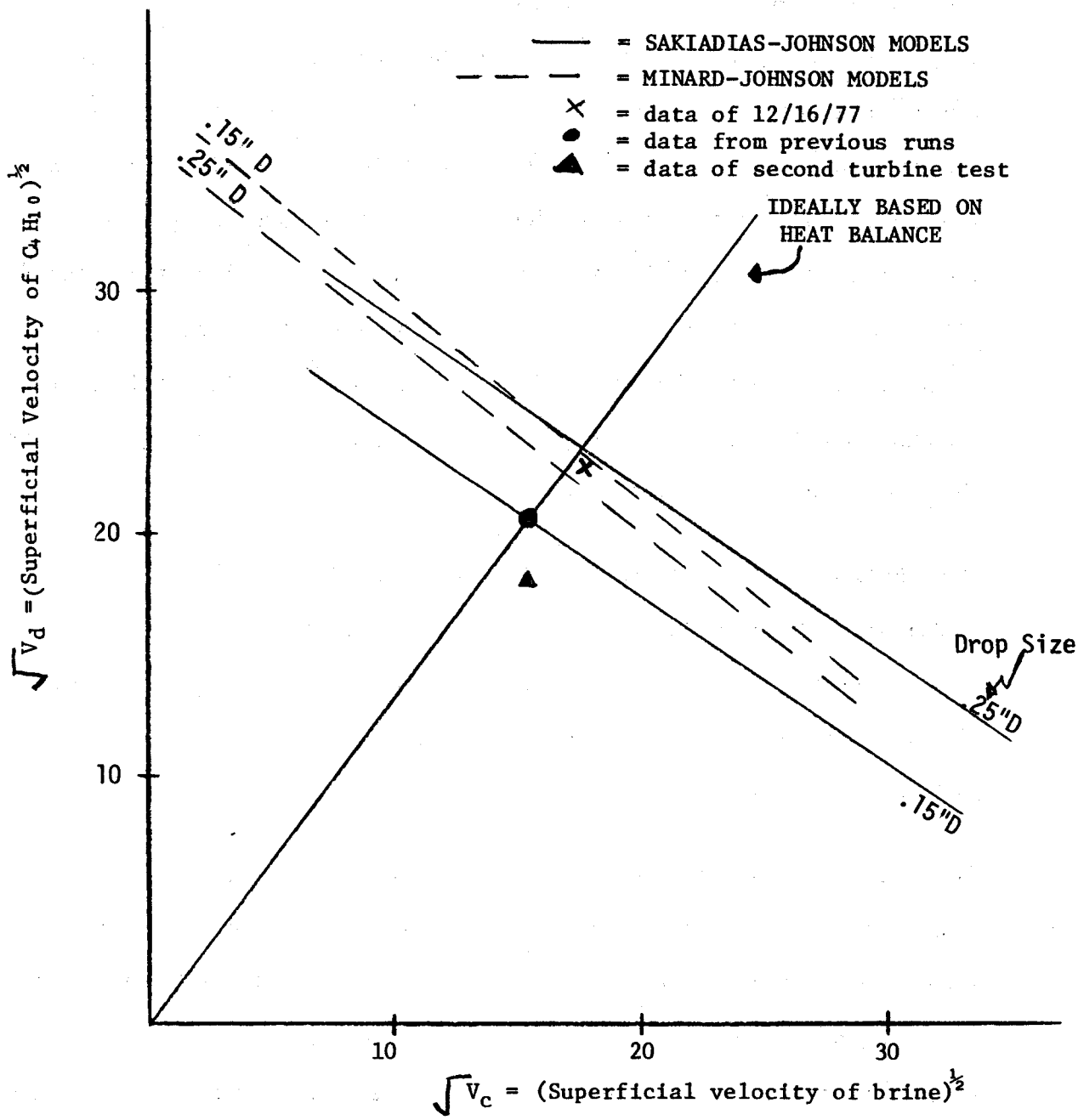
The flooding mechanisms usually applied, at least in theory, to predict flooding in spray towers may have been changed when the direct contact preheater was combined with the direct contact boiler. Normally, flooding in an Elgin-type Tower occurs from the top down. In other words, isobutane droplets arrive at a liquid-liquid interface where they coalesce. The rate of coalescence is usually independent of the dispersed phase flow rate, so that as the flow is increased, droplets start "backing up" underneath the interface. The zone of closely packed droplets continues to move downward until droplets are rejected from the bottom of the column of brine. This is flooding as defined earlier.

The two most popular theoretical equations relating to the flow rates of the phases in a spray column at the "flooding point" are: 1) the Minard-Johnson model[8] and the Sakiadis-Johnson[9] model. These relate column diameter and dispersed phase droplet diameter to the superficial velocities in the column. Both models are presented in Appendix A to this report.

To correlate flooding conditions predicted by these models with the direct contact heat exchanger performance, the theoretical equations were rearranged into a form suitable for plotting and then fitted with the appropriate DCHX operating data. The resulting curves are shown in Figure 4-1. Since both models are dependent on isobutane droplet size, two curves for each model were included for sensitivity comparison; one for a .15 inch diameter droplet

FIGURE 4-1

SUPERFICIAL VELOCITIES OF ISOBUTANE AND BRINE AT FLOODING



and one for a .25 inch droplet. Three data points are shown. One data point represents the high flow rate run of December 16th, one point indicates a typical initial run at 5.5 gpm brine and 10 gpm isobutane and the third point represents data summarizing the DCHX performance during the second turbine test which will be discussed in a later section of this report.

Both models indicate that the December 16 run should have been at or very near flooding. Unfortunately, based on "sniff tester" results of the effluent brine, flooding was never observed. This leaves us in doubt as to how close we actually came to flooding the DCHX and how much more the heat transfer coefficient can be increased by increasing the mass throughput.

However, since flow rates per tower cross sectional area have a direct bearing on performance and cost of equipment, the 20% increase of flows accomplished in our test heat exchanger implies that the tower diameter can be decreased approximately 10% at a substantial saving.

4.2 Determine Relationship of Column Height to Thermal Performance

This task was conceptually aimed at defining the individual height of the preheating and boiling sections of the direct contact heat exchanger. Since there is no mechanical device or physical barrier separating the vertical column into a preheater and vaporizer, we do not know the exact volumes of the two sections or the corresponding heights required for each section.

This task called for incrementally lowering the apparent level in the column (while maintaining constant isobutane inlet temperature and brine inlet temperature) and measuring the variation in heat transfer performance. By lowering this level, the preheating height should be shortened

and, as a result, the boiling pressure would be expected to decrease according to the Letan Kehat relationship (see Appendix B).

During the November and December experiments, this task was attempted by first adjusting the apparent free surface level until it was observed in the upper sight windows, and the unit was stabilized. Then, using the upper windows as a reference level, the apparent brine level was lowered again. Unfortunately, each time this was attempted, the unit became erratic as evidenced by fluctuating flows, level, overhead pressure and temperature and could not be controlled.

In changing the operating levels in the boiler, three distinct flow regions were observed and defined. From top to bottom, they are:

1. Turbulent Vapor Flow
2. Gray Frothing Liquid (very turbulent)
3. Clear Liquid with well formed small clear droplets rising through darker clear brine.

It was noted that a layer of vapor was visible above the turbulent boiling zone. This may have been water vapor mist caused by cooling of the water vapor by the isobutane vapor. Another observation was that the brine free surface level in the "Bullseye" was usually seven inches higher than the brine level indicated in the level gauge glass.

Although the attempts to verify the Letan Kehat theoretical model by adjusting the column height were unsuccessful during the November and December experiments, it was decided to use the data of December 16, 1977 (see Table 4-1) in the model as an initial indication of its validity and the overall predicted temperature profiles.

The initial attempts at fitting the data to the model resulted in an effective predicted preheater height of 9.3 feet which was greater than the observed height of the interface. The Values of M (ratio of wake to drop volumes) = .83 and m (volume of wake elements shed per volume of drop and unit length of column $-cm^{-1}$)=.03 were used for the calculations. These were suggested as average values to be used by Letan and Kehat in their original report[7].

Since the data did not fit the model, it was decided to make a sensitivity analysis to determine the overall effect of the values of M and m on the predicted effective height. This is shown as Table 4-2. From this analysis it was evident that changing the values of either M or m (or both) would affect the overall predicted value of the effective height ($\mathcal{Z}$) without significantly affecting the calculated value of the brine inlet temperature t_c. Based on these results it was decided to choose values of M and m that would set the predicted height $\mathcal{Z}$ at the observed boiling interface. These values are: M = .70 and m = .9141 ft^{-1}.

Figure 4-2 is a schematic representation of the model using these values and the other parameters calculated from the data of December 16, 1977. As indicated in the figure, the predicted boiling level, or interface between preheater and boiler, calculated at an overall height of 10.2 feet. However, since the isobutane dispersion plate outlet is approximately two feet up from the bottom of the column, and since by definition the heat transfer in the wake growth zone ($\mathcal{Z}<0$) is negligible, the overall effective calculated heightof the preheater matches the observed height.

TABLE 4-2

LETAN KEHAT MODEL

SENSITIVITY OF VALUES FOR M & m TO PREDICTED

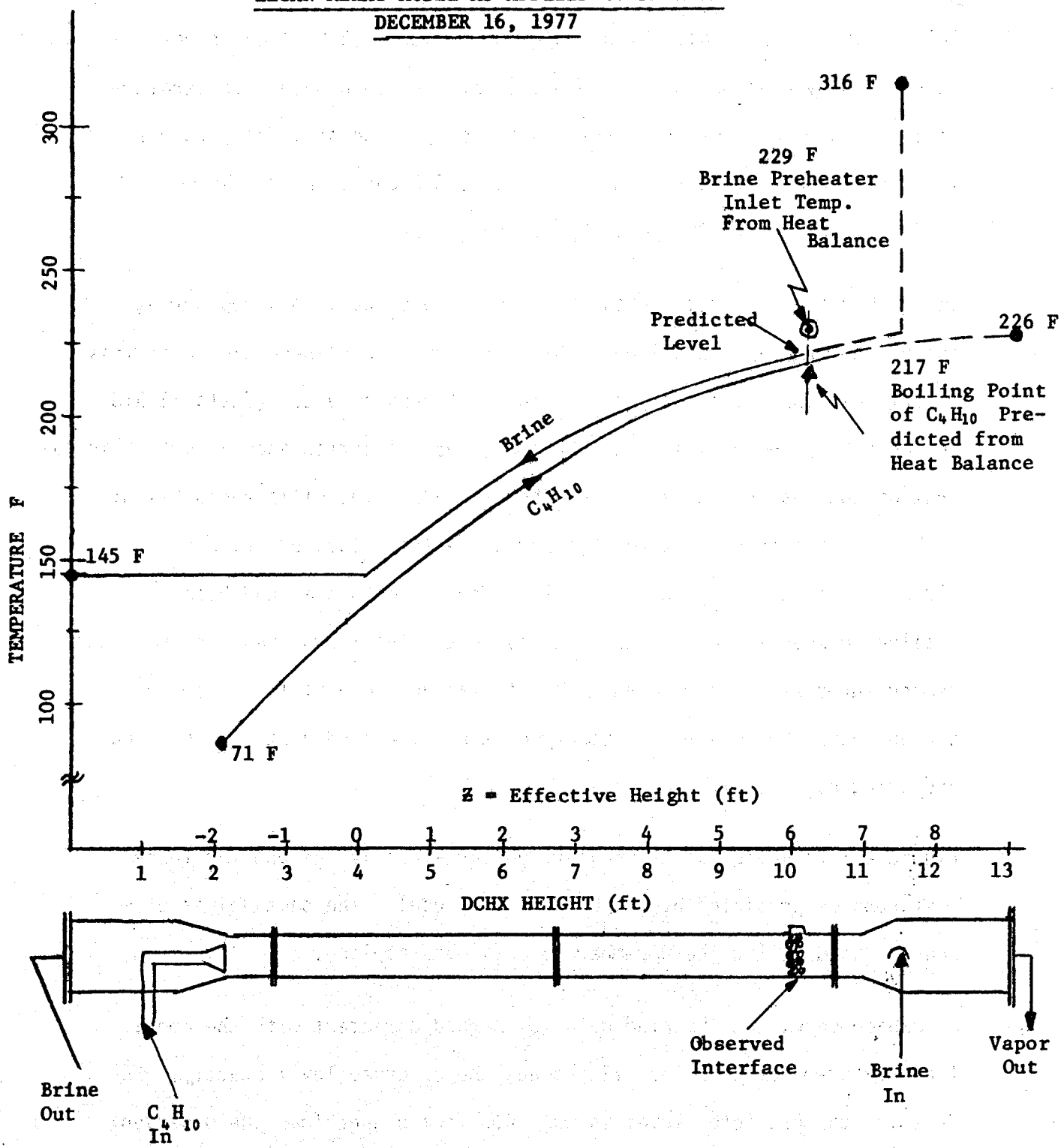
COLUMN HEIGHT

(Data Set: December 16,1977)

M	m	Z	T_c(calculated)
.62(dimensionless)	.92(ft^{-1})	6.2(feet)	219 (°F)
.62	.97	5.9	219
.65	.97	6.3	219
.83	.9144	9.3	218
1.0	.9144	12.1	195
.60	.9144	6.4	220
.60	.45	12.5	219
.83	.7	12.1	219
.60	.97	5.7	219
.60	.95	4.8	220
.83	.97	10.6	218
.4	.46	7.8	220
.4	.97	3.7	220
.7	.9144	6.2	220

FIGURE 4-2

LETAN KEHAT MODEL AS APPLIED TO DATA OF DECEMBER 16, 1977



Also shown in the figure are the isobutane boiling point temperature (217 F) and the preheater brine inlet temperature (229 F) which were calculated by heat balance. These indicate a "pinch point" temperature of 11 F. It is interesting to note that the Letan Kehat model predicts an isobutane boiling point temperature of 218 F and preheater brine inlet temperture of 220 F, or a "pinch point" of 2 F.

In further support of the Letan Kehat equations, data obtained during the brine carryover experiments (5/31/78 through 6/9/78-section 6 of this report) was applied to the model. The test runs selected (Tests 12 &13 in Table 6-1) showed mass flow rates and overall performance most similar to that of the test conducted on December 16,1977. The differences being: 1) brine was introduced through a new brine inlet located below the old spray inlet (see Figure 6-2); 2) a few thermocouples had been installed between the brine inlet and isobutane inlet and these intermediate temperatures were recorded and; 3) data was recorded at two different observed operating levels. A summary of the calculated heat balances and operating data is given in Table 4-3.

Figure 4-3 is a plot of temperature versus effective height for these test runs as predicted by the Letan Kehat model. The same values of M and m used to fit the December 16 data were applied.

As can be seen, the observed data is in good agreement with the model. The predicted level in Test 12 matches the observed level exactly. In Test 13, the predicted level is only 0.3 feet higher than the observed level.

As before, the model is not in exact agreement concerning the observed

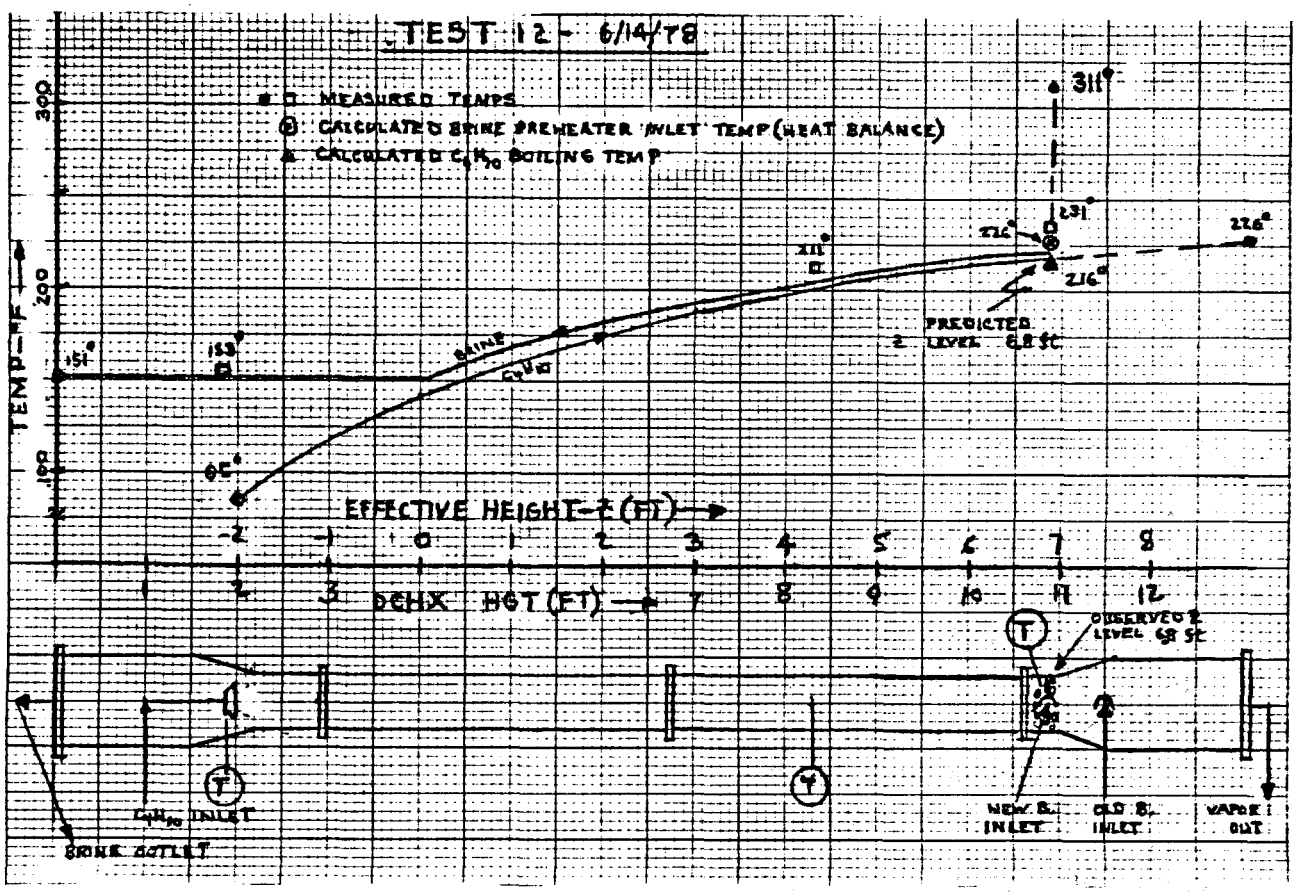
TABLE 4-3

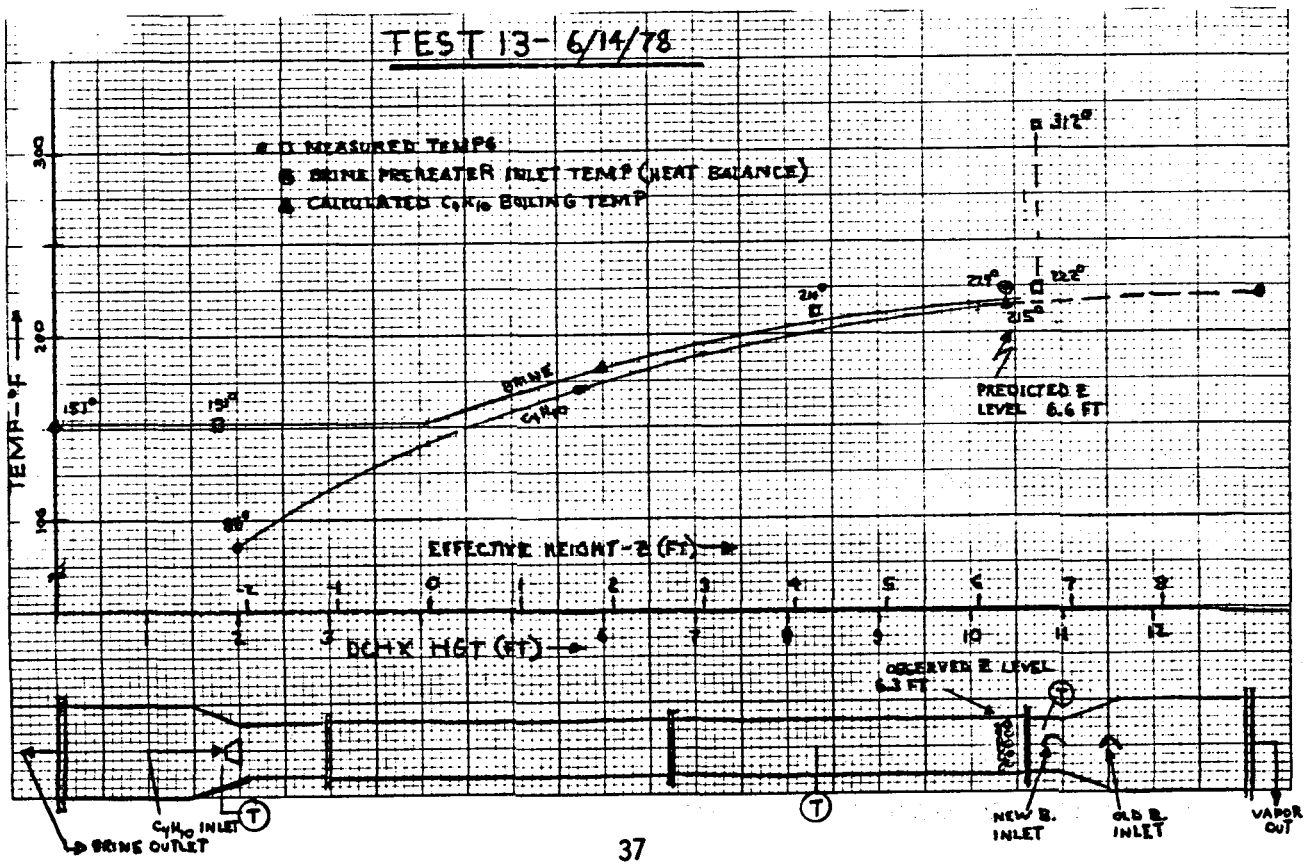
HEAT TRANSFER DATA FOR TEST 12 (6/14/78 & Test 13 (6/14/78)

		TEST 12(6/14/78)	Test 13(6/14/78)
INDICATED C_4H_{10} FLOW (gpm)		10.7	11.0
CORRECT C_4H_{10} FLOW (gpm)		9.8	10.1
C_4H_{10} MASS FLOW (lbs/HR)		2697	2743
INDICATED BRINE FLOW (gpm)		6.4	6.3
CORRECTED BRINE FLOW (gpm)		7.5	7.5
BRINE MASS FLOW (lbs/HR)		3438	3388
BOILER VAPOR WATER CONTENT (lbs/HR)		47	43.8
TOTAL BOILER VAPOR PRESSURE (psia)		316	314
ASSUMED C_4H_{10} VAPOR PRESSURE (psia)		300	298
ASSUMED H_2O VAPOR PRESSURE (psia)		15.9	15.7
BOILER VAPOR OUTLET TEMPERATURE (°F)		226	225
BRINE INLET TEMPERATURE (°F)		312 (calc.)	311(calc.)
BRINE OUTLET TEMPERATURE (°F)		152.4	151
C_4H_{10} (liq) INLET TEMPERATURE (°F)		85	85
BRINE INLET DENSITY (lbs/ft^3)		56.9	56.5
C_4H_{10} (liq) INLET DENSITY (lbs/ft^3)		34.2	34.2
CALCULATED C_4H_{10} BOILING TEMPERATURE (°F)		216	215
Q - preheat (BTU/HR)	LIQUID-LIQUID	252290	245445
LMTD - PREHEATER (°F)	LIQUID-LIQUID	30.1	28.6
Z (ft) (LETAN KEHAT)	LIQUID-LIQUID	6.8	6.6
U_V (BTU/HR-F-ft^3)	LIQUID-LIQUID	6281	6626
Q - Boiler (BTU/HR)	BOILER	297391	305222
LMTD - Boiler (F)	BOILER	35.3	34.1
Z (ft) BY DIFFERENCE	BOILER	3.5	3.7
U_V (BTU/HR-F-ft^3)	BOILER	12265	12327
Z (ft) OBSERVED INTERFACE		6.8	6.3
Q Radiation loss (BTU/HR-Ft^2-F)		3.58	3.58
BRINE INLET TEMPERATURE TO PREHEATER		226	224

FIGURE 4-3

DIAGRAMATIC REPRESENTATION OF LETAN KEHAT MODEL APPLIED TO TEST 12 & 13





and calculated temperatures in the upper section of the column. In all cases the "pinch point" predicted by the model is less than the calculated "pinch point".

It is evident that further experiments are required to optimize the model for use in DCHX applications. Additional thermocouples should be added in the mid-section of the DCHX column to check the actual temperature profiles against those predicted. Also, the model should be checked against a wider span of observed free surface levels.

SECTION 5

SECOND TURBINE TEST

SECTION 5

SECOND TURBINE TEST - ENDURANCE RUN

At the completion of the "500 hour" endurance run concluding the "First Turbine Test", the turbine, connecting piping, and a portion of the direct contact heat exchanger were disassembled and inspected for evidence of scaling. The only scale deposition noted was in the turbine nozzles, particularly in the end of the supersonic expansion cone. Analysis of the scale showed the primary constituents being oxides of silica and iron. The remainder of the loop was in good condition with no evidence of distress that would hamper continual operation.

Based on these results a second turbine test was scheduled with modifications expected to minimize brine carryover to the turbine, thus reducing scale and erosion possibilities.

5.1 Modifications and Preparation

The basic test loop consisted of the same components used for the first turbine test. These included a direct contact heat exchanger, an isobutane separator, a stripping column, a condenser, a hotwell, a brine feed pump, an isobutane circulation pump, a brine blowdown pump, a "hairpin" surface type heat exchanger, an axial flow turbine, a double reduction turbine gearbox, a torque meter and readout, a generator, a speed control, and an air cooled resistive load bank.

A knockout drum was installed upstream from the turbine inlet to ensure that no liquid droplets were carried into the turbine. A photograph of the installed knockout drum is shown as Figure 3-4. The drum was designed and installed by Barber-Nichols Co. and resembles a standard cyclone separator. The unit had a diameter of 6 inches and an overall height of about 36 inches. Isobutane vapor entered the unit tangentially through a 2" pipe and traveled downward in a spiral path, underneath a cylindrical shroud, and thence upward through a 6 inch mesh pack. The liquids removed from the vapor were collected

at the bottom and were to be drained automatically by a steam trap.

Two problems were encountered with the knockout drum. The liquid level in the sump of the vessel could not be determined because a gage glass was not installed. Secondly, the steam trap did not work satisfactorily.

In addition to the instrumentation and safety devices used for the First Turbine Test as outlined in the Final Report issued by Barber-Nichols[2], a new safety control valve and flow meter were added to the circuit. The control valve was a solenoid operated air energized valve that was located between the isobutane vapor supply line from the DCHX and the turbine exhaust line. This valve was normally closed, but would open on receiving the "scram" signal generated when the turbine inlet valve closed, thus depressurizing the system to the condenser.

A differential pressure orifice plate flow meter and associated recording chart were installed on the spent brine line just upstream of the final flashdrum. This was used to measure brine flow during the "hairpin" calibration tests.

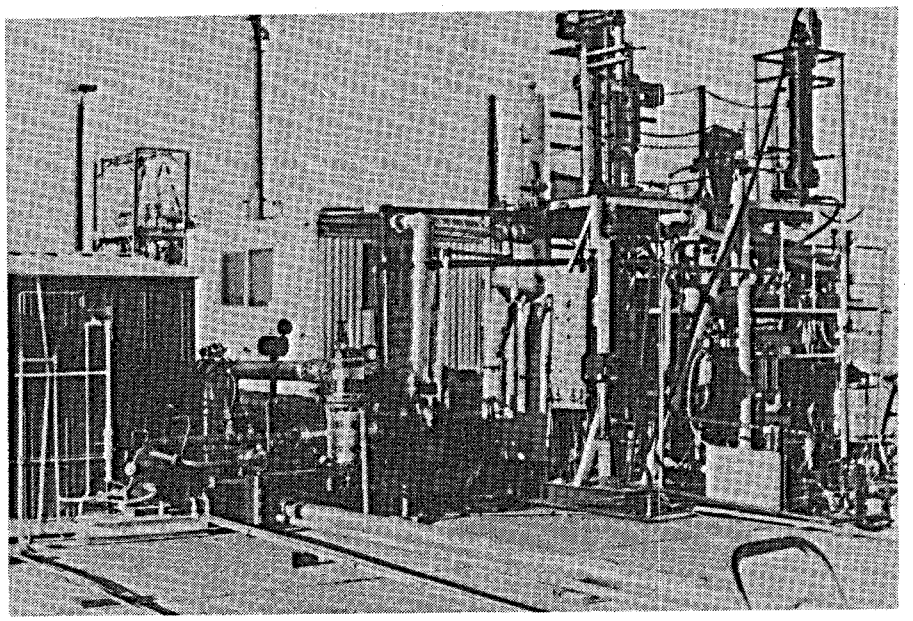
Photographs were taken of the complete loop prior to starting the run. Some of these showing the general layout and individual equipment are included in this report as Figures 5-1 through 5-6.

An updated P & I diagram showing the general relationship of the components is shown on page 44.

Prior to the start of the endurance test, all instrumentation was cleaned, inspected and recalibrated. Safety valves, pressure switches, pressure gages and electrical relays were tested and/or calibrated to ascertain safe operation during the run. As a final safety check the complete loop was hydrotested.

FIGURE 5-1

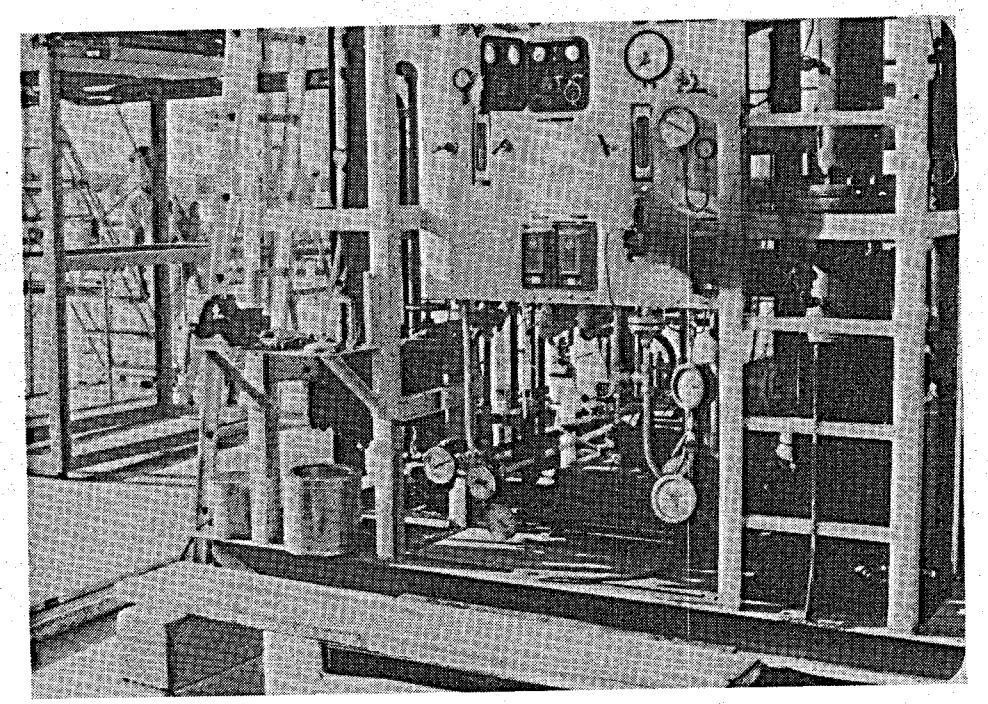
GENERAL LAYOUT - TURBINE, "HAIRPIN" EXCHANGER, KNOCK-OUT DRUM, DCHX MODULE, TWO-TUBE VERTICAL CONDENSER (OAK RIDGE TEST - SEE SECTION 8.0)



XBB 791-594

FIGURE 5-2

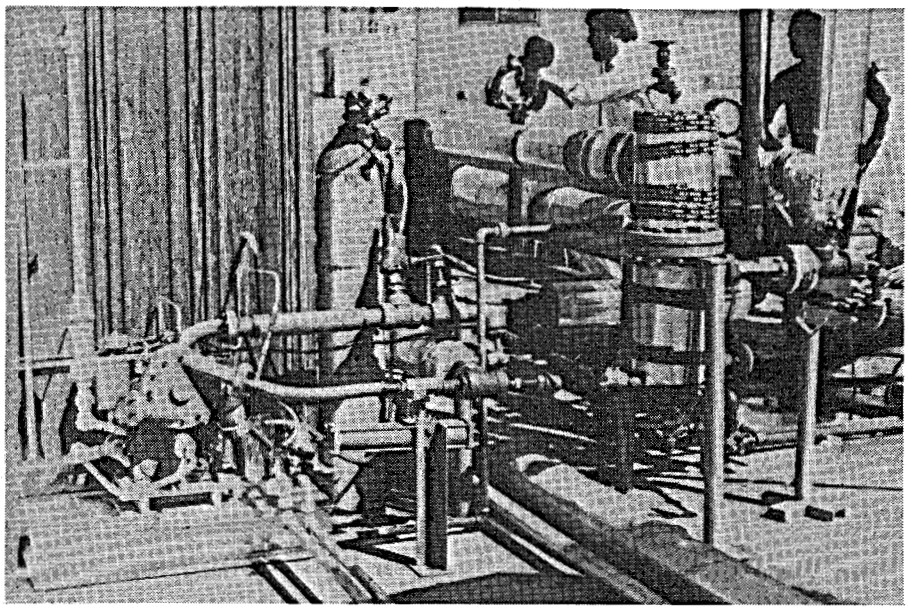
THE DCHX MODULE CONTROL PANEL



XBB 791-595

FIGURE 5-3

TURBO-GENERATOR ASSEMBLY CONSISTING OF AN AXIAL FLOW, PARTIAL ADMISSION TURBINE, A DOUBLE REDUCTION GEARBOX, AND A 60KW-3600 RPM KATO GENERATOR (NOT SHOWN). COURTESY OF BARBER-NICHOLS ENGINEERING COMPANY



XBB 791-604

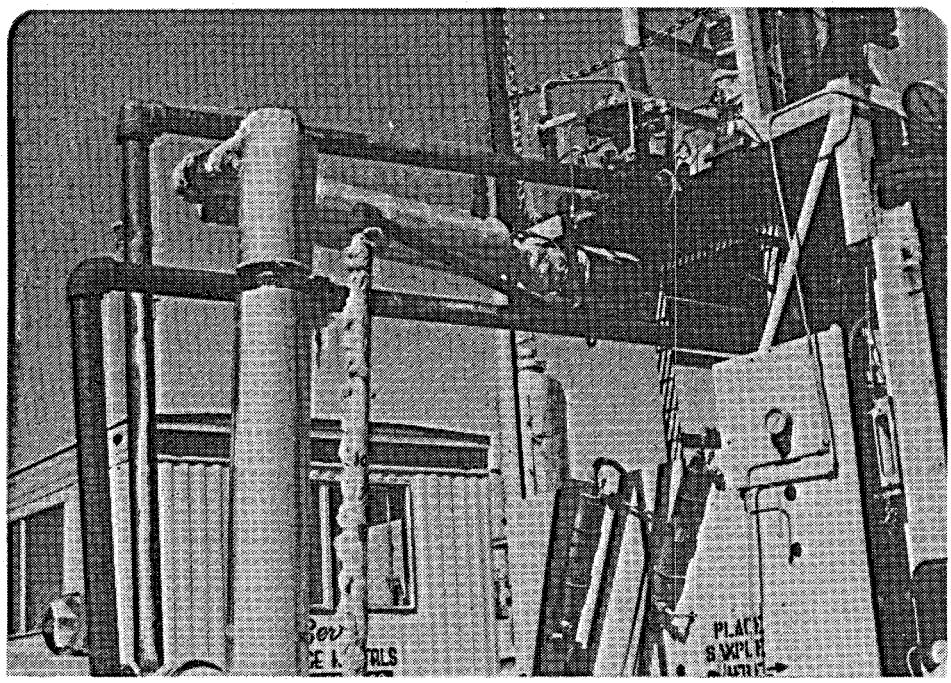
FIGURE 5-4

KNOCK-OUT DRUM

XBB 791-605

FIGURE 5-5

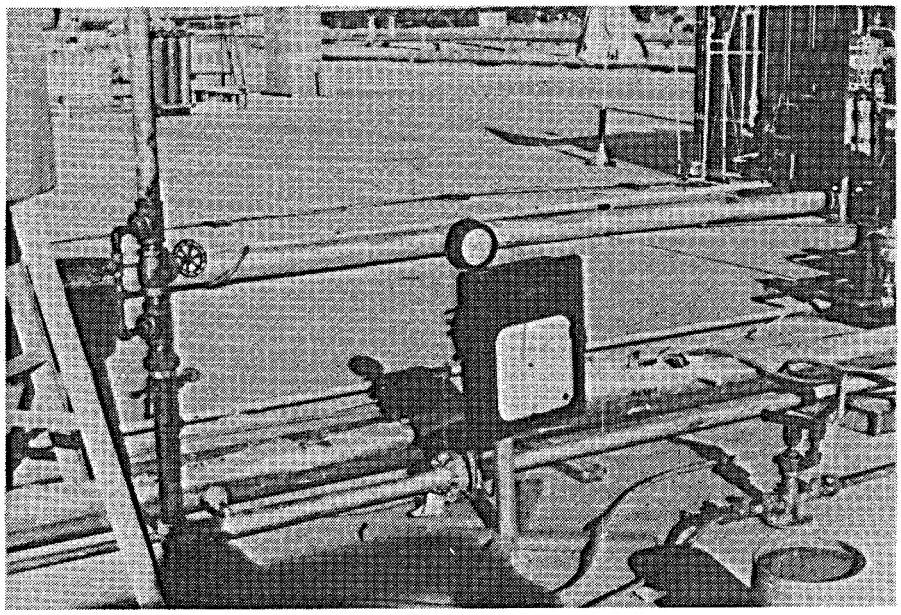
SOLENOID OPERATED CONTROL VALVE - ENERGIZED BY "SCRAM" SIGNAL TO DIVERT ISOBUTANE VAPOR DIRECTLY TO CONDENSER SHOULD TURBINE INLET VALVE CLOSE



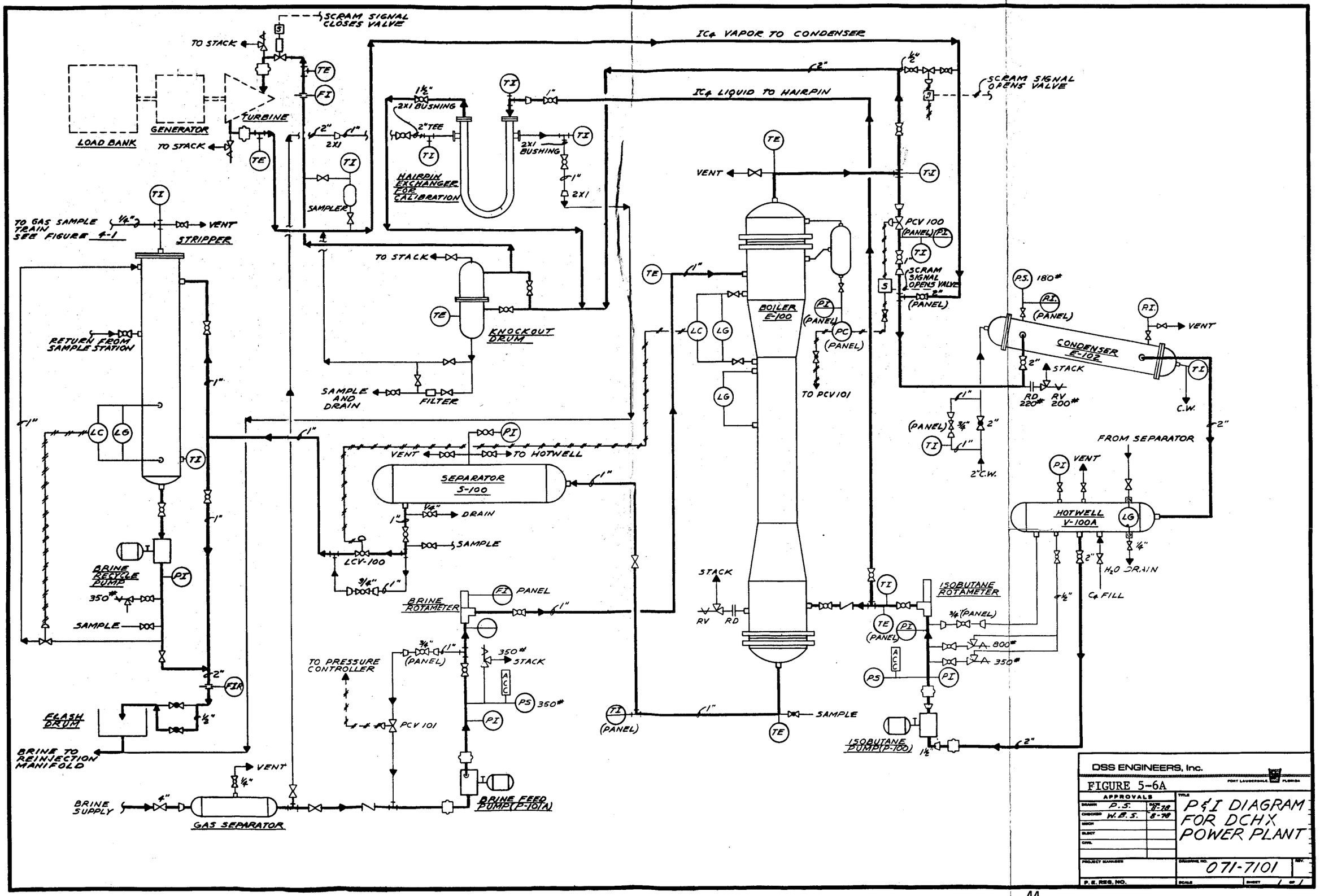
XBB 791-598

FIGURE 5-6

DIFFERENTIAL PRESSURE FLOW METER - USED TO MEASURE EFFLUENT BRINE FLOW FROM "HAIRPIN" EXCHANGER DURING TURBINE CALIBRATION



XBB 791-599


SCRAM SIGNAL CLOSES VALVE
TO STACK
LOAD BANK
GENERATOR
TURBINE
TO STACK
IC4 VAPOR TO CONDENSER
IC4 LIQUID TO HAIRPIN
SCRAM SIGNAL OPENS VALVE
2X1 BUSHING
2"TEE
HAIRPIN EXCHANGER FOR CALIBRATION
2X1 BUSHING
SAMPLER
TO GAS SAMPLE TRAIN SEE FIGURE 4-1
VENT
STRIPPER
TO STACK
KNOCKOUT DRUM
RETURN FROM SAMPLE STATION
SAMPLE AND DRAIN
FILTER
VENT
BOILER E-100
(PANEL)
TO PCV101
PCV 100
(PANEL)
SCRAM SIGNAL OPENS VALVE
(PANEL)
P.S. 180#
(PANEL)
CONDENSER E-102
VENT
STACK
RD 220#
RV 200#
C.W.
(PANEL)
2"C.W.
FROM SEPARATOR
VENT
VENT
TO HOTWELL
SEPARATOR S-100
DRAIN
SAMPLE
LCV-100
HOTWELL V-100A
H2O DRAIN
C4 FILL
BRINE RECYCLE PUMP
350#
SAMPLE
BRINE ROTAMETER
PANEL
STACK
RV
RD
ISOBUTANE ROTAMETER
(PANEL)
800#
350#
TO PRESSURE CONTROLLER
(PANEL)
350#
STACK
350#
PCV 101
(PANEL)
SAMPLE
ISOBUTANE PUMP (P-100)
FLASH DRUM
BRINE TO REINJECTION MANIFOLD
VENT
BRINE SUPPLY
GAS SEPARATOR
BRINE FEED PUMP (P-101A)
DSS ENGINEERS, Inc.
FIGURE 5-6A
APPROVALS
P.S.
W.B.S.
P&I DIAGRAM FOR DCHX POWER PLANT
071-7101

Rupture discs were removed and blank flanges were inserted and/or segments of the process piping and safety valves isolated. Then the unit was hydrotested to accommodate three separate pressure ranges; the boiler and piping for subcritical operation (315 psia design pressure), the isobutane pump, vapor piping and turbine for supercritical operation (600 psia design pressure), and the condenser at a design pressure of 200 psia.

After successful pressure testing, all blank flanges were removed and new rupture discs were reinserted in the circuit.

5.2 Hairpin Calibration

Calibration tests were performed prior to the endurance run using "pure" (no water or brine contamination) isobutane vapor generated in a conventional "hairpin" brine-to-isobutane surface heat exchanger. The object of these tests was to obtain baseline turbine and cycle performance data to be used by Barber Nichols Engineering in evaluating results of the direct contact heat exchanger tests and also to compare with the test results from the First Turbine Test. It was agreed beforehand that Barber Nichols would set the test conditions and take the necessary data and DSS would operate the DCHX loop accordingly.

The DSS DCHX isobutane operating loop was used as a calibration loop with the DCHX being replaced by the "hairpin" exchanger. The loop was instrumented to obtain turbine and cycle efficiencies over a range of operating parameters such as: amount of superheat, turbine pressure ratio, isobutane flow rate and gearbox output shaft speed.

The subcritical tests were run by setting the operating parameters, taking data, then changing one of the parameters and repeating the test. The isobutane flow rate was set by adjusting the isobutane pump bypass control and noting the isobutane flow meter on the DCHX control panel. The turbine inlet temperature was set by controlling the flow of brine to the hairpin using the new flow meter and

control valve installed in the brine discharge line. The turbine shaft speed was then controlled by adjusting the load bank with the generator speed controller.

When sufficient data was collected under subcritical conditions, a series of tests were run showing loop performance under supercritical conditions. The test sequence and procedure for the supercritical tests was the same as that used for the subcritical tests.

A full set of calibration data was collected by Barber-Nichols to use in turbine performance evaluation while spot check data was collected by DSS to ensure operation of the DCHX was meeting the requested test conditions. This spot check data is shown as Table 5-1.

The actual total time for calibration was 7 days. Upon completion of the subcritical and supercritical calibration tests, the hairpin exchanger was valved off and the endurance run was started. The operating parameters for the endurance run were selected from results of the subcritical isobutane calibration.

5.3 Endurance Run

The overall objective of DSS Engineers was to operate the DCHX Isobutane Loop up to a maximum of 200 hours in order to support Barber-Nichols turbine test efforts. The goals of this endurance run were 1) to evaluate turbine scaling problems associated with the DCHX with entrained moisture removed from the turbine vapor flow; 2) augment and verify experimental data obtained during the first turbine test and; 3) obtain additional data on the stripping column.

The endurance run began at 1345 on March 25, 1978, and was completed at 1510 hours on April 3, 1978. During this time period the DCHX loop accumulated a total of 203.9 hours and the turbo-generator accumulated 200 hours running

TABLE 5-1

HAIRPIN CALIBRATION - 2ND TURBINE TEST

DATE	WELL NO.	TEST CONDITION	TIME	BRINE INLET TEMP (°F)	BRINE OUTLET TEMP (°F)	BRINE FLOW (gpm)	ISOBUTANE INLET TEMP (°F)	ISOBUTANE OUTLET TEMP (°F)	ISOBUTANE FLOW (gpm)	TURBINE INLET (psi)	TURBINE OUTLET (psi)
3/16/78	6-2	SUB CRITICAL	2:07	330	145	4.8	80	209	9	180	42
			2:13	330	143	4.8	80	-	9	185	47
			2:17	-	140	4.8	79	199	9	240	46
			2:25	332	145	4.4	78	197	9	239	45
			2:33	-	150	4.8	78	199	9	245	46
			2:48	335	155	5.3	78	220	9	250	49
			2:53	336	156	5.2	78	221	9	250	49
			3:18	336	162	5.0	79	232	9	260	50
			3:29	336	162	5.5	77	239	9	258	50
			3:52	-	175	6.5	80	268	9	262	50
			3:58	336	176	6.5	79	273	9	268	51
			4:37	336	173	6.6	80	243	10.6	300	56
3/17/78			9:55	337	177	7	82	260	10.8	308	63
			10:23	-	218	9.5	81	309	10.2	304	63
			10:56	338	170	6.1	80	246	10.0	287	79
			-	338	177	7.1	82	271	10.0	298	87
			11:58	338	180	7.0	-	261	10.6	308	63
			3:21	330	165	5.4	83	250	8	230	52
			3:46	335	153	4.2	83	218	8	225	52
3/20/78			3:00	1-	165	5.8	84	243	10	262	60
			-	1-	160	5.5	84	231	10	260	60
			-	-	160	5.2	85	216	10	255	60
3/22/78			11:18	-	175	6.7	82	239	11	315	56
			-	-	166	6.1	80	220	11	310	54
3/23/78	6-1	SUPER CRITICAL	11:01	331	226	5.5	77	294	9.4	585	53
			11:30	330	216	4.8	77	290	9.4	565	53
			12:08	328	180	3.0	78	271	9.4	515	52
			2:44	328	166	2.6	79	267	9.4	500	52

time. Two personnel from Barber-Nichols and three from DSS Engineers, Inc. worked rotating shifts such that one technician from each company manned the test loop on a 24 hour a day, 7 day a week basis. In addition, two engineers from DSS and one from Barber-Nichols were present to provide technical engineering support.

As with the calibration tests, Barber-Nichols was responsible for setting the operating parameters and taking data necessary for turbine efficiency and scaling evaluations. However, DSS Engineers did collect data as a spot check on overall loop performance. This data is shown in Table 5-2.

During the endurance run, the DCHX loop and the turbo-generator were shut down for a total of 14.8 hours for various reasons. The overall on-stream factor was 93.2%. A summary of downtime and cause is shown in Table 5-3.

The largest single cause for shutdown was for transferring from one supply well to another. Brine supply well 6-2 was used to initiate the run. Then, the experimenters were informed by LBL that well 6-2 was scheduled for periodic maintenance and "acid-dosing" on March 27, 1978. Transfer was made on that date to supply well 8-1 causing a 3.5 hour downtime delay. However, after several unsuccessful attempts to restart the rig were made, it was discovered that the brine temperature and pressure from supply well 8-1 were too low to accommodate operation demands (manifold temperature @ 305 F and pressure @ 80 psig). Therefore, it was decided to switch back to supply well 6-2 for the remainder of the run. These incidents caused an additional 4.25 hours of delay.

Isobutane consumption or loss was monitored throughout the run. After initial filling of the loop at the onset of the endurance run, a total of 596 pounds of isobutane was added to maintain a constant operating level in the loop. Figure 5-7 A shows the cumulative isobutane added as a function of hours of operation.

TABLE 5-2

2ND TURBINE ENDURANCE TEST - PERFORMANCE DATA SUMMARY OF DCHX - ISOBUTANE POWER LOOP

DATE	3/26/76	3/26/78	3/26/78	3/27/78	3/27/78	3/31/78
TIME	9:07	9:45	12:45	8:34	3:32	10:15
WELL NO.	6-2	6-2	6-2	6-2	8-1	6-2
DCHX						
Vapor - psig	300	300	300	300	305	320
IC_4 Flow - gpm	9.4	9.1	9.4	9.1	10.2	9.4
IC_4 Outlet Temp - °F	230	230	228	230	215	230
IC_4 Inlet Temp - °F	78	81	84	77	86	75
Brine Flow - gpm	5.3	5.25	5.25	5.4	5.9	5.75
Brine Outlet Temp. - °F	148	148	147	147	150	149
Brine Inlet Temp. - °F	323	324	322	321	302	316
Condenser Press - psig	70	66	78	60	65	62
*CW Inlet Temp. - °F	59	61	65	59	69	62
CW Outlet Temp. - °F	60	71	76	60	75	71
TURBINE						
Inlet Temp. - °F	225	226	222	224	207	221
Inlet Press. - psig	290	290	290	290	300	305
Outlet Temp - °F	160	164	160	157	133	149
Outlet Press. - psig	69	64	75	61	63	59
RPM	2750	2750	2754	2750	2750	2753

*CW = CONDENSER COOLING WATER

(Con't on next page)

TABLE 5-2 (Con't)

2ND TURBINE ENDURANCE TEST - PERFORMANCE DATA SUMMARY OF DCHX - ISOBUTANE POWER LOOP (Cont'd)

DATE	4/1/78	4/2/78	4/2/78	4/2/78	4/2/78	4/3/78	4/3/78	4/3/78	AVERAGES 3/26-4/3/78
TIME	8:55	8:34	11:31	12:00	3:32	8:24	9.53	2.54	
WELL NO.	6-2	6-2	6-2	6-2	6-2	6-2	6-2	6-2	
DCHX									
Vapor - psig	310	318	312	312	311	314	315	316	309
**IC_4 Flow -gpm	9.6	9.4	8.9	9.1	9.5	9.3	9.1	8.9	9.3
IC_4 Outlet Temp. - °F	228	228	227	231	229	226	231	232	228
IC_4 Inlet Temp. - °F	72	70	75	73	72	70	70	74	76
**Brine Flow - gpm	5.2	5.4	5.25	5.1	5.5	5.1	5.2	5.1	5.3
Brine Outlet Temp. - °F	138	145	137	137	146	132	133	142	142
Brine Inlet Temp. - °F	320	316	320	319	315	316	318	319	318
Condenser Press - psig	59	59	60	60	62	60	61	60	63
*CW Inlet Temp. - °F	60	57	59	59	61	58	55	61	60
CW Outlet Temp. - °F	-	67	70	70	71	68	68	72	
TURBINE									
Inlet Temp. - °F	217	219	227	222	219	218	225	227	221
Inlet Press. - psig	310	308	305	300	305	305	305	300	300
Outlet Temp. - °F	145	147	161	154	154	150	160	162	154
Outlet Press - psig.	57	56	59	57	62	57	60	59	61
RPM	-	2750	2750	2750	2750	2750	2750	2750	2751

*CW = CONDENSER COOLING WATER

** These are flows as "indicated" by rotameter; correction factors must be applied before use.

TABLE 5-3

2ND TURBINE TEST - DOWNTIME ANALYSIS

DATE	DOWN TIME HRS	REASON	DAILY RUN TIME
3/25	0.25	BN gas alarm drift	11.0
3/26	-0-	-	24.0
3/27	3.5	Transfer to well 8-1	
	4.25	Transfer to well 6-2	16.25
3/28	0.25	120 volt power out	23.75
3/29	-0-	-	24.0
3/30	3.58	Initial shut down due to high gear box psi on turbine proceduralerror in start up resulted in isobutane dump	
	0.25	Turbine nozzle inspection	20.17
3/31	-0-	-	24.0
4/1	-0-	-	24.0
4/2	0.5	BN's gas alarm drift	
	0.25	BN's gas alarm drift	23.75
4/3	2.0	Air compressor down	13.0
TOTALS	14.83		203.9

Overall on-stream factor = 93.2%

DSS on-stream factor = 98.2%

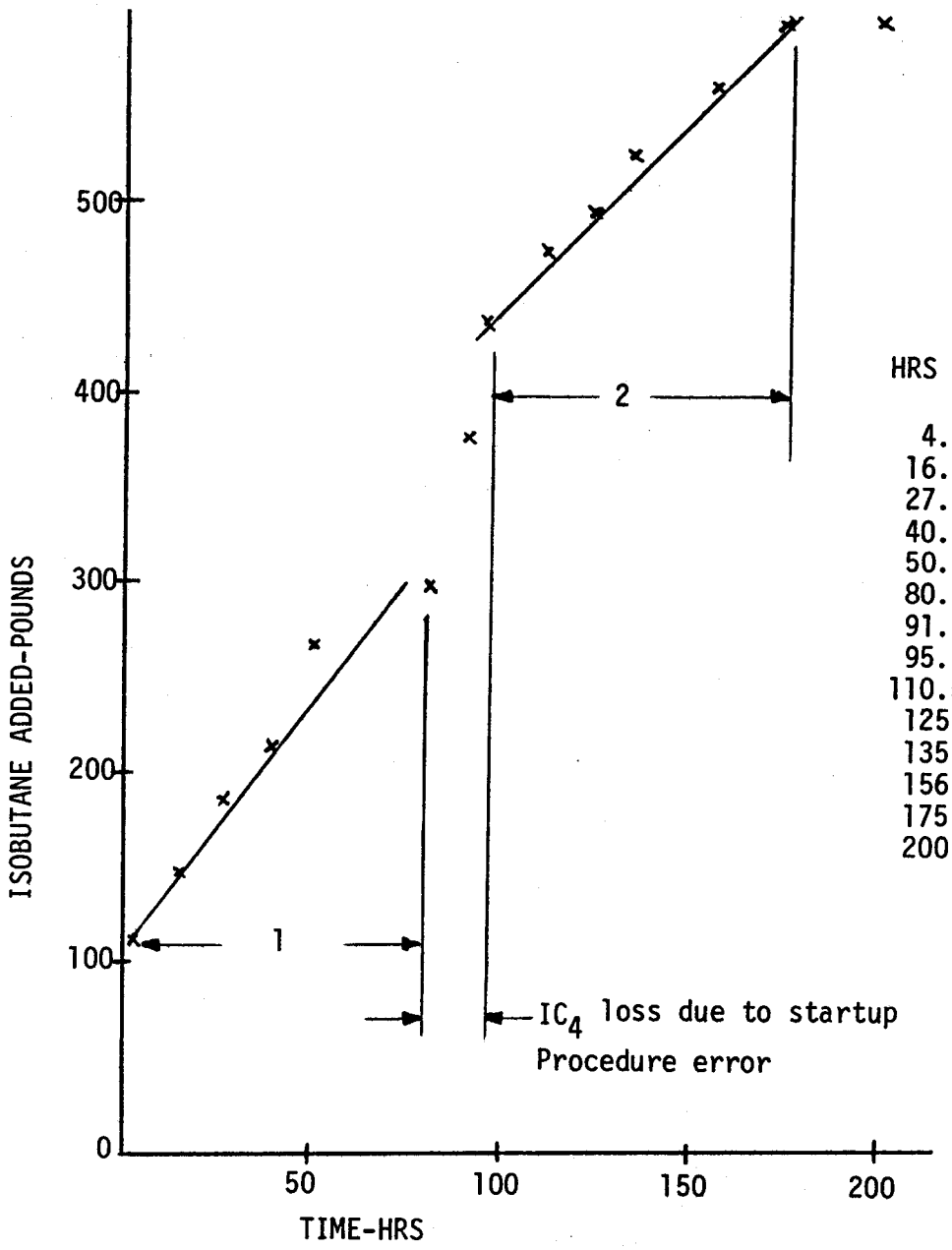
BN on-stream factor = 99.4%

DSS & BN on-stream factor = 97.6%

East Mesa Site on-stream =95.5%

FIGURE 5-7A

ISOBUTANE CONSUMPTION
VS
RUN TIME



HRS Run	TOTAL LBS IC_4 ADDED
4.5	111
16.25	147
27.0	187
40.25	211
50.5	268
80.5	298
91.5	327
95.6	436
110.5	471
125	494
135	526
156	561
175	596
200	596

RUN AVG IC_4 CONSUMPTION = 2.98 lbs/HR
AVG_1 IC_4 CONSUMPTION = 2.46 lbs/HR
AVG_2 IC_4 CONSUMPTION = 2.02 lbs/HR
"NORMAL" AVG CONSUMPTION = 2.24 lbs/HR

The total average isobutane consumption for the run was 2.98 pounds per hour. However, approximately 80 hours into the run, an abnormal isobutane loss occurred as a result of a startup procedure error and 70 lbs of isobutane had to be charged to the rig. Therefore, excluding this loss, the "normal" average isobutane consumption for the run calculates as 2.24 pounds per hour.

The average circulating flow of isobutane measured was 9.3 gpm (8.5 gpm corrected) or 2359 lbs/hr. Thus, the consumption (or losses) of isobutane averaged approximately .095% ($^{wt}/_{wt}$) of the total isobutane being circulated through the loop.

The average measured brine flow during the endurance run was 5.3 gpm (6.28 gpm corrected) or 2856 lbs/hr and the average temperature of the brine leaving the boiler was 142 F. The boiler pressure averaged 315 psia. At these conditions of pressure and temperature the theoretical solubility of isobutane in the brine is approximately 386 ppm (see Section 6 of this report). Thus approximately 1.2 lbs/hr of isobutane lost can <u>theoretically</u> be accounted for as leaving the system solubilized in the effluent brine. This quantity is probably less considering the <u>measured</u> isobutane solubility at 200 ppm (section 6). In any event, it is evident that over half of the "consummed" isobutane probably resulted from leaks about the system.

It should be noted that the "consumption" rate of 2.24 pounds per hour verifies rates reported for the First Turbine Test.

5.4 Teardown Inspection Results

At the conclusion of the endurance run the Direct Contact Heat Exchanger Loop was dismantled and the internals given a thorough inspection. The internal surfaces showed no unusual scale deposits or other evidence of high levels or brine carryover. The surfaces were just as they have been in previous inspections. There was a very thin uniform layer of scale

covering the carbon steel surfaces which was not deposited during the run, but a result of nearly two years of previous testing. The demister mesh was clean and did not show any evidence of scale deposition. Photographs showing the condition of the DCHX components after the run are included in this report as Figures 5-8 through 5-11.

Teardown of the turbine assembly revealed scaling of the turbine nozzle as in the first turbine test. Apparently brine was still being carried over from the direct contact heat exchanger into the turbine despite the installation of the knock-out drum.

The possible explanations for the carryover are the following:

1. Liquid brine droplets were carried upward from the brine free surface in the boiler and through the six inches of demister mesh.

2. The brine either evaporated to dryness and dry brine components were carried through the knock-out drum to the turbine, or;

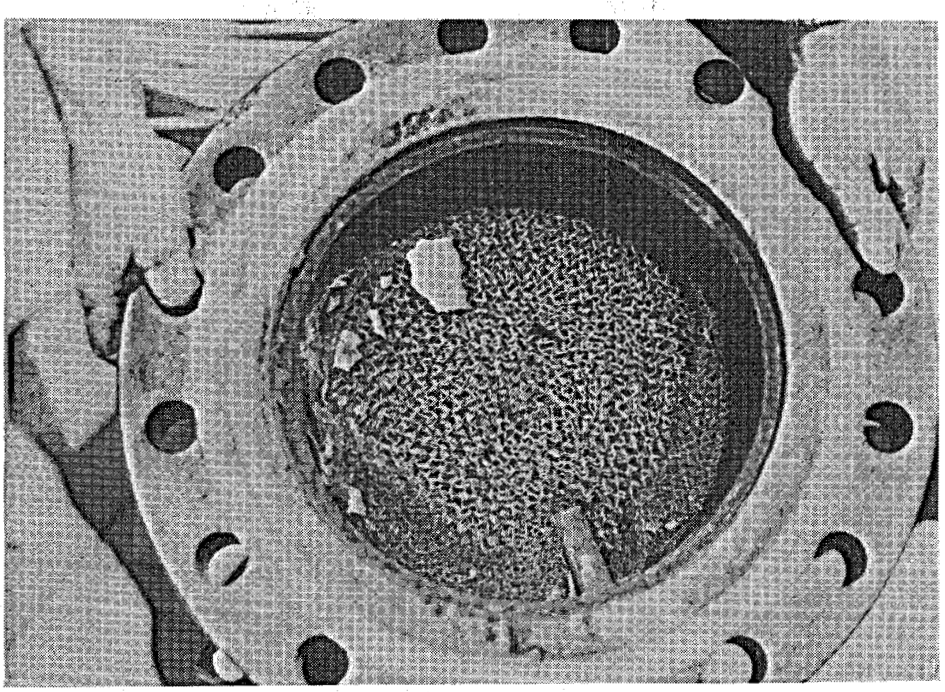
3. Since the knock-out drum was not equipped with a trap and/or continuous blowdown mechanism, the liquid level could have risen too high and brine droplets could have been carried through the drum to the turbine.

If the brine operating level in the boiler was too high, excessive liquid could have splashed up through the mesh. However, the level controller seemed to be operating satisfactorily during the turbine tests, and the level, according to visual observations, was "normal".

FIGURE 5-8

POST ENDURANCE RUN TEARDOWN AND INSPECTION

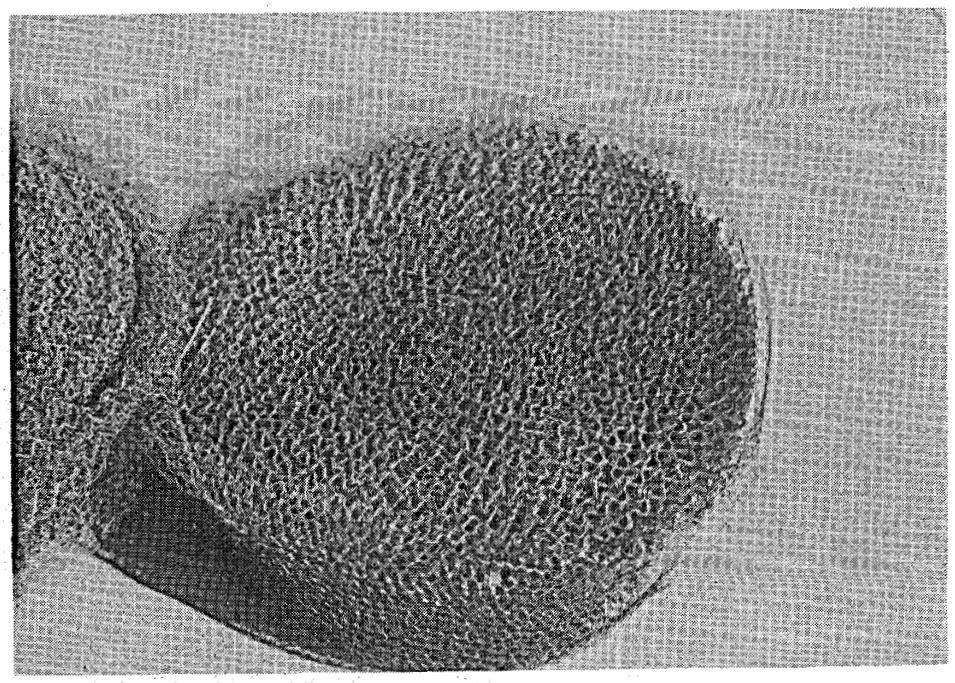
UPPER DCHX HEAD SECTION (10 INCH DIAMETER)
SHOWING DEMISTER MESH PAD. IRON OXIDE
EXFOLIATED ONTO PAD ON DISASSEMBLY



XBB 791-596

FIGURE 5-9

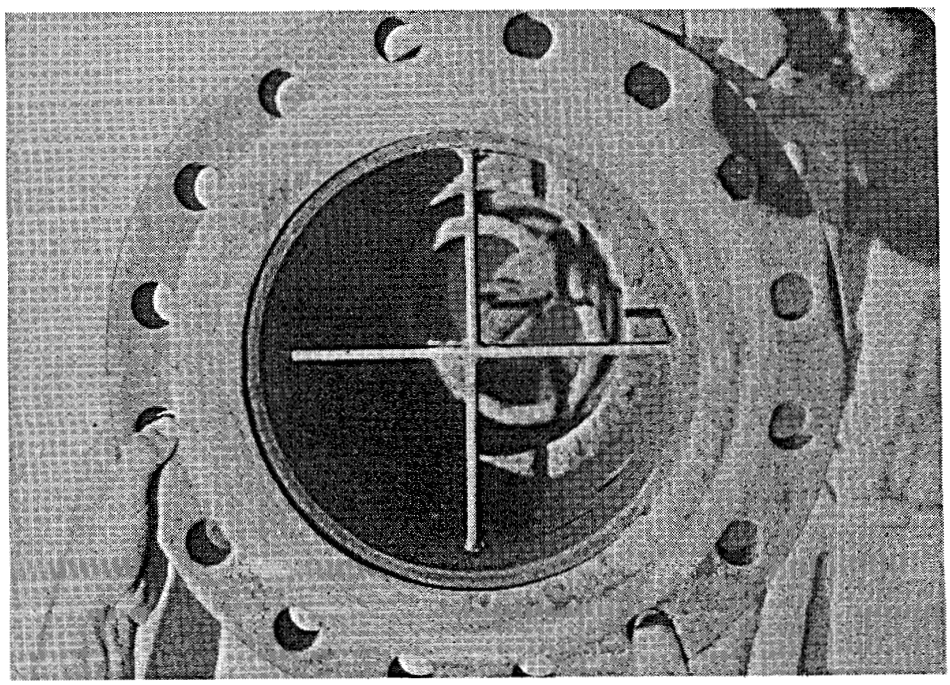
STAINLESS STEEL WIRE KNIT DEMISTER
ON DISASSEMBLY



XBB 791-597

FIGURE 5-10

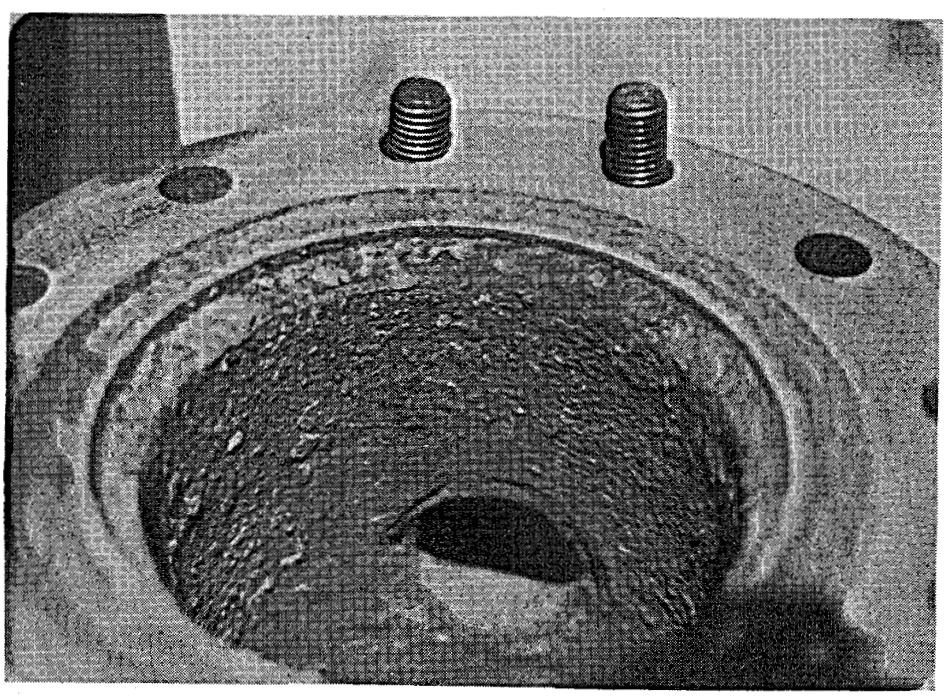
POST ENDURANCE RUN TEARDOWN AND INSPECTION
UPPER DCHX HEAD SECTION WITH DEMISTER PAD REMOVED.
UPPER SURFACE OF BRINE DISTRIBUTION RING NOZZLE SHOWN
BELOW DEMISTER PAD SUPPORT "CROSS".



XBB 791-588

FIGURE 5-11

MID SECTION OF DCHX SHOWING TYPICAL IRON OXIDE SCALE



XBB 791-589

The knock-out drum was piped such that any water accumulated could be manually drained to the pad or directed into the condenser. Unfortunately there was no level gage on the side of the knock-out drum and the drum could have filled with water (or brine) between the periodic draining, allowing carryover to the turbine.

It should be noted that a water trap was installed on the knock-out drum for the brine carryover tests which were performed following the endurance run. This trap was designed to blowdown water to waste and functioned well with minimal isobutane loss.

SECTION 6

DEGASSING COLUMN EXPERIMENTS

SECTION 6

DEGASSSING COLUMN EXPERIMENTS

6.1 Introduction

As isobutane droplets rise through the brine in the direct contact heat exchanger, small quantities become dissolved and exit the unit with the brine. Although the theoretical equilibrium solubility of isobutane in the brine is low (360 ppm at T = 140 F and 300 psig for fresh water and low saline solutions[10]), there has been concern that even small amounts would constitute a significant loss in the full scale power plant. To reduce the amount of isobutane dissolved in the brine blowdown, a degassing column was designed and installed on the test unit to drop the brine pressure and to allow more of the dissolved gases to be removed from the brine before it leaves the unit.

Experimental work was authorized under both parts of the contractual purchase order ((1) Purchase Order 4366002 & (2) Change Order #1 to Purchase Order 4366002) to collect data about the degassing column. The purpose of these experiments was to determine the amount of isobutane dissolved in the column inlet and outlet streams and to evaluate the performance of the column.

The degassing column circuit was set up, instrumented and initially operated to obtain data in January and February of 1978. Numerous problems in collecting, analyzing and interpreting the data were encountered. The results of these tests were considered inconsistent and therefore not fully developed. However, an outline of the column testing equipment, procedures, data, and a brief discussion of the results have been included in this report as Appendix C, so that the magnitude of the problems encountered can be realized.

Data was collected during the Second Endurance Run (Purchase Order 4366002)

using a simplified degassing column circuit, and mass balances for CO_2 and isobutane as well as solubilities and degassing efficiencies were calculated. Further degassing column experiments verifying these results were scheduled to be conducted during the Oak Ridge Condenser Testing (change order #1). However, because of the numerous operating and condenser design problems encountered during this time period the system never stabilized to the point that these follow-up experiments could be conducted.

The only contribution made to the degassing column efforts during the time frame of the contract extension was the development of a more accurate laboratory procedure for determining residual Co_2 carbonate.

It should be noted that the original purpose for conducting these experiments was to provide isobutane solubility and other data that would be useful in designing working fluid recovery systems. At the onset of this work, it was not fully realized the magnitude the influence of CO_2 (soluble and free) contained in the brine would have on these recovery systems. As a result methods of collecting, analyzing and interpreting CO_2 data were in a developmental stage throughout the extent of this contract.

Following is a summary of the degassing column experiments conducted during the Second Endurance Run as part of the change order #1 contract.

6.2 Equipment

(a) Degassing Column

The degassing column consists of a 6 ft section of 6 in. diameter schedule 40 pipe. The upper end of the column is sealed with a 6 in. blind flange and the bottom is sealed with a 6 in. pipe cap. Connections are provided for brine

inlet and outlet, vapor outlet, brine recirculation, ports for a level controller, level glass, and miscellaneous openings for pressure gages, thermocouples, and sight glasses. The level controller at the bottom of the column is connected to a control valve in the brine blowdown pump.

Brine is dispersed into the top of the degassing column through a spray nozzle. The wetted surface area inside the column is increased by the addition of a 3 ft. section packed with 5/8" polyethylene pall rings. A steel grid is installed at the bottom of the column to prevent these rings from being carried out the bottom with the brine. The knit mesh pack of stainless steel at the top of the column helps to coalesce small droplets of brine and prevents these from being carried out with the vapor.

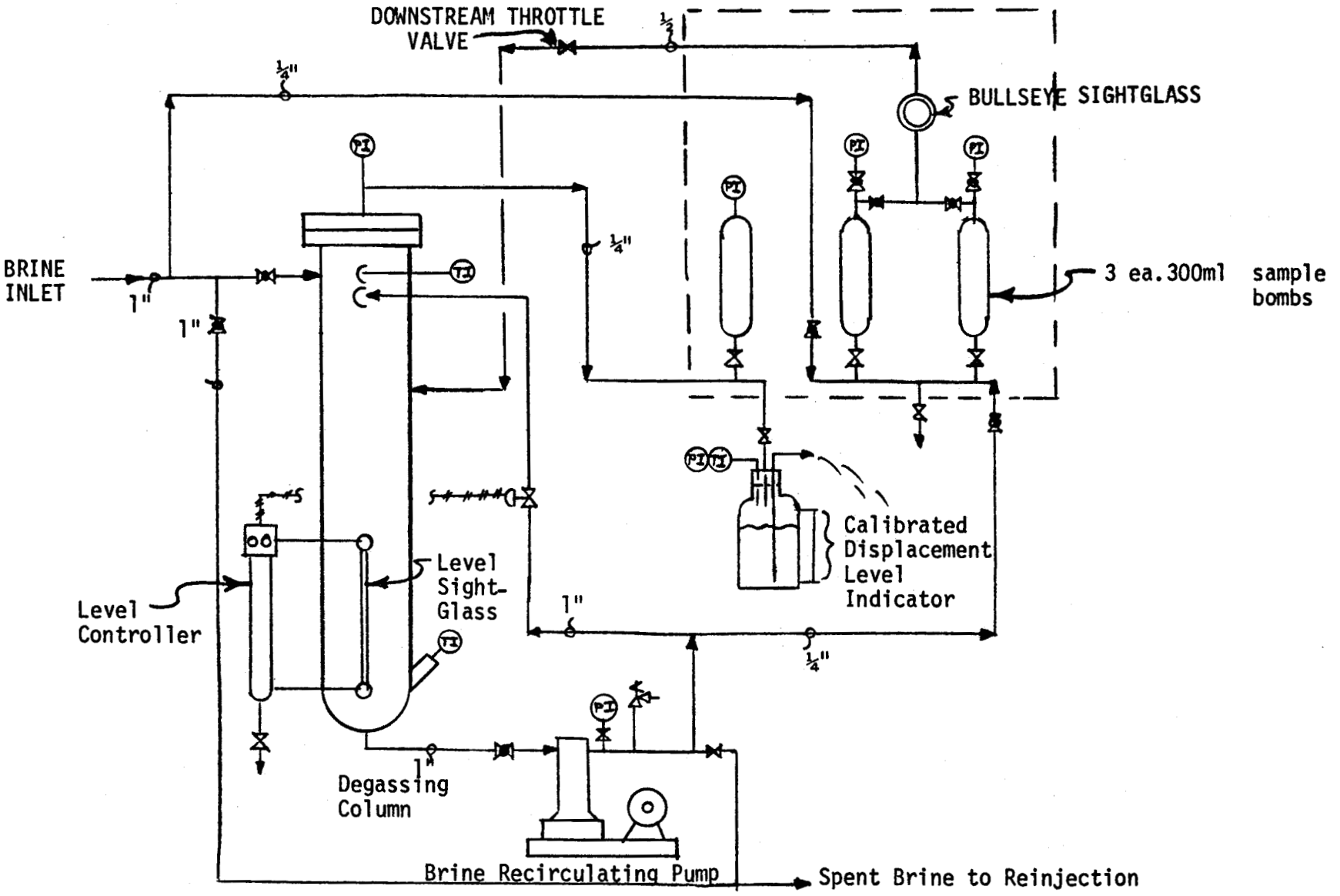
Instrumentation on the degassing column includes the thermocouples for brine outlet and vapor space temperature, pressure gage and brine level glass and level controller. A positive displacement pump is provided to pump the brine to the reinjection system or to recirculate it back to the degassing column.

(b) Isobutane Sampling Apparatus

The apparatus used in the isobutane degassing and sampling system is shown in Figure 6-1. Samples were collected at three locations to quantify and qualify the operational performance of the degassing column. These consisted of a liquid brine inlet sample, a liquid brine outlet sample and a vapor outlet sample taken from the top of the column. The vapor-out line terminated at the top of a 5 gallon water bottle calibrated at 1500 ml increments. The bottle was fitted with a separate immersion leg with the inlet of the leg at the inside bottom of the bottle and the outlet open to atmosphere. A 3-hole laboratory cork was used to assure an air-tight seal. The bottle was also equipped with temperature and pressure gauges. This setup was used to measure gas

FIGURE 6-1

P&I DIAGRAM FOR DEGASSING COLUMN & SAMPLING TRAIN



flow rate by water displacement.

A sampling panel was constructed to facilitate the taking of brine samples. Sampling lines from various points terminate with ball valves at the manifold on the sampling panel. Swagelok fittings were used to connect a 300 ml sample bomb between the sampling manifold and the downstream piping. Immediately downstream of the sampling bomb, the sample passes through a section of 1 in. diameter pipe. This section of pipe is equipped with 1 in. bullseye (to view the brine flow), a pressure gage, and a thermocouple. A throttling valve to regulate the sample flow was placed between this section of piping and the degassing column. An additional ball valve on the manifold was used to relieve the pressure in the line before the sample bomb was removed.

6.3 Operating Procedure for Degassing Column

The direct contact heat exchanger unit was started with the brine blowdown bypassing the degassing column. Once stable operating conditions for the unit had been established and the brine outlet temperature was down to approximately 150 F, the degassing column brine inlet valve was opened while closing the bypass valve. The gas inside the degassing column was vented to atmosphere through the gas outlet line which had not yet been placed in the measuring bottle. Except for the gas vent, the degassing column was completely closed off while filling with brine. When the brine level in the degassing column reached the bullseye sight glass on the column, the blowdown pump on the suction line was opened and the pump started. At the same time the level controller was placed into commission.

Since the blowdown pump would empty the system to the flash tank faster than the recycle system could react, the valve between the pump and the flash tank

had to be throttled. After balancing the throttle valve with the air operated level control valve on the recycle line, a level approximately midway on the level sight glass could be maintained and the column would stabilize. The valve on the vent line would then be throttled until the column pressure was 3-5 psig. This was the average pressure range of the column after the vent line and immersion leg assembly was placed in the gas flow measuring bottle.

6.4 Sampling Technique

Basically there were two different types of samples taken: (1) liquid and (2) gas. A sampling panel was constructed as described in the previous section to facilitate the taking of these samples. Brine sample lines made of 1/4" stainless steel tubing were run from two different locations: (1) separator outlet, and (2) discharge from the brine blowdown pump between the pump and downstream control valves.

Before samples were taken, a series of operating and degassing column performance data was obtained. This data included measuring the gas flow rate from the top of the column. This was accomplished by filling the 5 gallon water bottle with water, placing the vapor outlet immersion leg assembly into the bottle and recording the time water was displaced by the inflow of non-condensable gas at 1500 ml increments. A typical set of data is shown as Figure 6-2.

To assure reliability and reproductibility of data, the same specific sequence of data and sample collecting was used for each experiment. This was as follows: (1) Stabilize degassing column; (2) connect sample bombs to sample manifold, (3) record pertinent DCHX operating data and degassing column data; (4) measure and record gas flow rate data (4-6 readings); (5) before water bottle blows empty take gas sample; (6) take brine outlet sample;

FIGURE 6-2

DEGASSING COLUMN DATA SHEET

3 April '78

TIME 11^{45}/AM

1. Gas sample bomb initially evacuated to: 27.6 "Hg
2. Temp. of H_2O in calibrated bottle: 86 °F
3. Column vapor temp: 145 °F
4. Column pressure: 2.5 psig
5. Brine out flow rate: 4.5 gpm
6. Brine out temperature 128 °F
7. Brine inlet flow rate: 5.0 gpm
8. Isobutane flow thru rig: 9.1 gpm
9. Gas flow rate data:

	BOTTLE PRESSURE (psig)	TIME (sec)
a.	3.0	58
b.	3.0	49
c.	3.25	34
d.	3.5	29
e.	3.5	25
f.		

10. Final gas bomb pressure: 3.5 psig
11. Final column out bomb pressure: 0 psig
12. Final column in bomb pressure 320 psig

COMMENTS:

Column on stream for 1 hour prior to test.

(7) take brine inlet sample; (8) reconfirm operating data.

The gas sample was taken in a 300 ml sample bomb equipped with a combination pressure vacuum gauge. This bomb had been previously leak-tested and evacuated to 28-29 inch vacuum in the chemistry lab. The sample was taken by slowly opening the needle inlet valve on the bomb immediately after taking the gas flow rate data and before the water bottle blew empty. This assured that the bomb could be pressurized and the column was still operating under stable conditons.

When taking brine samples, a sample bomb was mounted on the panel using swagelok fittings. The ball valve for the particular line being sampled was opened and the line purged by allowing brine to flow out the drain valves on the sampling manifold. The drain valve was then closed and the valves on the sampling bomb were opened. Like the gas bomb, these sample bombs had been previously evacuated in the chemistry lab on the site to approximately 28-29 inches of Hg vacuum. The downstream throttling valve was then opened slightly so that brine flowed through the sample bomb. The bullseye sight glass was observed to make sure that no bubbles were present, thus insuring that flashing did not occur. After brine flowed through the sample bomb, the downstream valve on the sample bomb was closed, followed by the upstream valve. The sample bomb was then removed from the panel, labeled, and operating data recorded.

6.5 Lab Analysis

After the brine and gas samples were collected, the sample bombs were taken to the East Mesa Test Site Chemistry Lab for analysis. The quantity of isobutane and free carbon dioxide in the gas samples were determined using the gas chromatograph. The brine samples were first flashed and the amounts of CO_2 and isobutane in the gas phase determined on the gas chromatograph. Then attempts were made at determining the residual (or soluble) CO_2 of the liquid phase

gravimetrically.

Vent Gas Analysis

The gas samples collected at the degassing column vent were at a pressure of 3-5 psig. Since each sample was injected into the G.C. three times for three separate analysis, the 3-5 psig pressure was borderline low and, therefore, each bomb was pressurized with air to 10-15 psig thus providing the necessary driving force. The bomb pressure before and after adding the air was noted and recorded. This was crucial in determining the total moles of gas in each bomb sample and consequently the moles of each constituent. The bomb pressure before each sample was injected into the G.C. was also recorded.

Brine Sample Analysis

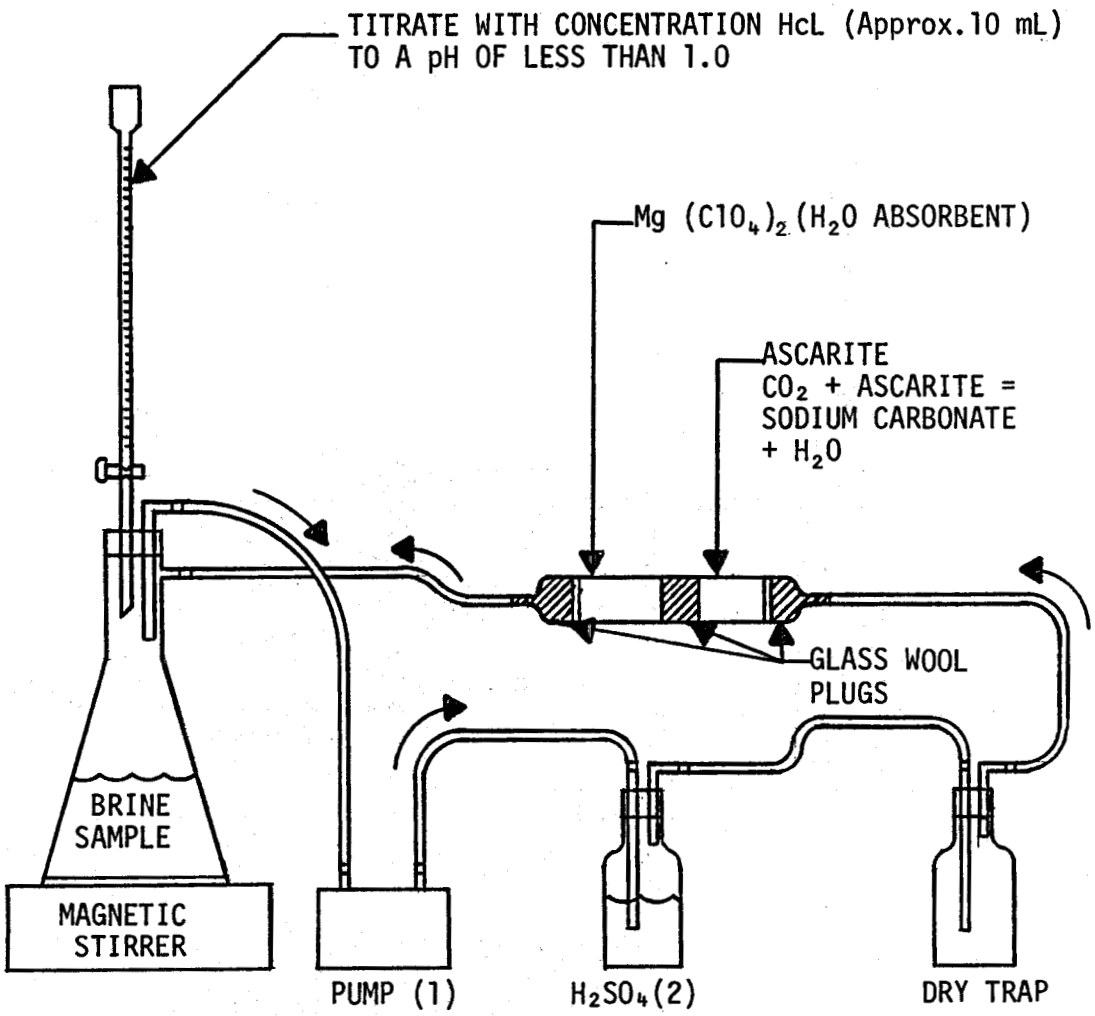
Each brine sample bomb was connected to a second 300 ml sample bomb which had previously been evacuated to 28-29 inches Hg in the lab. This vacuum had been recorded. The brine sample bomb was then placed in a warm water bath (140-160 F) and heated. After a period of heating, the valves beween the sample bomb and the evacuated bomb were opened allowing the gas in the brine sample to flash into the evacuated bomb. The final pressure (still under vacuum) of the two bombs was then recorded. After flashing, the bombs were disconnected and the gas filled bomb was pressurized with air to between 10-15 psig and the final pressure recorded. This was then connected to the G. C. and analyzed for Isobutane and CO_2 in the same manner as the vent gases.

After flashing hydrocarbons and volatile CO_2 from the original brine sample, the amount of CO_2 remaining in the liquid phase of the sample was determined in the laboratory using gravimetric means. (Initial tests conducted in the lab showed that virtually all the isobutane had been flashed from the sample

by the heating and flashing procedure). Since the procedures necessary to determine the liquid phase CO_2 were being developed and optimized using the actual brine samples, two quantitative analysis apparatus trains were tested. These are shown in Figures 6-3 and 6-4. Referring to Figure 6-3, the following procedure was used to determine the amount of residual CO_2 left in brine samples 592, 593, 599, 600 after flashing each for gas phase G.C. analysis.

The amount of brine remaining in the original sample bomb after flashing was measured to the nearest ml and that value recorded. The sample was then transferred into a 1000 ml erlenmeyer flask containing a magnetic stirrer bar. The flask was tightly sealed with a two-hole-stopper and placed on a magnetic mixing plate. A titrating buret containing concentrated HCl was fitted into one hole of the stopper. The otherhole was fitted with a glass ell tube. Tygon tubing was used to sequentially connect the following items in a closed-loop gas flow scheme: (1) glass ell to suction side of a Perkin-Elmer diaphragm pump (2) pump discharge to sub-surface leg of flask containing H_2SO_4 (3) vapor space of H_2SO_4 flask to dry trap, (4) dry trap to sectionalized plastic absorbent holder containing ascarite in the first section and a water absorbent $Mg(ClO_4)_2$ in the second section, and (5) absorbent holder to side port of erlenmeyer flask.

After starting the pump and assuring a flow of gas in the system, approximately 10 ml of concentrated HCl was added to the agitated brine sample lowering the pH to below 1.0 thus liberating CO_2. The gas was passed through the pump and bubbled through the sulfuric acid to remove any water. It then flowed through the dry trap and through a previously weighed absorbent container. Here, Co_2 would react with the ascarite forming sodium carbonate and water. The water would then be absorbed by the magnesium perchlorate. Gas was allowed to circulate through the system for 10 minutes after the HCl addition.



(1) PERKIN-ELMER DIAPHRAGM PUMP
(SERIAL NO. 64768).

(2) H_2SO_4 USED TO ABSORB H_2O CARRYOVER

FIGURE 6-3 LAB SET UP NUMBER 1 USED TO DETERMINE RESIDUAL CO_2 ON SAMPLE NOS. 592, 593, 599 & 600.

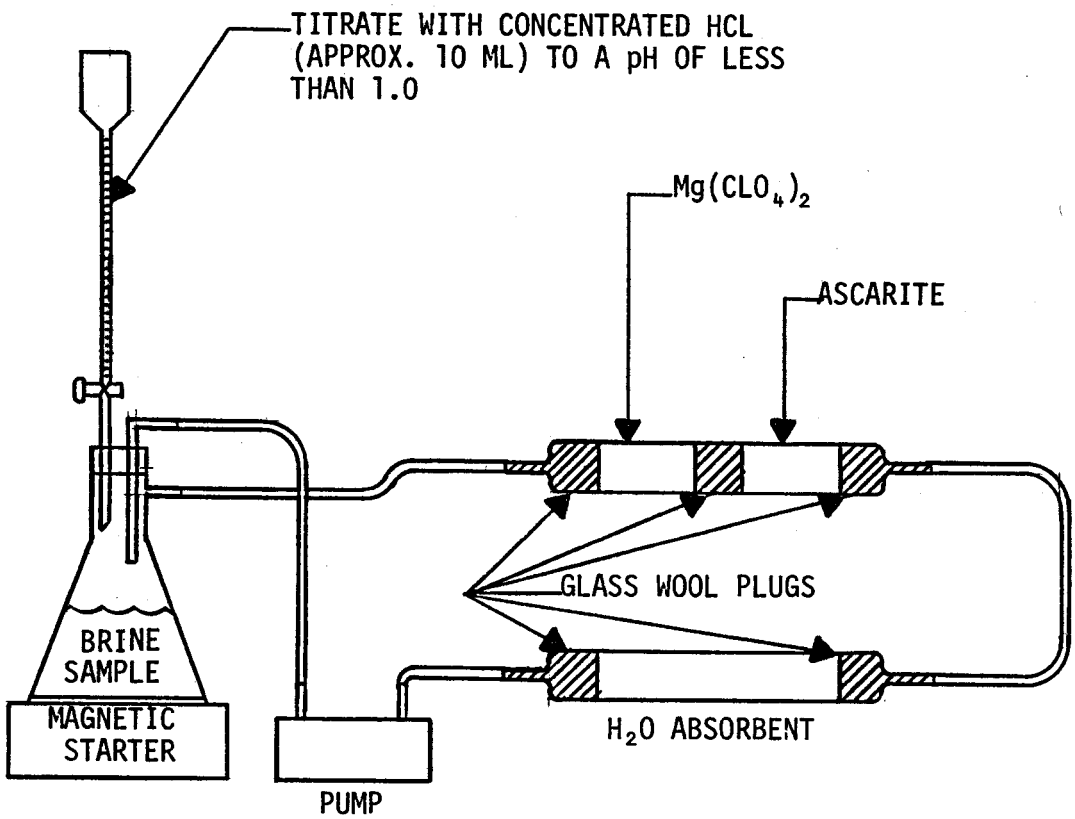


FIGURE 6-4 LAB SET UP USED TO DETERMINE RESIDUAL CO_2 ON SAMPLE NOS. 615, 616, 621, 622, 626 & 627

This was sufficient to displace the erlenmeyer volume several times. The absorbent holder was then disconnected from the circuit, capped, and reweighed.

The weight gain of the absorbents and the amount of brine sample collected were then used to calculate the CO_2 concentration. This in turn was related to the gas phase CO_2 and total brine flow rate to arrive at a total CO_2 mass flow rate.

During subsequent analysis runs using well head brine samples, there was evidence of slight entrained water carryover from the H_2SO_4 flask to the absorbent. This resulted in a small carryover error. Thus, setup 2 (Figure 6-4) was devised and used to analyze brine samples 615, 616, 621, 622, 626 and 627. As shown, a holder containing additional water absorbent was substituted for the H_2SO_4 flask and dry trap. The other equipment remained unchanged and the same procedures were followed.

6.6 Results

Table 6-1 is a summary of the measured degassing column operating variables required to construct the mass balances.

Table 6-2 gives a summary of the liquid phase (soluble) CO_2 analysis results These are results of the gravimetric procedures performed on the brine samples after heating and flashing in the laboratory. The reader should note that the inlet samples were flashed twice in an effort to maximize the amount of isobutane volatilized to the gas phase while the brine out samples were flashed only once because of time and bomb availability considerations. Also, the samples were not all laboratory flashed at the same temperature since this was dependent on the temperature of the tap water available that day. Therefore, in two cases (samples of 3/31/78 and 4/3/78) the CO_2 concentration in the

TABLE 6-1

SUMMARY OF DEGASSING COLUMN

OPERATING DATA

TEST NO.	DATE	INDICATED BRINE FLOW (gpm)[1]	DCHX INLET BRINE TEMP (°F)[2]	DEGASSING COLUMN OUTLET BRINE TEMP (°F)	CORRECTED BRINE FLOW (gpm)	BRINE MASS FLOW (lbs/hr)	MEASURED VAPOR FLOW RATE @ STP (ml/sec)	COLUMN VAPOR TEMP (°F)	COLUMN VAPOR PRESSURE (psig)[3]
1	3/31/78	5.75	318	142	6.80	3090	44.20	155	3.0-4.0
2	4/3/78	5.00	320	128	5.90	2681	46.24	145	2.5-3.5
3	4/5/78	5.70	320	140	6.75	3068	43.28	153	3.0-4.4
4	4/6/78AM	5.80	320	138	6.87	3086	40.99	153	3.5-4.4
5	4/6/78PM	5.75	318	137	6.80	3090	41.86	154	3.4-4.3

(1) Brine into DCHX. Assume brine into DCHX = Brine into degassing column, therefore, neglects blowdown losses.

(2) Temperature of Brine into DCHX used for correcting flow rate (≠ Temp of brine into degassing column).

(3) Range of degassing column outlet vapor pressure measured during flow rate determination and sampling.

TABLE 6-2

DEGASSING COLUMN BRINE SAMPLES

LIQUID PHASE CARBONATE ANALYSIS RESULTS

LAB SAMPLE NUMBER	TEST NO.	DATE SAMPLE COLLECTED	DEGASSING COLUMN SAMPLE LOCATION	VOLUME OF LIQ. PHASE MEASURED[2]	NET WEIGHT OF CARBONATES AS CO_2 MEASURED[1] (mg)
592*	1	3/31/78	INLET	296	58.2
593*	1	3/31/78	OUTLET	276	68.0
599*	2	4/3/78	INLET	296	53.8
600*	2	4/3/78	OUTLET	289	54.4
615**	3	4/5/78	INLET	300	91.9
616**	3	4/5/78	OUTLET	285	66.4
621**	4	4/6/78 AM	INLET	275	103.9
622**	4	4/6/78 AM	OUTLET	295	101.4
626**	5	4/6/78 PM	INLET	147[3]	73.4
627**	5	4/7/78 PM	OUTLET	300	113.5

1. Liquid Phase CO_2 = Total carbonates remaining in brine sample after heating and flashing sample in laboratory for G.C. gas analysis. It should be noted that the inlet samples were double flashed and the outlet samples flashed only once.

2. Volume of liquid phase measured = volume of brine remaining in sample bomb after flashing in laboratory.

3. Some of this sample was spilled while measuring after the laboratory flash procedure.

* CO_2 determined using lab setup No. 1 (see Figure 6-3)

** CO_2 determined using lab setup No. 2 (see Figure 6-4)

outlet appears to be higher than the brine inlet. As a result, the "residual" or liquid phase carbonate expressed as CO_2 must be added to the amount of gaseous CO_2 volatilized from the same sample before such a comparison may be made.

Table 6-3 is a summary of the isobutane and CO_2 laboratory analysis (liquid phase and gaseous phases) of the samples taken about the degassing column. These were used to construct mass balances about the column and also attempt a correlation with theoretical solubility values.

(a) Mass Balances

Table 6-4 presents the mass balance results for isobutane and carbonates calculated from the degassing column data collected during the period 3/31/78 to 4/6/78. The mass flows for isobutane balance quite well with all but one of the balances agreeing within 5%. The flows for carbonates expressed as CO_2 are also in good agreement; the deviation between input and output CO_2 flows on all but one test being less than 10%.

Test 5 shows the largest deviation in mass balance closure for both isobutane and CO_2. This is attributed to a leaking bomb reported by the analytical laboratory. However, the results are still considered meaningful and good for pilot plant levels of accuracy.

(b) Solubility of Isobutane

The theoretical equilibrium solubility of isobutane in the brine was calculated for the degassing column effluent brine using a correlation equation developed by Hellstrom:", i.e.,

$$\mathrm{Ln}\,(X) = -0.61424839 + \frac{7.0329254 \times 10^3}{T} + 15.946457\,\mathrm{Ln}\left(\frac{T}{1000}\right)$$

$$+ W_B\left[0.09582649 + \frac{0.0552885 \times 10^3}{T} + 0.29563845\,\mathrm{Ln}\left(\frac{T}{1000}\right)\right]$$

TABLE 6-3

DEGASSING COLUMN SAMPLES

LABORATORY ANALYSIS RESULTS

SAMPLING DATE	TEST NO.	LAB SAMPLE NO.	DEGASSING COLUMN SAMPLE DESCRIPTION	ISOBUTANE ANALYSIS BY G.C. (% Vol.)[3]	ISOBUTANE ANALYSIS BY G.C. (mg)	CO_2 ANALYSIS RESULTS GAS CHROMATOGRAPHY (% Vol.)	CO_2 ANALYSIS RESULTS GAS CHROMATOGRAPHY (mg)	CO_2 ANALYSIS RESULTS GRAVIMETRIC[4] (mg)	TOTAL CO_2 (mg)
3/31/78	1	591	Vapor Outlet	18.75	397.00	14.40	231.0	-	231
		592	[1] Brine Inlet (1st Flash)	2.03	43.10	2.45	39.4	-	39.4
		592	Brine Inlet (2nd Flash)	.42	9.06	2.45	9.4	58.4	67.8
		593	Brine Outlet	.09	1.90	1.94	31.2	68.0	99.2
4/3/78	2	598	Vapor Outlet	15.00	325.00	15.20	250.0	-	250.0
		599	Brine Inlet (1st Flash)	2.75	56.90	6.21	97.8	-	97.8
		599	Brine Inlet (2nd Flash)	.23	4.76	3.50	55.1	53.8	108.9
		600	Brine Outlet	.18	3.69	6.45	101.6	54.4	156.0
4/5/78	3[2]	614	Vapor Outlet	17.40	364.00	15.20	241.0	-	241.0
		615	Brine Inlet	2.47	52.40	6.47	104.0	91.7	195.7
		616	Brine Outlet	0.15	3.18	6.02	95.7	66.4	162.1
4/6/78AM	4	620	Vapor Outlet	14.40	302.00	18.90	300.0	-	300.0
		621	Brine Inlet(1st Flash)	2.58	54.00	7.81	124.0	-	124.0
		621	Brine Inlet(2nd Flash)	0.31	6.55	3.40	48.5	104.0	152.5
		622	Brine Outlet	0.15	3.16	7.48	120.0	101.0	221.0
4/6/78PM	5	625	Vapor Outlet	14.10	306.00	18.40	300.0	-	300.0
		626	Brine Inlet(1st Flash)	2.40	50.30	7.24	115.0	-	115.0
		626	Brine Inlet(2nd Flash)	.22	4.59	3.53	56.1	73.4	129.5
		627	Brine Outlet	.16	3.43	7.34	119.5	113.5	233.0

(1) First laboratory conducted flash of inlet brine sample.

(2) Brine inlet sample was only flashed once in laboratory.

(3) It should be noted that this volume percent is not representative of vapor above degassing column since air has been added to the sample in the laboratory.

(4) Total carbonates in brine sample after flashing.

TABLE 6-4

MASS BALANCES OF CARBONATES AND ISOBUTANE

ABOUT THE DEGASSING COLUMN

TEST NO.	DATE	ISOBUTANE BALANCES INLET VIA BRINE (lbs/hr)	OUTLET VIA BRINE (lbs/hr)	OUTLET VIA VAPOR (lbs/hr)	PERCENT[1] CLOSURE	CARBONATE BALANCES - (expressed as CO_2) INLET VIA BRINE (lbs/hr)	OUTLET VIA BRINE (lbs/hr)	OUTLET VIA VAPOR (lbs/hr)	PERCENT[1] CLOSURE
1	3/31/78	0.553	0.020	0.533	100.00	1.46	1.05	0.30	99.92
2	4/3/78	0.568	0.034	0.518	99.97	1.90	1.44	0.39	99.96
3	4/5/78	0.596	0.033	0.570	100.01	2.06	1.7	0.34	99.99
4	4/6/78AM	0.564	0.030	0.533	99.99	2.59	2.08	0.55	100.01
5	4/6/78PM	0.577	0.036	0.504	99.94	2.57[2]	2.45	0.49	100.14

(1) Percent closure on balance = 100 - [(inlet-outlet)/inlet]

(2) Low value is attributed to a reported leak in the bomb.

WHERE: T = Temperature, K

W_B = weight percent of NacL in brine

X = solubility, ppm/atmos

atmos = partial pressure of C_4H_{10}

As indicated, this equation was derived from experimental data of the system C_4H_{10} - H_2O - NacL. In applying this equation to the East Mesa brine, the value W_B was set equal to zero, thus representing a C_4H_{10} - H_2O system.

Since this correlation requires knowledge of the partial pressure of C_4H_{10}, calculations involving application of the ideal gas law were necessary. The relationship used was:

$$C_4H_{10}\ \%\ (V/V) \text{ in Column Vapor} = \frac{V_{C_4H_{10}}}{V_{Total}} = \frac{n_{C_4H_{10}}}{n_{Total}} \quad \frac{P_{C_4H_{10}}}{P_{Total}}$$

A summary of these calculations is given in Table 6-5 and 6-6. The theoretical solubility calculated for each test is also included in Table 6-6.

Table 6-7 shows a comparison between the theoretical solubilities of C_4H_{10} in the degassing column effluent brine and the measured C_4H_{10} concentrations. These are in good agreement for accuracy expected from pilot plant data. The results indicate that the theoretical equation may be used to closely estimate the C_4H_{10} concentrations to expect in the East Mesa effluent brine at conditions of low pressure and temperature. However, further experiments will be necessary to verify the equation at higher pressures and temperature, i.e., at DCHX discharge conditons.

The measured concentrations of C_4H_{10} in the degassing column inlet stream

TABLE 6-5

DETERMINATION OF THEORETICAL SOLUBILITY OF C_4H_{10}

IN DEGASSING COLUMN EFFLUENT BRINE[1]

TEST NO.	LAB TEMP (°F)	BOMB PRESS AFTER AIR (atmos)	TOTAL GAS IN BOMB AFTER AIR (moles x 10^{-6})	G.C. RESULTS C_4H_{10} (%v/v)	G.C. RESULTS CO_2 (%v/v)	C_4H_{10} MOLES ($\times 10^{-6}$)	CO_2 MOLES ($\times 10^{-6}$)	BOMB PRESS BEFORE AIR (Atmos)	TOTAL GAS IN BOMB BEFORE AIR (Moles x 10^{-6})	COMPOSITION COLUMN (C_4H_{10})	COMPOSITION COLUMN COMPOSITION OF DEGASSING COLUMN VAPORS (mole percent) (C_4H_{10})	COMPOSITION COLUMN COMPOSITION OF DEGASSING COLUMN VAPORS (mole percent) OTHER
1	73	2.97	81.65	18.75	14.40	15.31	11.76	1.27	34.92	43.85	33.68	22.47
2	73	3.04	83.58	15.00	15.20	12.54	12.70	1.29	35.44	35.38	35.84	28.78
3	73	2.94	80.83	17.40	15.20	14.06	12.28	1.30	35.74	39.34	34.36	26.30
4	75	2.94	80.53	14.40	18.90	11.60	15.22	1.27	34.79	33.34	43.75	22.91
5	75	3.04	83.26	14.10	18.40	11.74	15.32	1.27	34.79	33.75	44.04	22.21

(1) Summary of calculation necessary to determine partial pressure of C_4H_{10} in vapor stream from the degassing column. Compositions of vapor outlet i.e., samples 591, 598, 614, 620, 625 (see Table 6-3)

TABLE 6-6

Determination of Theoretical Solubility of C_4H_{10}

Test No.	Temp. (F)	BRINE C_4H_{10} Theoretical Solubility (ppm/atmos)(1)	OUTLET C_4H_{10} Partial Pressure (atmos)	C_4H_{10} Theoretical Solubility (ppm)
1	142 F	19.17	.54	10.4
2	128 F	30.80	.43	13.2
3	140 F	19.51	.50	9.8
4	138 F	19.85	.42	8.4
5	138 F	20.02	.43	8.6

( ) Calculated using Hellstrom equation:

$$\mathrm{Ln}\,(x) = {}^{-}0.61424839 + \frac{7.0329254 \times 10^3}{T} + 15.946457\,\mathrm{Ln}\left(\frac{I}{1000}\right)$$

x = solubility in (ppm/atmos)

TABLE 6-7

Theoretical Solubility of C_4H_{10} in Degassing Column Exit Brine
VS
Measured Concentrations

Test No.	Average Degassing Column Pressure (Atmos)	Average Brine Temp. (F)	Theoretical C_4H_{10} Solubility(1) (ppm)	Calculated Concentration in Brine (ppm)
1	1.24	142	10.4	6.4
2	1.20	128	13.2	12.4
3	1.24	140	9.8	10.8
4	1.27	138	8.4	10.7
5	1.27	137	8.6	11.6

(1) Theoretical concentration of C_4H_{10} in fresh water at stated conditions of pressure and temperature.

are given below. The theoretical solubilities were not calculated because the necessary conditions of brine temperature and pressure were never recorded.

MEASURED CONCENTRATION OF C_4H_{10} IN DEGASSING COLUMN BRINE INLET STREAM

Test No.	C_4H_{10} Concentration (ppm)
1	177
2	209
3	192
4	203
5	186

(c) Carbonate and CO_2 Analysis of the Brine

Table 6-8 shows a summary of the CO_2 carbonate content of the inlet and outlet brine streams of the degassing column. The concentrations of each stream are shown in two parts; 1) CO_2 concentration determined by laboratory flashing and G.C. analyis and (2) carbonate concentration (expressed as CO_2) of the liquid brine phase after laboratory flashing as determined gravimetrically. Since the data of test No. 1 is over an order of magnitude lower than the other test data, it appears that this test may not be representative.

Attempts were made at correlating these results with published solubility data[10,13] for the systems: 1) CO_2 in sea water and, 2) CO_2 in fresh water. Graphs of these two systems were constructed from the data within the operating parameters of the degassing column effluent brine and are given in Appendix (d). Table 6-9 shows the results of this comparison.

As expected, there is not good agreement between the measured values and the theoretical solubilities partly because the East Mesa brine contains soluble

TABLE 6-8

Measured CO_2 and Carbonates (as CO_2) of Degassing Column Brine Samples

Test No.	Outlet Brine			Inlet Brine[1]		
	Determined By Flashing (ppm)	Determined Gravimetrically (ppm)	Total (ppm)	Determined By Flashing (ppm)	Determined Gravimetrically (ppm)	Total (ppm)
1	12.2	23.4	35.6	166	198	364
2	343	184	527	519	183	702
3	324	225	549	353	311	664
4	406	342	748	585	353	938
5	405	384	789	581	249	829

(1) For purposes of calculation the specific volume of brine used to calculate these was .01632 ft^3/lb corresponding to a temperature of 145 F. The true temperature was never recorded.

TABLE 6-9

Comparison of Theoretical Solubilities and Measured Carbonate Content of the Degassing Column Effluent Brine

Test No.	Flashed (ppm)	Gravimetric (ppm)	Total (ppm)	Theoretical CO_2 in Sea Water[10] (ppm)	Theoretical CO_2 in Fresh Water[13] (ppm)
1	12.2	23.4	35.6	220	950
2	343	184	527	235	1020
3	324	225	549	240	960
4	406	342	748	330	960
5	405	384	789	350	980

carbonates and bicarbonates.

(d) Degassing Column Efficiency

The purpose of the degassing column is to remove as much of the isobutane from the brine as possible by sharply dropping the pressure of the brine stream. The maximum limit on the amount of isobutane which may be removed is the equilibrium solubility of the isobutane in the brine at the degassing column operating conditions. The main parameters determining this solubility are the partial pressure of isobutane in the gas phase over the liquid and the degassing column operating temperature. For the operating conditions of the stripping column for this set of samples the measured equilibrium solubility averaged 10.4 ppm.

Degassing column efficiency was calculated by dividing the amount of isobutane which was actually removed in the column by the theoretical maximum amount of isobutane which could be removed. For this set of data the stripping column efficiency averaged 98%. This removal rate is quite good and only approximately 5% of the isobutane which was originally dissolved in the brine inlet remains in the brine outlet of the column.

Because sufficient data was not obtained to determine the relative amounts of carbon dioxide present as dissolved gas, carbonate and bicarbonate, the efficiency of the degassifier at removing dissolved carbon dioxide gas was not determined.

6.7 Discussion and Recommendations

Much has been learned about the degassing column system, sampling, isobutane and CO_2 analysis, and interpretation of test results since this preliminary work was completed. The following recommendations should be considered when future work concerning the determination of isobutane and CO_2 in brine is proposed.

Sampling of the vapors leaving the degassing column vent appears straightforward and the G.C. results should reflect accurate analysis of the vapor composition. It is suggested that larger gas samples of one liter or more should be obtained or, if possible, a continuous sampler should be employed. This would require relocating the G.C. unit to the sampling site. Also, the degassing column should be operated at a higher pressure, say 8-10 psig, such that the gas sample does not have to be pressurized with air prior to injecting into the G.C. unit. As a matter of technicality the degassing column should be operated at various overhead pressures and samples taken and analyzed.

A more accurate method of measuring the flow rate of the vapors leaving the degassifier is required. Measurement of gas flow rate could be very much simplified by using a gas flow meter or "wet test" meter correctly sized to handle the full flow rate of gasses exiting the column. This could not be made readily available within the time frame of the previous testing.

Since bomb pressure is used to determine the total moles of gas collected, it is imperative that pressure and temperature readings are accurate.

Therefore, instrumentation should be selected and calibrated accordingly.

Sampling of the brine streams using the methods outlined is also recommended. Once again, larger samples should be obtained. Since the main problem encountered in brine sampling was leaking valves on the sample bombs, new valves that can withstand the high temperatures and pressure should be researched and obtained.

The main problem encountered on analyzing the data was differentiating between soluble CO_2 and CO_2 present in a carbonate or bi-carbonate form. As previously stated, the importance of CO_2 contained in the brine to hydrocarbon recovery was not fully realized at the onset of the work and therefore analysis methods for differentiating between these forms (although straight forward) were never utilized.

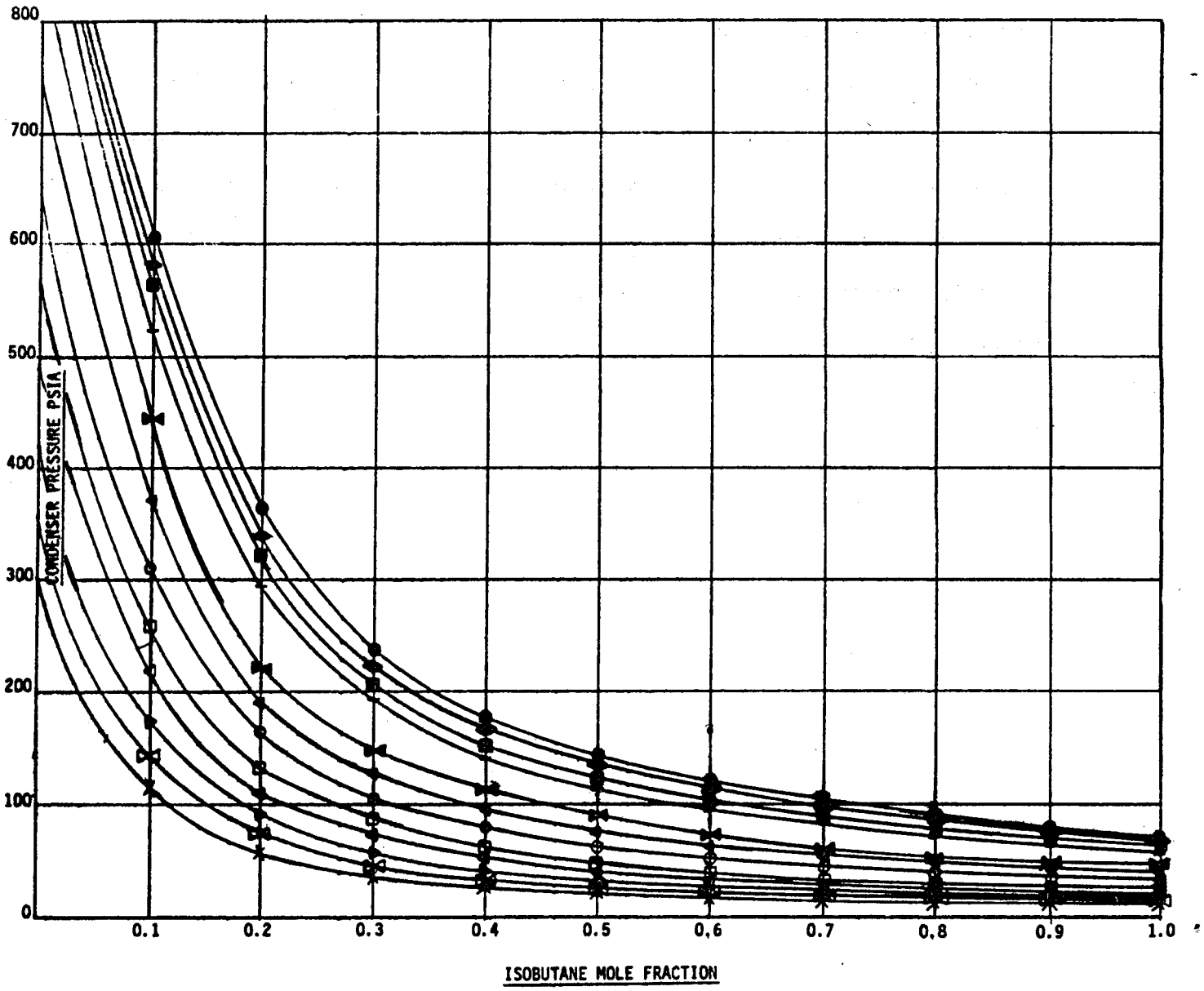
One method is based on a simple pH determination followed by a phenolphthalein and then methyl orange end point titration. These procedures are standard lab practice for determining free CO_2 and the three forms of alkalinity in water and are outlined in detail in Standard Methods.[16] The carbonate chemistry of both flashed and unflashed brine samples taken from the East Mesa wells has been discussed by H.A. Papazian[17] in a paper that compares measured values with theoretical values. These will be helpful in outlining a procedure for future analysis work.

6.8 Isobutane Recovery

A problem exists in the recovery of the isobutane dissolved in the brine. Stripping columns have demonstrated good efficiency in removing the dissolved isobutane from the brine. The stripping column also liberates carbon dioxide from the brine, and as a result, the vapor leaving the stripping column is a mixture of isobutane and carbon dioxide. The

problem becomes how to recover the isobutane from the gas mixture. In order to recover 90% of the isobutane in the mixture by polytropic compression and condensation, a condenser pressure of 850 psi would be necessary. A family of curves is shown on Figure 6-5 showing the relationship of condenser pressure and mole fraction of isobutane in the gas mixture. By utilizing compression with refrigeration a lower pressure condenser is possible and the energy requirement for the system will be lower. An absorption refrigeration system utilizing the hot brine discharge from the DCHX could provide a low power refrigeration system. An even more efficient system could possibly be designed using both the pressure and the heat of the brine leaving the DCHX in a vacuum freeze ejector-absorber refrigeration cycle.

FIGURE 6-5
CONDENSER PRESSURE REQUIRED
TO CONDENSE ISOBUTANE FROM
A MIXTURE OF ISOBUTANE AND CO_2



CONDENSING TEMPERATURE

● -100 F	○ - 50 F
◆ - 95 F	□ - 40 F
■ - 90 F	◁ - 30 F
▬ - 85 F	▽ - 20 F
⧗ - 70 F	⧖ - 10 F
◀ - 60 F	X - 0 F

SECTION 7

BRINE CARRYOVER EXPERIMENTS

SECTION 7

BRINE CARRYOVER EXPERIMENTS

The common result of both the First and Second Turbine Endurance Test runs was that on teardown of the turbine assembly concluding each run, scale deposition was noted in the turbine nozzles, particularly in the end of the supersonic expansion cone. This scaling resulted in a decrease in overall turbine efficiency which was experienced during both Endurance Tests. It was hypothesized that the scaling was caused by brine mist and/or entrainment being carried to the turbine by the isobutane vapor.

Based on these results, DSS Engineers, Inc., was contracted by Lawrence Berkeley Laboratory (Change No. 1 to Purchase Order No. 4366002 - Task 8.0 & 9.0) to modify the Direct Contact Heat Exchanger Isobutane Loop and perform brine carryover tests. The specific objectives of this test program were to operate the modified loop to: 1) quantify and qualify the brine carryover in the isobutane vapor stream, 2) characterize the carryover as a function of the main DCHX operating variables, and 3) investigate means to minimize the brine carryover.

This section of the report is a summary of the results of the work performed on these tasks.

7.1 Theory

In conventional steam power plants the two contaminants most commonly encountered in the steam from the boiler are tiny droplets of liquid containing dissolved solids and silica. The silica may be found dissolved in the droplets or as a silica vapor. Since there is a relatively large concentration of silica present in the geothermal brine it is not surprising that silica is depositing in the turbine blading. Deposits on steam turbine blades have occurred with as little as .6 ppm dissolved solids in steam.

Liquid carryover is caused by three basic mechanisms: foaming, misting and priming. Foaming causes carryover when a stable froth, like sea foam, is formed at

the free surface of the brine and becomes entrained in the gas leaving the boiler. This problem is easily controlled in steam boilers by chemical treatment of the boiler feed. However, in the DCHX, such control over the purity of the geothermal brine is impossible. No foaming has been observed in this test unit, but the vapor space is difficult to observe and we would not rule out the possibility that it has occurred.

Foaming could be a problem with different brine and working fluid combinations, depending upon the impurities found in the fluids.

The second mechanism causing carryover, misting, has been described by Nalco[3] as a fog-like mist like that formed over champagne and ginger ale. It is thought that tiny particles of water are thrown off by the sudden bursting of isobutane bubbles at the water surface.

Priming includes all carryover situations caused by significant slugs or gulps of water being lifted upward by the isobutane gas or other boiling liquid. Several situations can cause this condition. A sudden demand for isobutane gas by the turbine/generator and the accompanying pressure drop in the boiler may cause a sudden increase in isobutane gas volume in the boiler. This in turn creates a higher level in the boiler and higher release of bubbles. In conventional boilers with horizontal cylindrical steam drums, a rise in water level creates less surface area for gas release. In the case of the DCHX, however, a rise in level usually creates a greater gas release surface because of the tapered enlargement at the top of the boiler. Conversely, if we lower the free surface level from the 10 inch section into the straight section of six inch column we have reduced the free surface area by $10^2/6^2$ or 2.77 times.

For a steam/water system in which boiling occurs in a vertical column, the maximum allowable vapor release velocity is 3 ft/sec. At generation rates requireing higher release rates, the bubbles do not have time to disengage from the

water and begin to back up. This in turn causes the mixture density to decrease and the level rises. It will also give a false level reading in a sight glass. The situation in the isobutane DCHX is very similar. If excessive vapor velocities in the two phase boiling zone occur then isobutane bubbles will "swell" the volume of the mixture causing the level of the mixture to rise and carry over.

The Sakiadis-Johnson correlation for calculating flooding velocities is also applicable to spray columns where gas bubbles are rising against downcoming brine. The correlation was used to evaluate a flooding velocity of isobutane bubbles in brine at the base line flow conditions. Figure 7-1 shows flooding lines for both liquid-liquid and gas-liquid systems. The gas system was evaluated assuming that isobutane droplets of .15 inch diameter completely vaporize at 220 F, thus creating uniform bubbles of .3 inch diameter. The flow conditions at which flooding occurs is predicted to be at an isobutane gas superficial velocity of .75 ft/sec. In the liquid phase, flooding occurs at much lower velocities, but on a mass flow basis a greater flow of liquid is possible than in the gas phase. This analysis indicates that in theory, the vapor in liquid velocity is limiting the size of the boiler and not the liquid-liquid section of the column.

The above analysis assumes that vaporization occurs as the liquid droplets are rising evenly towards the free surface and that complete vaporization occurs just before or at the free surface. If instead we assume that the liquid isobutane droplets arrive at or near the free surface before they are completely vaporized, then the previously described model is not valid.

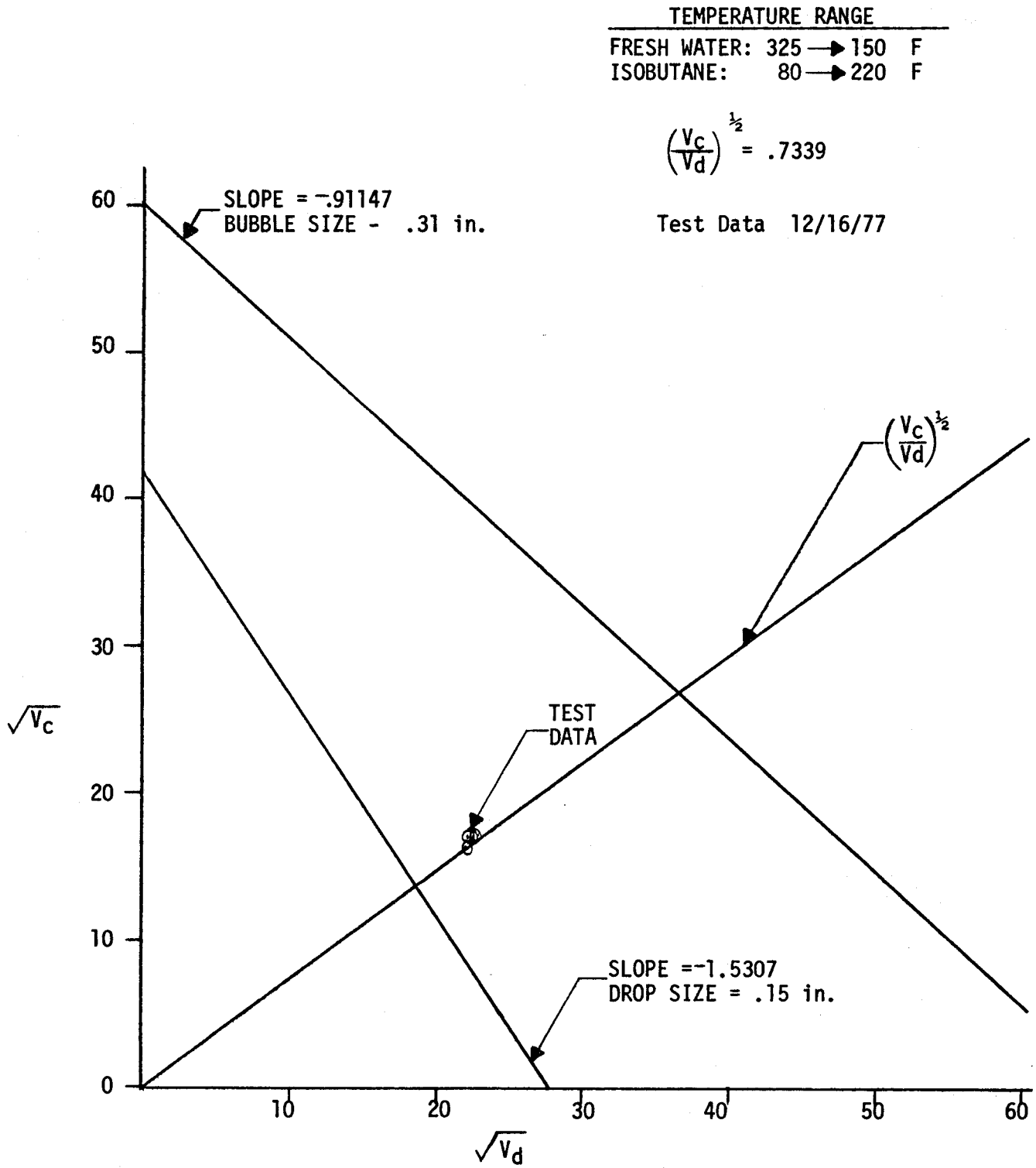
An alternate model for the boiling section would be to assume that the droplets do indeed arrive at the free surface incompletely vaporized. Furthermore, one could assume that the free surface is in motion depending on the brine

FIGURE 7-1

SUPERFICIAL VELOCITY OF

ISOBUTANE AND FRESH WATER

SAKIADIS & JOHNSON MODEL



inlet configuration. For the tangential inlet used in the most recent tests we could assume that the free surface is revolving about the vertical axis of the column. The centrifugal action is imparted by the brine and water vapor velocity acting tangentially on the free surface. For the brine flow rates and brine inlet size currently used the two phase mixture velocity is 13 ft/sec. This is calculated assuming 1.5% of the brine flashes at the brine control valve and has reached equilibrium by the time it enters the boiler. Such circular motion has never been observed in the DCHX, however. The sight windows are located about nine inches below the new tangential inlet so it may be possible that the circular motion is damped before reaching the windows.

7.2 Modifications and Additional Equipment Requirements

Several modifications to the basic Direct Contact Heat Exchanger Loop were required before the brine carryover experiments could be successfully conducted. These modifications and the associated new instrumentation and equipment installations are outlined below.

a) Boiler Modification

One of the initial explanations for the brine carryover experienced during the endurance runs was that the brine operating level in the boiler was too high and excessive liquid was splashing up through the mesh. Therefore, it was proposed that boiler level should be one of the operating variables to monitor in attempting to minimize carryover. The original boiler level controller was equipped with a 15 inch long sight gauge glass. To allow a greater span in boiler level control, a second level controller and gauge sight glass was installed in series with and below the original glass.

The second major boiler modification was the installation of an alternate brine inlet below the existing one. The hypothetical reason for this was twofold: 1) to increase the vapor space in the boiler and; 2) to introduce

the brine at the free surface level without spraying such that the effect of minimizing turbulence in this section of the boiler could be monitored. The new brine inlet was installed such that the brine would be admitted tangentially to mix with liquid isobutane as it swirled against boiler sidewalls. The alternate inlet was equipped with appropriate valves so that either brine inlet could be used. Figure 7-2 shows the installation of the dual level controllers and the new brine inlet.

With this inlet the boiler simulates the well mixed homogeneous reactor shown diagramatically by Figure 2, Porter 1965 (Reference 6), which consisted of a co-current type mixing heat exchanger section feeding a cyclonic flash vapor separator. This exchanger was shown to have about 5 times the U_V of other proposed designs.

The DSS unit uses the tangential inlet top section of the preheater shell as a co-current direct contact heat exchanger as well as for a vapor-liquid separator thus allowing the highest efficiency type of boiler to be superimposed directly on top of the preheater.

In addition to the modification above, a recording pressure gauge and additional thermocouples were installed in the upper section of the boiler for a more accurate determination of superheat conditions. The pressure recorder used was a Taylor Model 76JF138 equipped with a 316 SS Bourdon Tube. The thermocouples were Type J, Iron-Constantan and were installed in oil filled wells. These were electrically connected to a "Speedomax" recorder providing a continuous chart readout.

b) "Dummy" Turbine Nozzle Assembly

In order to simulate turbine pressure drop and provide a media for scale deposition so that a comparison could be made between the scaling results of the Endurance Runs and subject brine carryover experiments, a "dummy" turbine nozzle assembly was fabricated.

The assembly consisted of a nozzle press-fitted in the center of a two inch flange plate and the appropriate two inch, 600 #ASA treated flanges. Each flange was tapped to facilitate a standard pressure gauge. The nozzle was designed after consultation

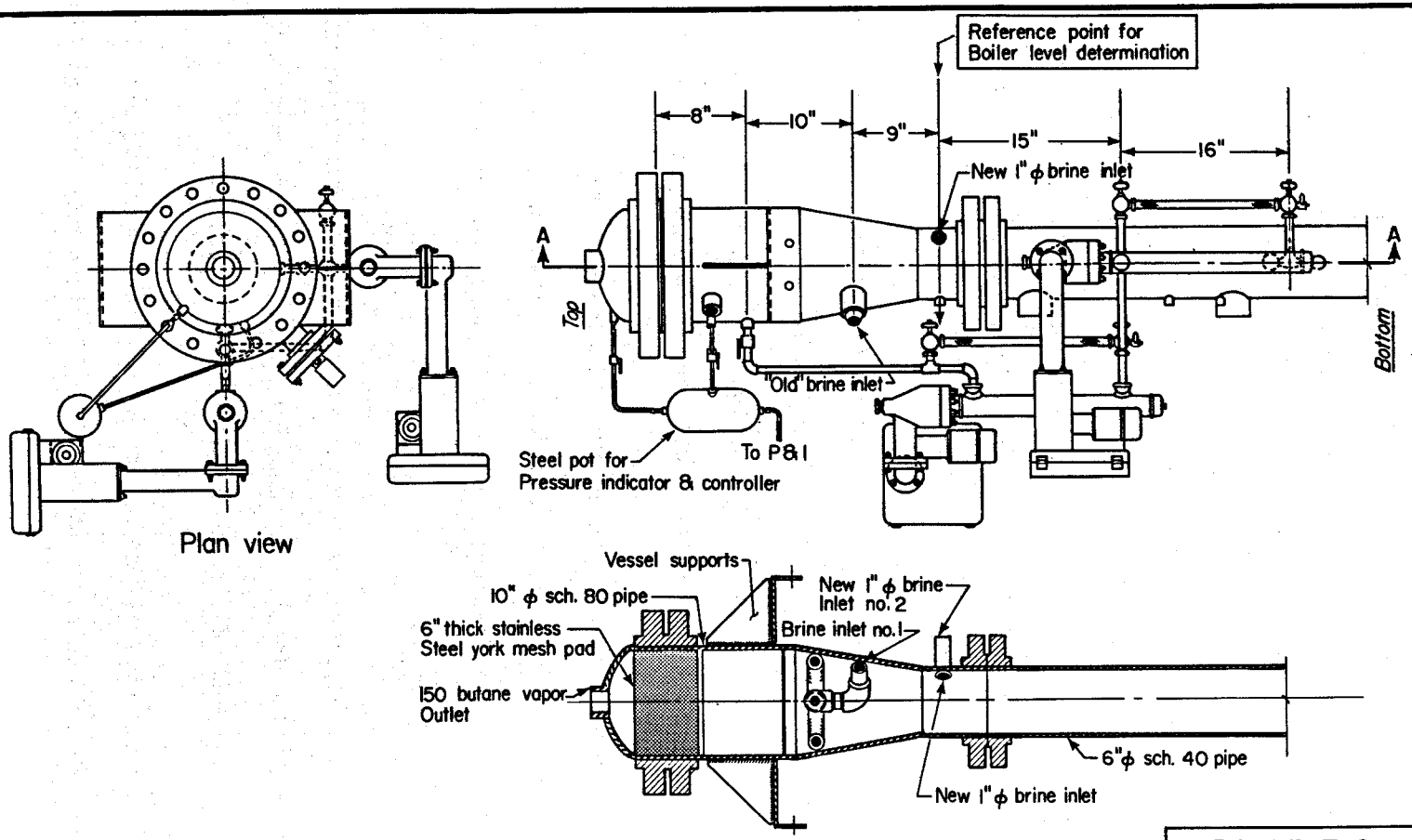


FIGURE 7-2
DUAL LEVEL
CONTROLLER
INSTALLATION

XBL 792-8274

with Barber Nichols Engineering and then machined from Type 303 Stainless Steel. A detailed drawing of the nozzle and a cutaway showing the critical dimensions of the assembly are shown as Figures 7-3 and 7-4.

The assembly was installed in the isobutane vapor line downstream of the knockout drum. Photographs of the assembly and location of the installation are shown as Figures 7-5 and 7-6.

(c) Conductivity Cell and Water Trap Installation

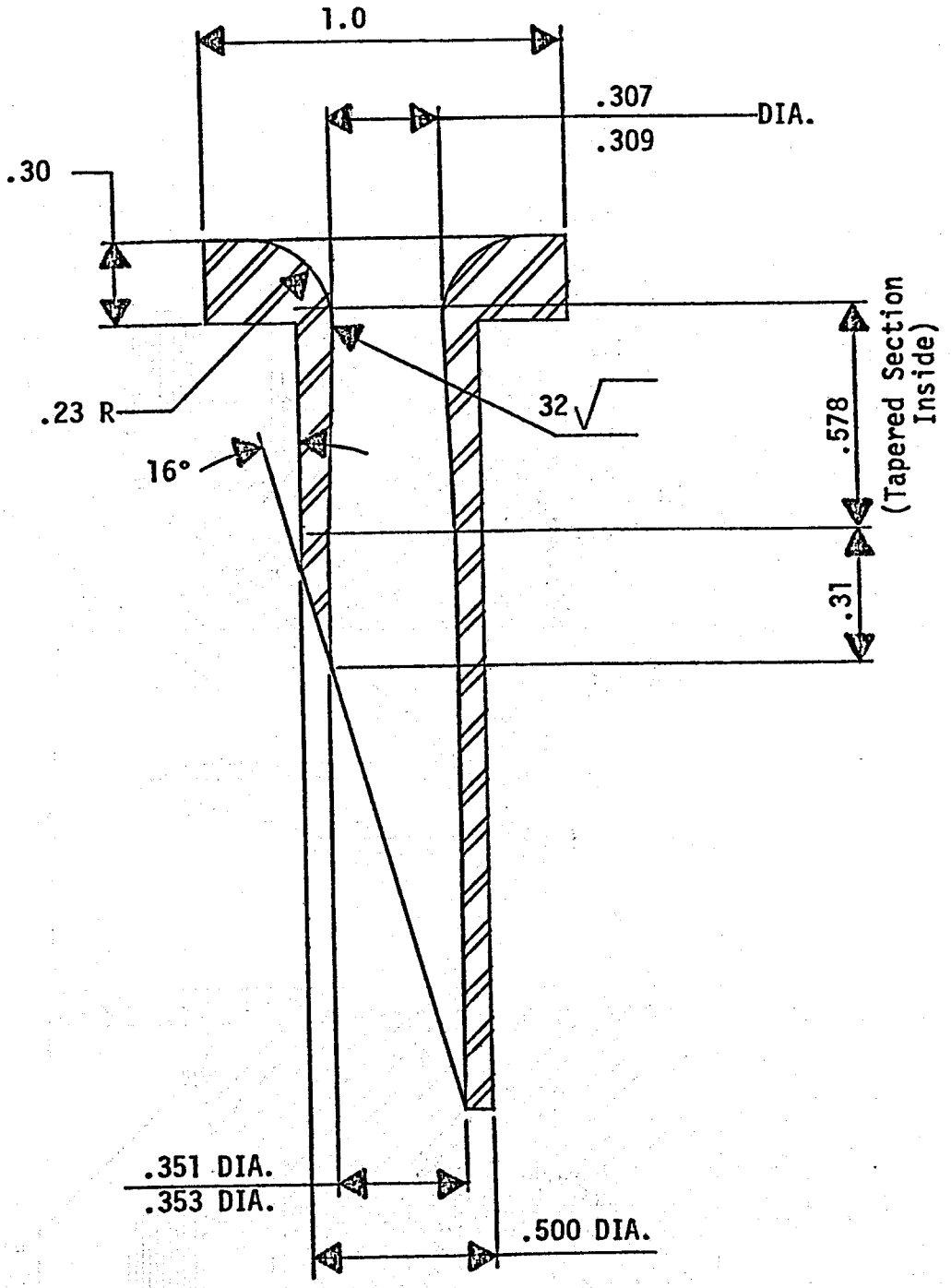
In an effort to monitor the amount of water collected in the knockout drum and minimize carryover to the "dummy" nozzle, a float type water trap was installed on the bottom drain line of the knockout drum. This allowed for continuous blowdown of water collected in the knockout drum.

To monitor the salinity of the blowdown effluent from the knockout drum and the hotwell, conductivity cells were installed in the blowdown lines downstream of the corresponding water traps. The conductivity cells were Leeds & Northrup Model #4905-10-33-088-7. Each cell was equipped with an internal temperature compensator.

The cells were supplemented by new conductivity indicators which in turn were electrically connected to the "Speedomax" recorder thus providing a continuous printed readout. The conductivity indicators were Leeds & Northrup Model #7073-17-01-104-6-00-130.

Since conductivity readings are very sensitive to changes in temperature, thermocouples were also installed in the blowdown lines to check the performance of the temperature compensators and calibrate the conductivity cells.

P & I drawings of the conductivity cells and water trap installations are shown as Figures 7-7 and 7-8 Photographs of the installations are shown as Figures 7-9 and 7-10.



DUMMY TURBINE NOZZLE DETAIL

FIGURE 7-3

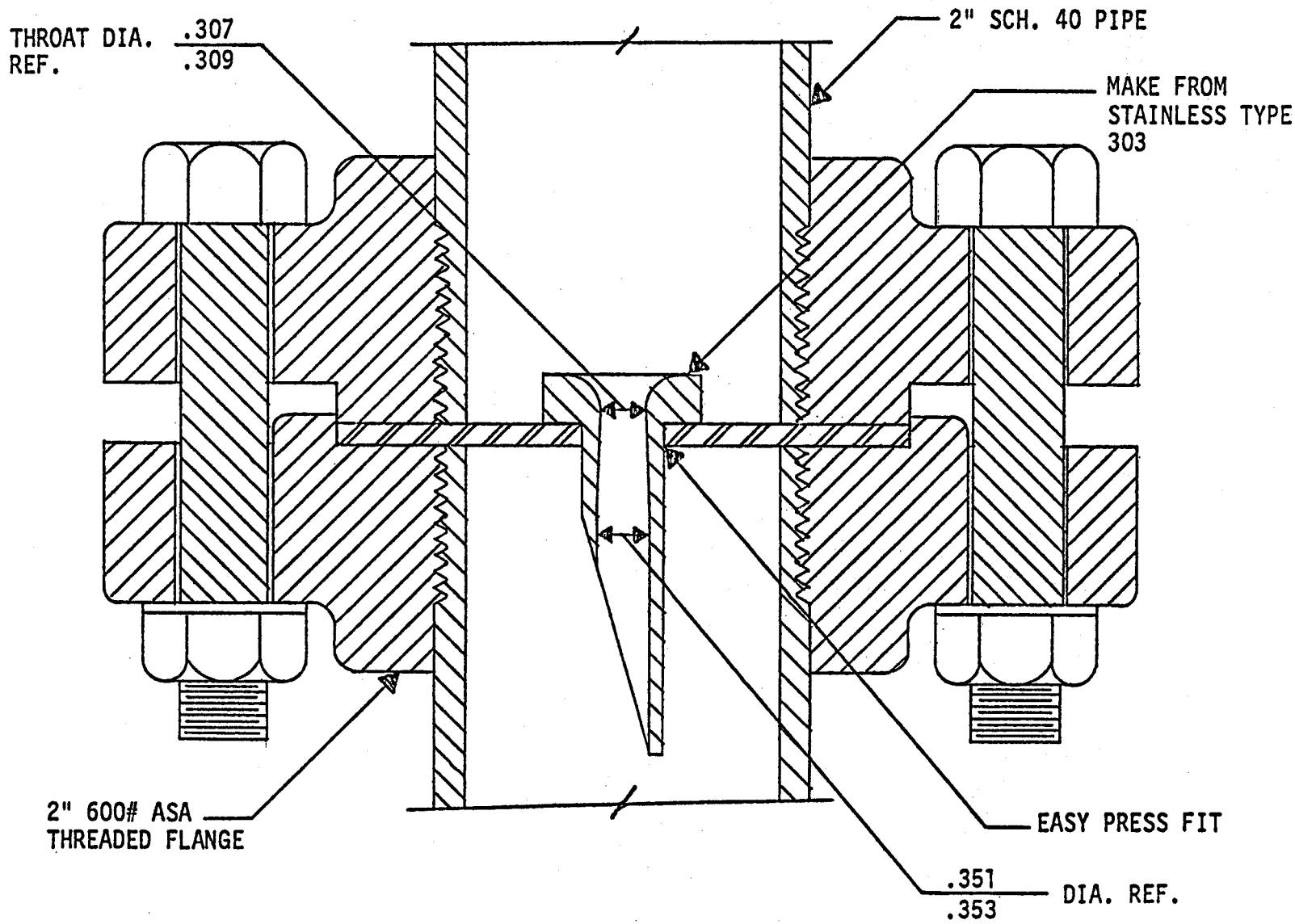
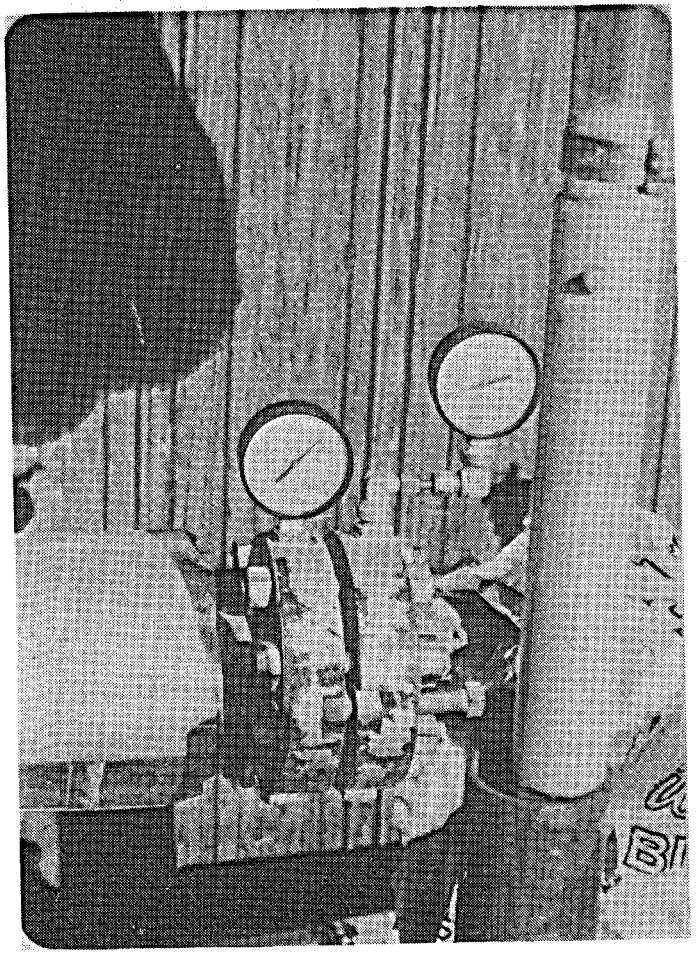


FIGURE 7-4

DUMMY TURBINE NOZZLE ASSEMBLY

FIGURE 7-5

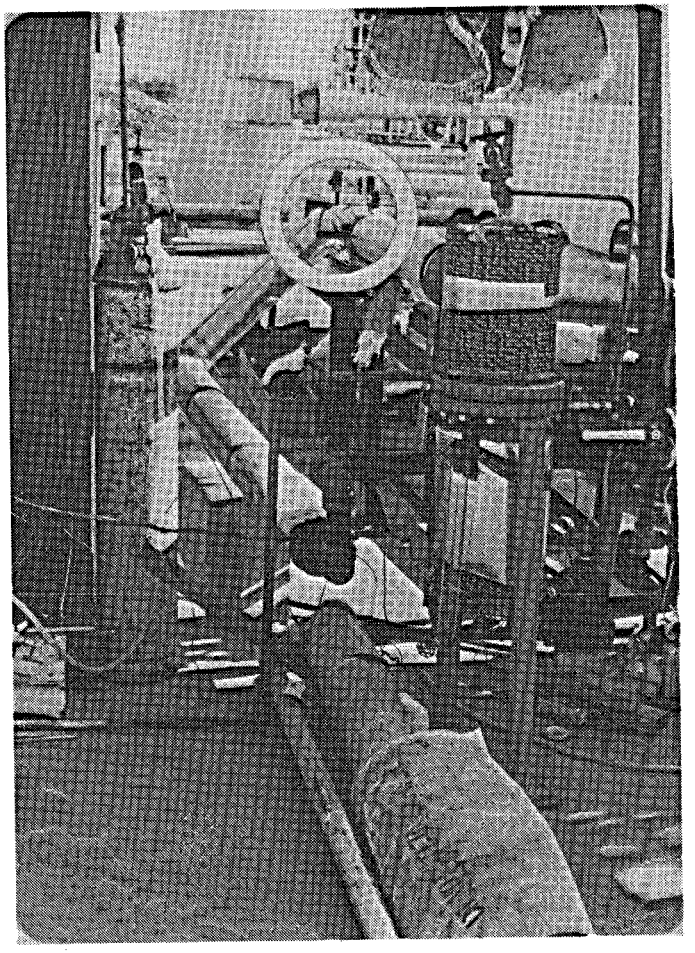
"DUMMY" TURBINE NOZZLE ASSEMBLY



XBB 791-592

FIGURE 7-6

LOCATION OF "DUMMY" NOZZLE ASSEMBLY
IN PIPING CIRCUIT



XBB 791-593

FIGURES 7-7 and 7-8

CONDUCTIVITY CELL & WATER TRAP INSTALLATION

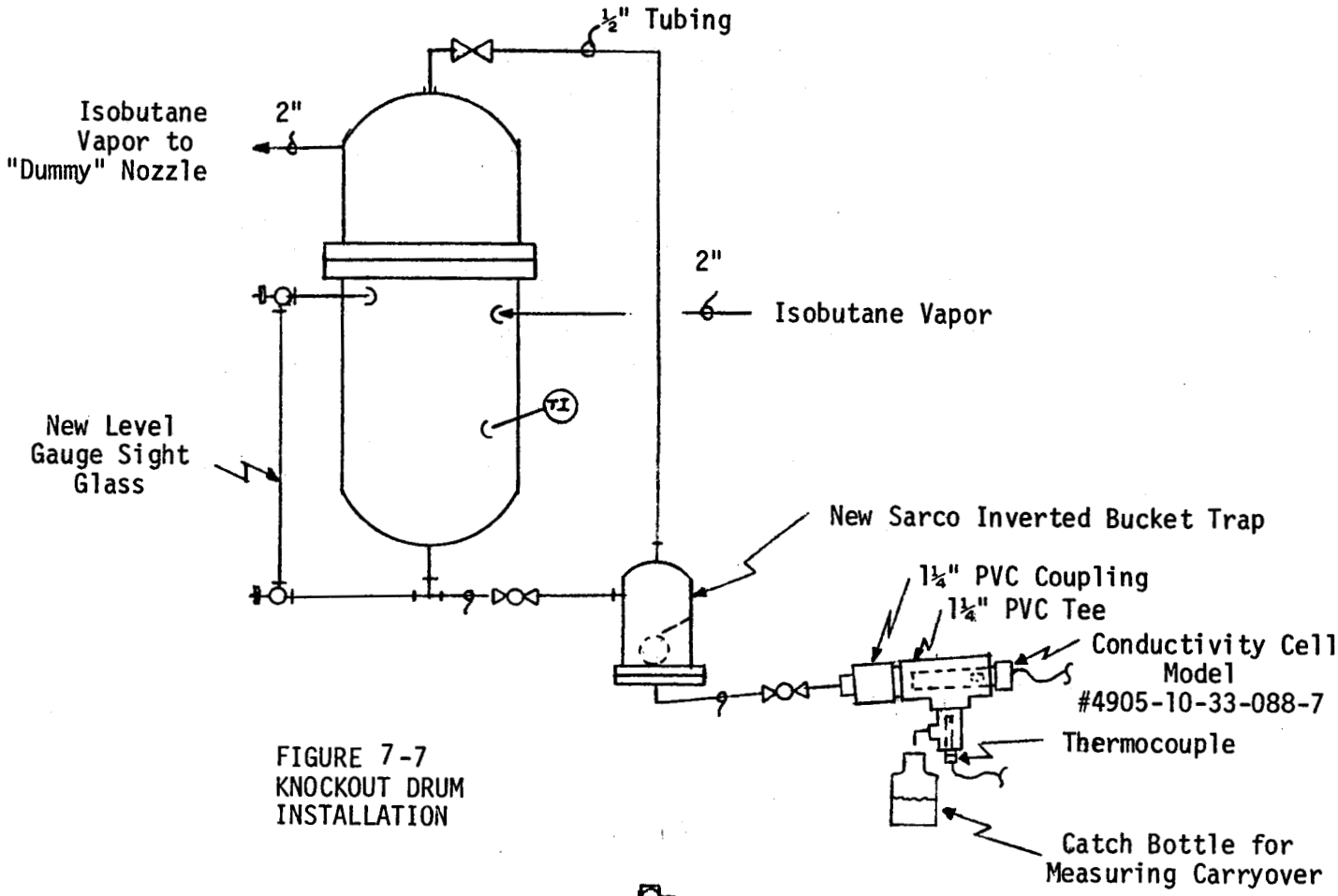


FIGURE 7-7
KNOCKOUT DRUM
INSTALLATION

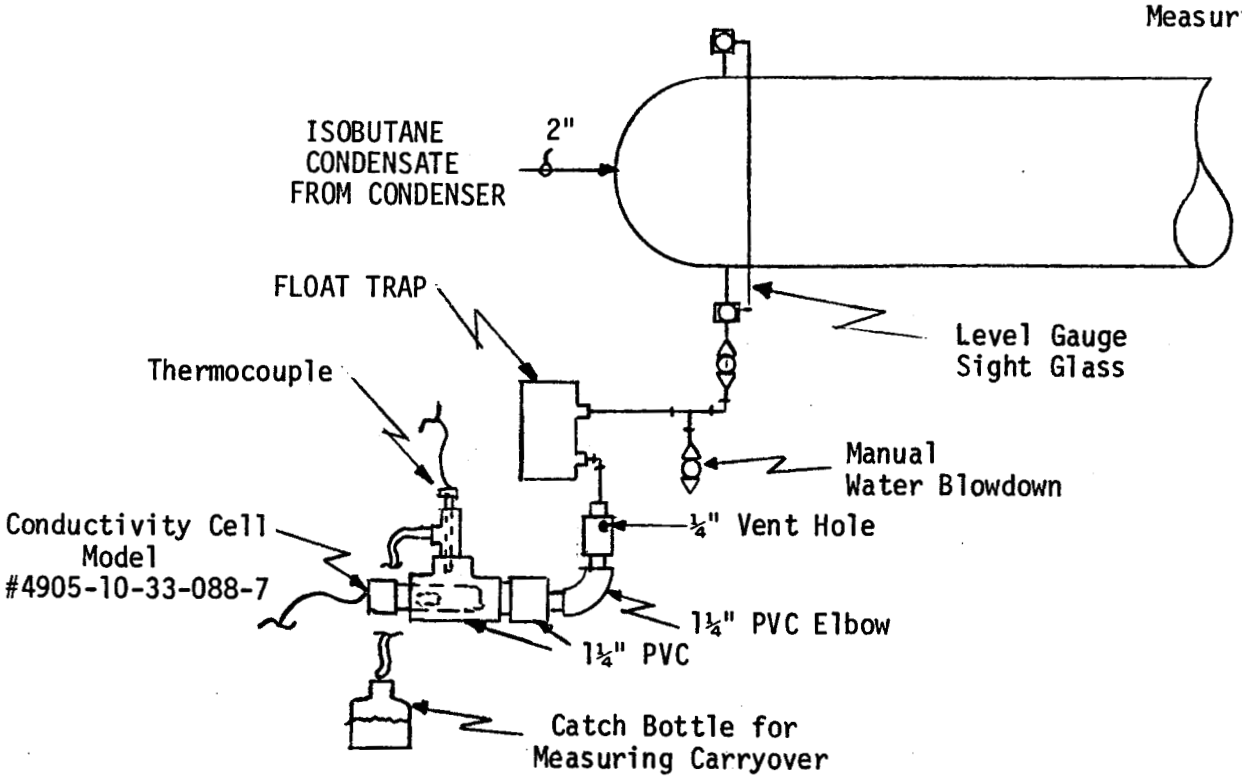
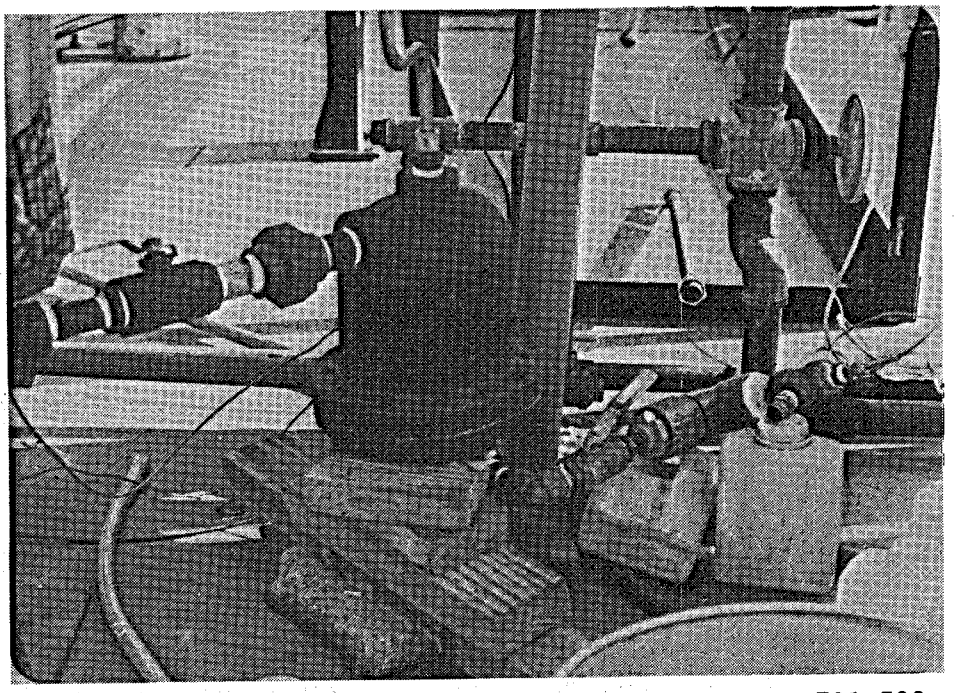


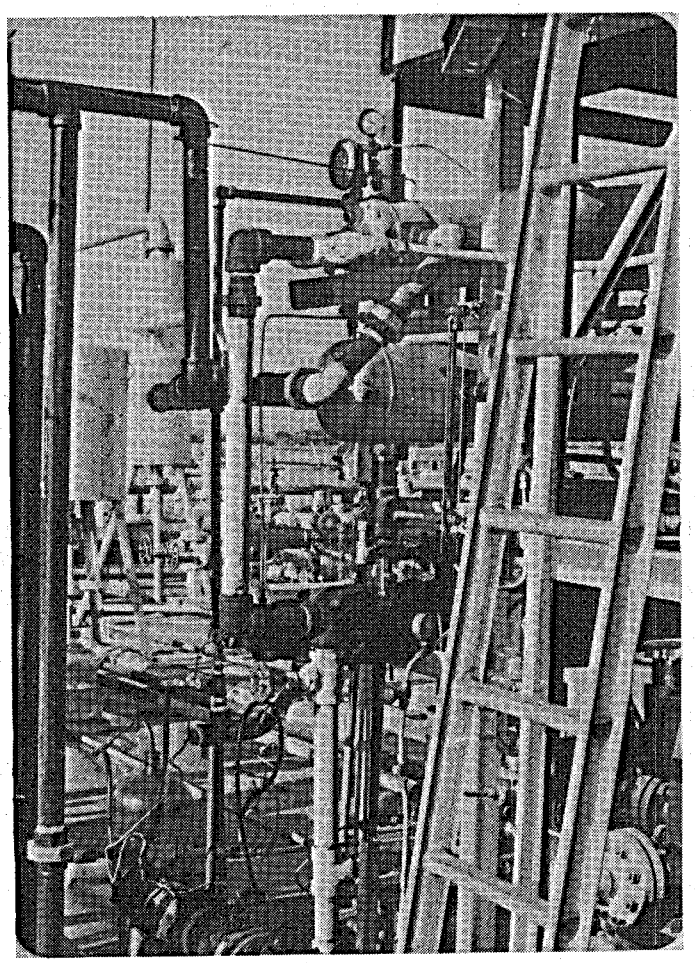
FIGURE 5-8
HOTWELL
INSTALLATION

FIGURE 7-9

SARCO WATER TRAP INSTALLED AT BOTTOM OF KNOCKOUT DRUM. ALSO SHOWN IS CONDUCTIVITY PROBE AND THERMOCOUPLE ASSEMBLY FOR MEASURING CONDUCTIVITY OF KNOCKOUT DRUM BLOWDOWN.



XBB 791-590



XBB 791-591

FIGURE 7-10

HOTWELL CONDUCTIVITY PROBE ASSEMBLY FOR MEASURING HOTWELL BLOWDOWN CONDUCTIVITY

d) Miscellaneous

To facilitate monitoring the performance of the new water trap, a level gauge glass was installed on the knockout drum.

In addition, one-half of the dip tube (vapor down-comer) in the knockout drum was removed to provide more liquid volume in the sump of the drum.

7.3 Procedure

The conductivity concept used by industry for blowdown control in recirculating cooling water systems was chosen as the method to monitor changes in the TDS content of the knockout drum and hotwell blowdown during the carryover testing.

Specific conductance is inversely proportional to electrical resistance. Since pure water is highly resistant to the passage of an electrical current, it has a low specific conductance. However, inorganic compounds such as sodium chloride, potassium chloride and sodium sulfate will dissociate in water forming positive and negative ions which will conduct electricity in proportion to the amount of ions present. Thus, water containing dissolved salts becomes a better conductor of electricity and the specific conductance is increased.

This method of measuring total ionic concentration by conductivity is accurate down to the level of approximately 0.5 - 1.0 ppm ionizable solids. However, it is exceedingly sensitive to temperature changes as well as the installation and orientation of the measuring cell in the field. Therefore, it was decided to calibrate the cells and check the reliability of the temperature compensators prior to starting the actual carryover tests.

A .025N (1778.38 ppm) Kcl solution was prepared in the laboratory to be used as a standard reference for calibration of the conductivity cells. The theoretical specific conductance (umhos) vs temperature for this solution is as follows:

Temp (C)	Specific Conductance (umhos)
0	1630
18	2446
25	2784

Each cell was placed in turn in a glass graduated cylinder containing a portion of the reference solution. A thermocouple was also inserted in the cylinder. The graduated cylinder was then placed in an ice bath and the conductivity and temperature were monitored using the conductivity meter and "speedomax" recorder. After a series of data points were obtained, the graduated cylinder was placed in a hot water bath and the corresponding data recorded. Figure 7-11 shows a typical chart readout of the data.

The data were then manipulated to obtain working curves for determining the salinity of both the knockout drum and hotwell blowdown in terms of equivalent ppm KCl. These curves are shown as Figure 7-12.

Eighteen carryover tests were conducted during the period May 31, 1978 - June 9, 1978. The time of each test was set at an arbitrary 90 minutes after initially allowing the DCHX - Isobutane loop to stabilize for 1 to 2 hours. Tests were conducted with brine flowing to the DCHX through the "new" brine inlet. Then, comparative tests were run for brine introduced through the "old" brine inlet. The general procedure used was as follows:

a) Start the DCHX at a controlled isobutane flow rate, brine flow rate, and boiler level. Allow system to equilibrate.

b) Monitor all pressures, temperatures, flow rates, levels, and conductivity at 10 minute intervals as well as record all possible data on the continuous readout charts.

c) Collect all blowdown effluent from the knockout drum and hotwell

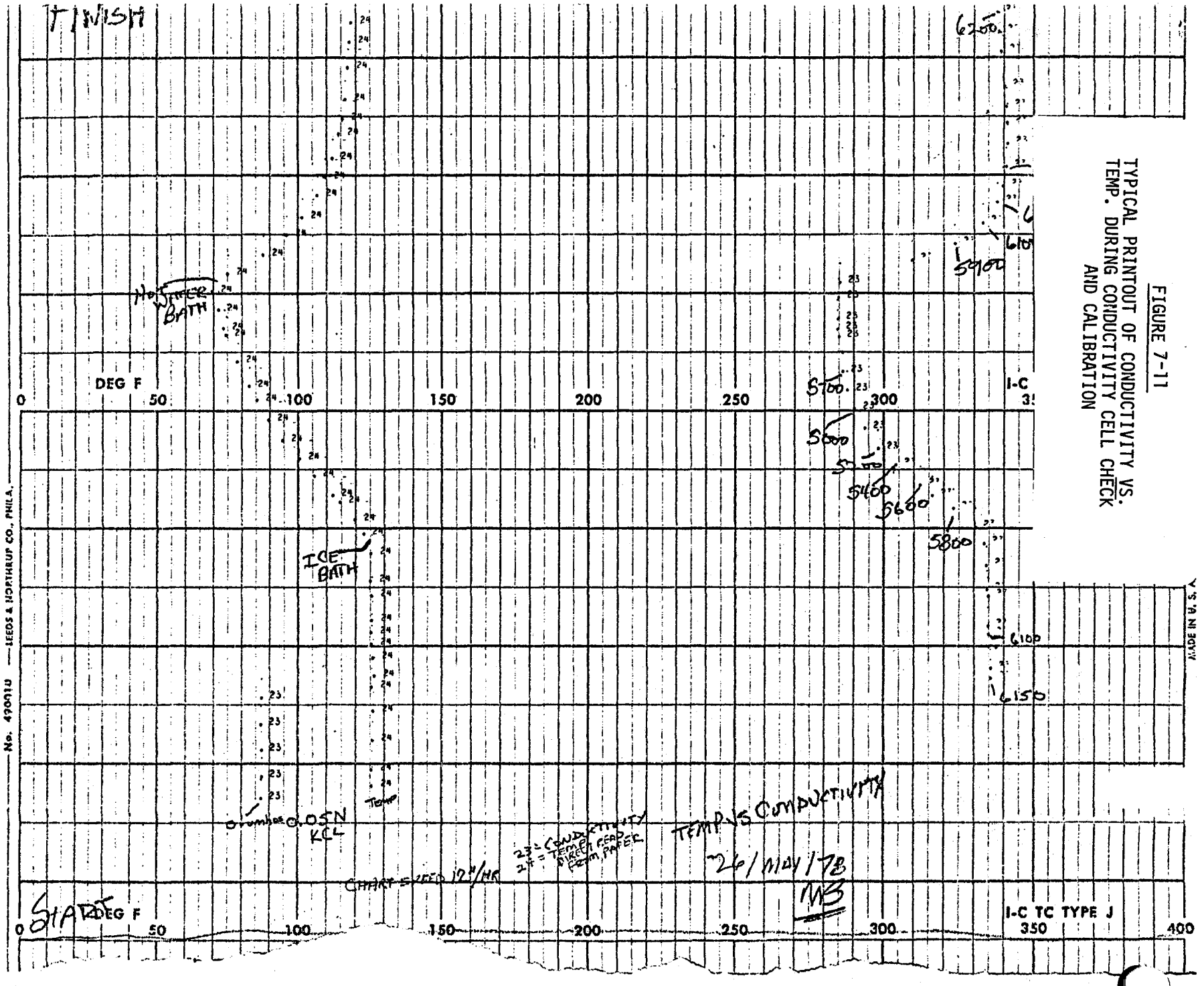
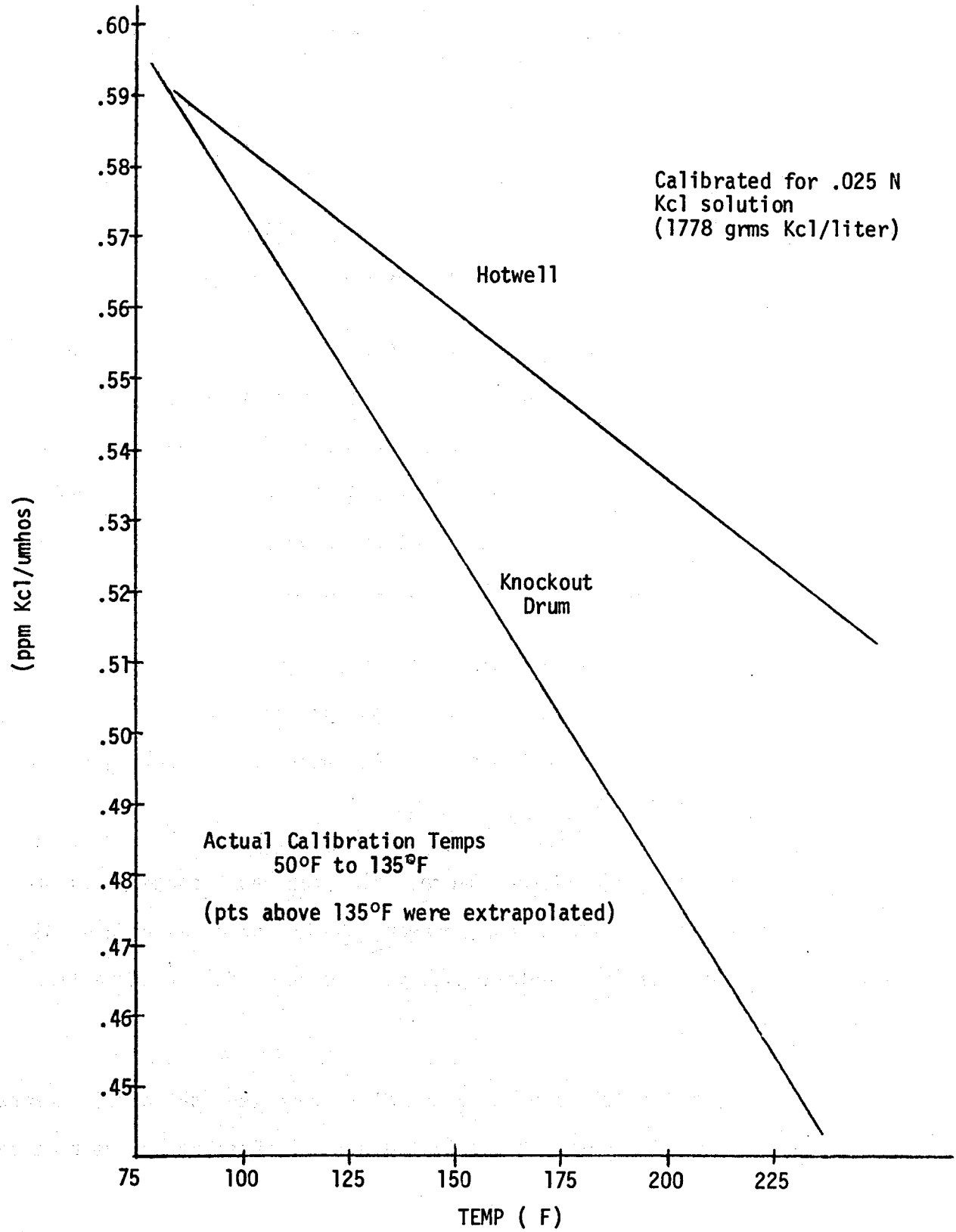


FIGURE 7-11

TYPICAL PRINTOUT OF CONDUCTIVITY VS. TEMP. DURING CONDUCTIVITY CELL CHECK AND CALIBRATION

FIGURE 7-12

TEMPERATURE CORRECTION FOR CONDUCTIVITY PROBES



water traps in appropriate containers. Measure and record total content of each at end of test.

d) Change level in boiler holding brine and isobutane flow rate constant. Allow system to equilibrate and repeat b) and c) above.

e) Change flow rates and level and repeat data collection.

7.4 Results and Discussion

Table 7-1 is a summary of the data collected which was used to quantify and qualify the water vapor present in the vapor generated by the boiler. The values on the Table are the arithmetic averages for each test run.

No definite correlations between boiler operating level and the amount or salinity of the water content of the isobutane vapor stream are apparent. The only significant result is that the high knockout drum water blowdown rates measured during tests 4,6, and 10 were accompanied by the highest measured salinity. This may indicate that brine or dissolved salts passed through the demister pad and into the knockout drum.

Table 7-2 is a summary of the partial pressure, degrees superheat of isobutane and weight fraction water content of the vapor phase. These values were calculated from the data shown on Table 7-1. Attempts at correlating these were unsuccessful.

Also included on Table 7-2 is the theoretical water vapor content[14] of the vapor stream for each test. As can be seen, the measured values are all higher than theoretical but, unfortunately, no correlation or correction factor is apparent.

It should be noted that the conductivity values reported (salinity) represent average values and, in some cases, selected values. Because of the physical setup of the conductivity cells in their respective wells, low blowdown flow conditions may not have been sufficient to purge residual salts or previous

TABLE 7-1

CARRYOVER DATA SUMMARY - MEASURED FLOW & SALINITY VALUES

	Date 1978	Test #	BRINE FLOW GPM	BRINE FLOW lbs/hr	ISO FLOW GPM	ISO FLOW lbs/hr	DCHX BOILER Level[1] (inches)	KNOCKOUT DRUM Flow liter/hr	KNOCKOUT DRUM Flow lbs/hr	KNOCKOUT DRUM Conduct. (umhos)	KNOCKOUT DRUM Salinity (ppm)	HOTWELL Flow liter/hr	HOTWELL Flow lbs/hr	HOTWELL Conduct. (Umhos)	HOTWELL Salinity (ppm)
NEW BRINE INLET	5/31	1	5.0	2664	8.5	2318	4.5	1.9	4.2	600	338	17.4	38.4	600	354
	5/31	2	6.1	2785	8.1	2211	7.2	1.8	4.0	600	324	16.0	35.3	600	358
	6/1	3	4.9	2213	7.6	2097	4.0	1.7	3.7	533	288	17.5	38.5	1600	947
	6/2	4	5.9	2664	8.2	2274	16.0	6.1	13.4	5200	2725	20.1	44.4	567	336
	6/5	5	4.8	2168	7.4	2047	6.4	2.0	4.3	586	333	23.1	50.8	600	355
	6/5	6	4.8	2168	7.7	2115	16.3	27.8	61.2	6800	3250	41.4	91.2	3186	1886
	6/5	7	3.0	1355	6.8	1870	6.0	2.9	6.4	700	381	5.9	13.1	600	355
	6/6	8	4.0	1806	6.9	1926	1.5	1.4	3.1	600	341	14.1	31.0	572	339
	6/6	9	4.2	1897	6.9	1888	6.7	1.2	2.6	343	195	15.0	33.0	600	355
	6/6	10	4.3	1942	6.5	1787	14.5	168.7	371.7	6400	3059	13.1	28.8	600	355
	6/13	11	7.2	3252	9.8	2704	0	.9	2.0	*4000-1100	-	19.9	43.8	400	237
	6/14	12	7.5	3387	9.8	2704	1.0	.8	1.9	450	254	20.5	45.1	400	238
	6/14	13	7.5	3387	10.1	2779	12.0	1.5	3.3	385	215	19.9	43.8	425	251
OLD INLET	6/7	14	4.2	1897	6.8	1875	.5	2.6	5.8	400	227	14.0	30.9	650	388
	6/7	15	4.2	1897	6.5	1794	6.0	1.4	3.1	400	226	20.2	44.6	600	355
	6/8	16	5.3	2394	7.8	2135	11.0	3.1	6.9	675	354	40.0	88.1	700	411
	6/9	17	5.3	2394	8.5	2357	0	2.1	4.6	443	252	8.2	18.1	757	448
	6/9	18	5.3	2394	7.9	2165	5.6	2.2	4.8	350	193	15.9	35.0	700	414

* power went off, shutdown rig, salinity up and not sufficient flow thru cell well to purge salts

(1) inches below new brine inlet - see Figure 7-2

TABLE 7-2

CARRYOVER DATA SUMMARY - CALCULATED VALUES

Test No.	Observed Boiler Vapor Temp.(F)	Observed Boiler Vapor Pressure (psia)	Calculated Boiling Temp.(F)	C_4H_{10} (psia)	H_2O (psia)	C_4H_{10} Super-heat (F)	$\frac{lbs\ H_2O(HW)}{lb\ C_4H_{10}}$	$\frac{lbs\ H_2O(KO)}{lb\ C_4H_{10}}$	$\frac{lbs\ H_2O(Tot)}{lb\ C_4H_{10}}$	Theoretical* $\frac{lbs\ H_2O}{lb\ C_4H_{10}}$
1	212	259	198	248.0	11.0	14	.0166	.0018	.0184	.0095
2	225	263	199	251.5	11.5	26	.0160	.0018	.0178	.0096
3	219	213	181	205.3	7.7	38	.0184	.0018	.0202	.0084
4	216	251	195	240.6	10.4	21	.0195	.0059	.0254	.0093
5	232	194	173	187.6	6.4	59	.0248	.0021	.0269	.0080
6	223	202	177	196	7.0	46	.0431	.0289	.0720	.0082
7	163	167	161	162	4.9	2	.0070	.0034	.0104	.0073
8	210	206	178	198	7.2	32	.0161	.0016	.0177	.0083
9	213	205	178	198	7.2	35	.0175	.0014	.0189	.0083
10	208	198	175	191	6.7	33	.0161	.2080	.2241	.0081
11	226	317	216	300	15.9	10	.0162	.0007	.0169	.0105
12	226	316	216	300	15.9	10	.0167	.0007	.0174	.0105
13	223	314	215	298	15.5	8	.0158	.0012	.0170	.0104
14	205	196	174	189	6.6	31	.0165	.0031	.0196	.0081
15	230	197	174	189	6.6	33	.0249	.0017	.0266	.0081
16	225	280	205	268	12.8	20	.0413	.0032	.0445	.0099
17	215	278	204	265	12.5	11	.0077	.0020	.0097	.0098
18	222	283	206	271	13	16	.0162	.0022	.0184	.0099

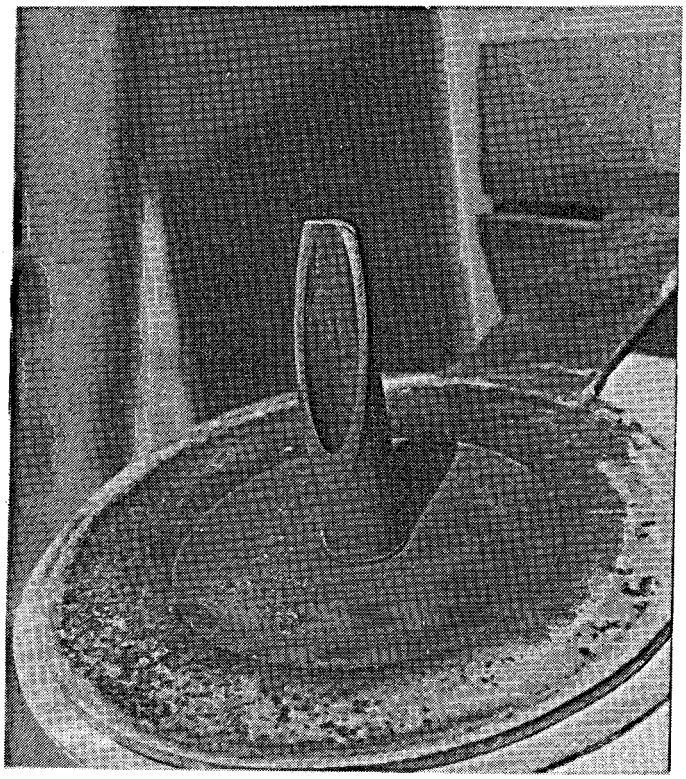
brine from the wells. It is suggested that a different conductivity sample setup employing a positive flush or purge system be utilized in future runs.

Another observation of the data included in Table 7-1 is the salinity content of the hotwell blowdown. Theoretically, the blowdown should only be condensed water vapor having a very low or negligible salinity. The measured salinity can be adequately explained by acknowledging the premise that ammonium bicarbonate may be formed on cooling in the condenser. The fact that ammonia is present in the vapors has been verified by Bechtel.[15]

At the end of the testing period, the "dummy" turbine nozzle was removed from the circuit and examined for scale deposition. It is estimated that the nozzle was intermittently in service for a total of 120 hours. The surfaces of the nozzle were found to be free of any significant scale deposits. Only a fine black powdery coating which later analyzed as carbon was evident. Photographs of the nozzle taken at the time of examination for scaling are shown as Figures 7-18 through 7-21.

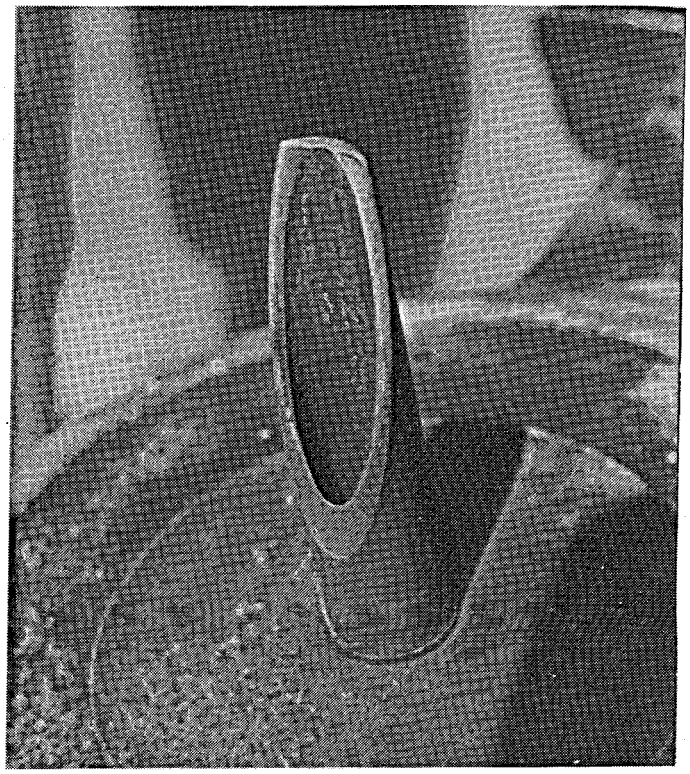
PHOTOGRAPHS OF "DUMMY" TURBINE NOZZLE TAKEN AT COMPLETION OF CARRYOVER TESTS SHOWING THE RELATIVELY SCALE FREE CONDITION OBSERVED

FIGURE 7-18



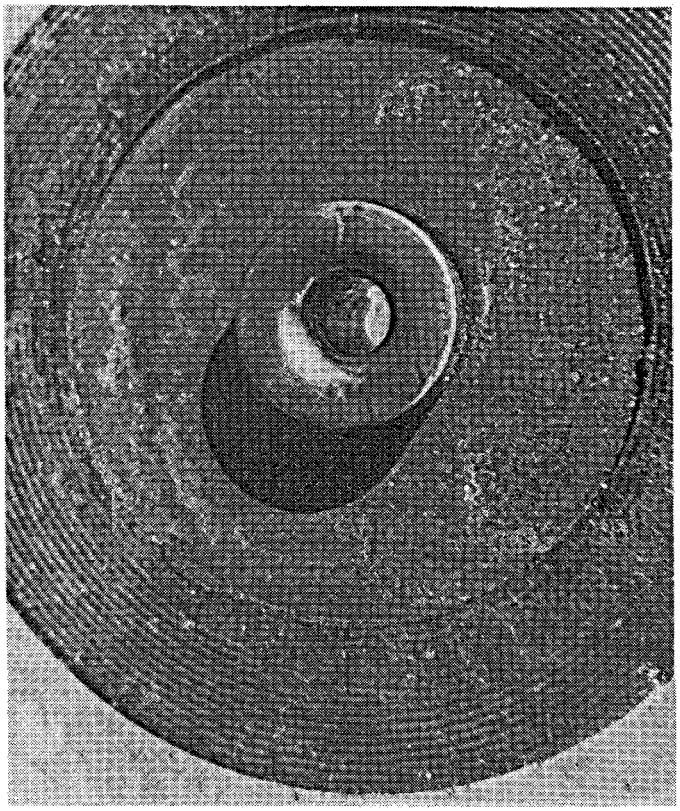
XBB 791-606

FIGURE 7-19



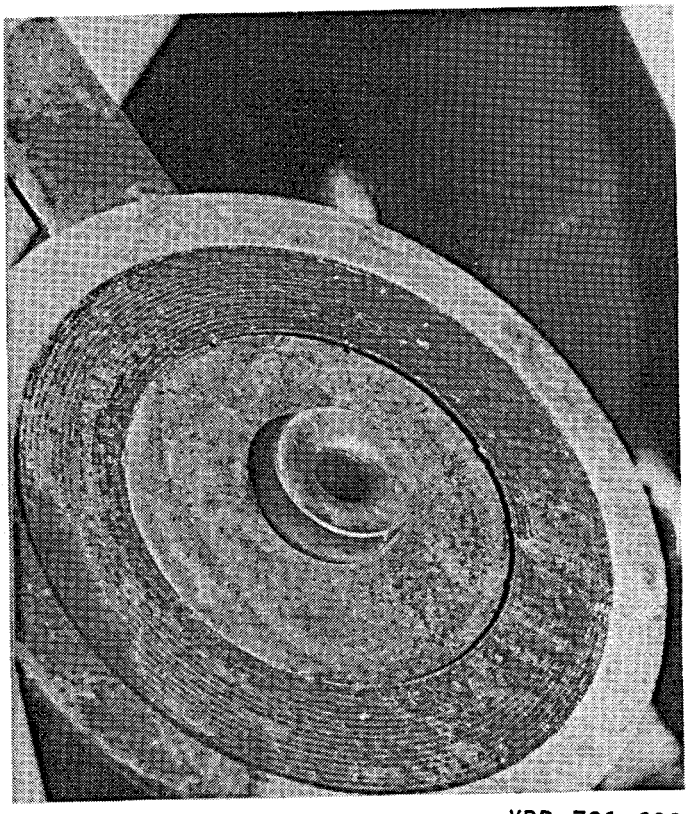
XBB 791-607

FIGURE 7-20



XBB 791-608

FIGURE 7-21



XBB 791-609

SECTION 8

ORNL CONDENSER TESTS

SECTION 8

ORNL CONDENSER TESTING

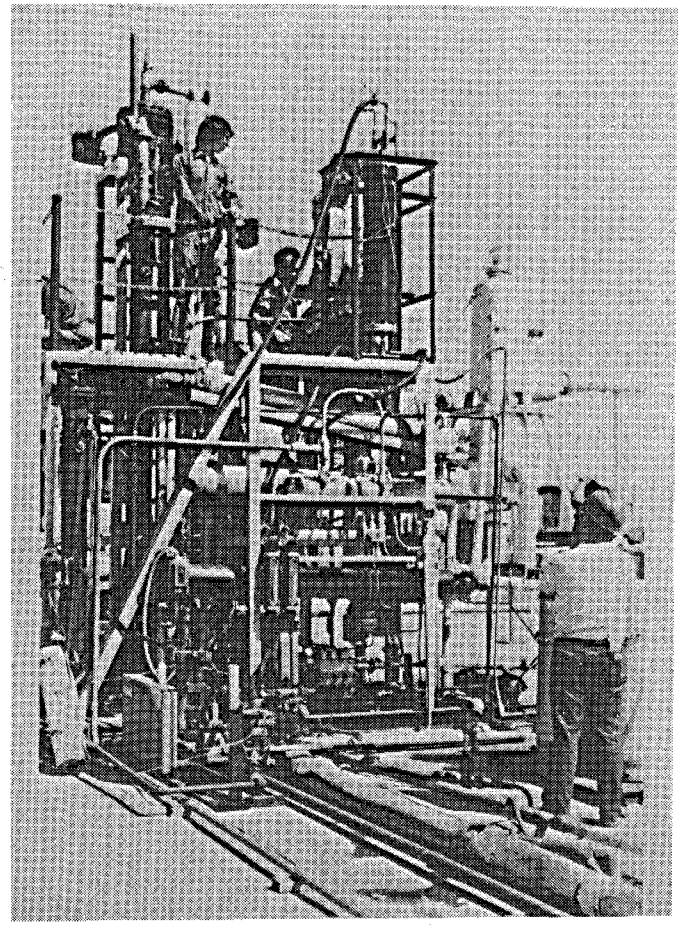
8.1 Introduction

In the utilization of low temperature geothermal energy for power production, heat transfer considerations become of increasing economical and technological significance due to typically low conversion efficiencies. Oak Ridge National Laboratory has initiated a heat transfer development program to improve the condensation heat transfer effectiveness for a variety of hydrocarbon and fluorocarbon working fluids to be used in these low temperature geothermal power cycles. This development work is based on the results of a program conducted by ORNL as part of the OSW Seawater Desalting Project which involved testing a variety of vertical fluted (Gregorig) condenser tubes.

As part of their geothermal applications program, ORNL planned a series of condenser performance tests using isobutane vapor generated by the DCHX. The initial test was not specifically contracted, but, by mutual consent, was to be performed simultaneously with the Second Turbine Test.

In preparation for this test, a two-tube stainless steel vertical shell-and-tube condenser was located by ORNL personnel on the upper deck of the DCHX platform. The condenser was equipped with instrumentation necessary to evaluate the difference in heat transfer performance between smooth tubes and fluted tubes. The ORNL condenser was piped parallel to the DCHX condenser to receive part of the isobutane vapors exiting the turbine. These vapors would be condensed on the outer surface of the tubes and returned to the DCHX hotwell by gravity. East Mesa Test site cooling water on the tubeside was used for cooling. Valves were located on the vapor inlet and condensate return lines of the ORNL condenser such that it could be isolated and dismantled without interfering with the Turbine Tests. Photographs of the condenser are shown as Figures 8-1 and 8-2.

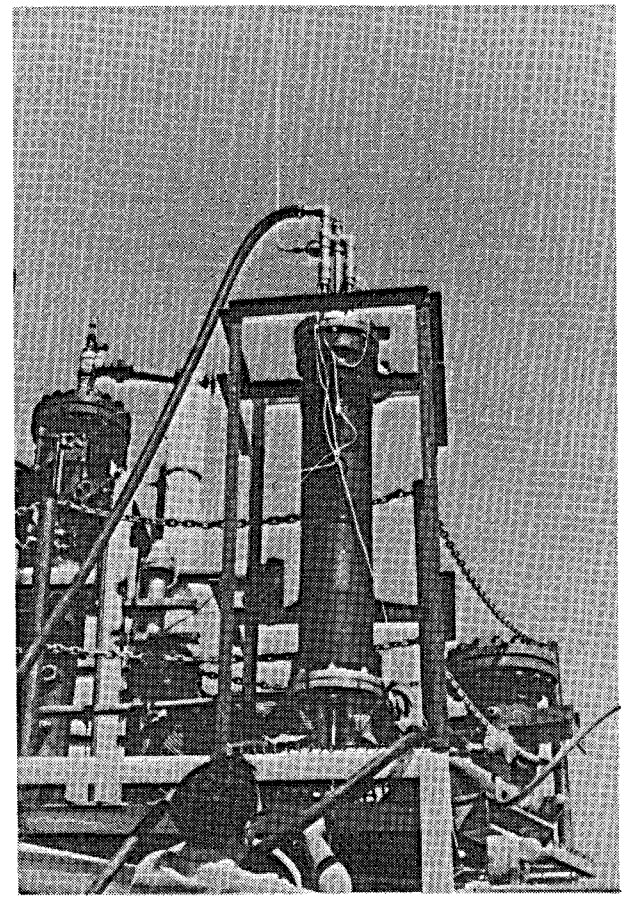
PHOTOGRAPHS OF THE OAK RIDGE NATIONAL LABORATORY
TWO-TUBE VERTICAL SHELL AND TUBE ISOBUTANE CONDENSER



XBB 791-602

FIGURE 8-1

GENERAL LOCATION OF ORNL
CONDENSER ON DCHX MODULE



XBB 791-603

FIGURE 8-2

ORNL PERSONNEL INSTALLING
WATER LINES TO CONDENSER

Several operational problems were encountered associated with the ORNL condenser, during the condenser tube performance tests. The main problem resulting from parallel operation of the condensers was that a higher hotwell pressure was experienced than when the ORNL condenser was isolated. A possible explanation of this is that the ORNL condenser may have had a lower shell-side pressure drop than the DCHX condenser. This, coupled with the fact that no provisions were made to accurately control or measure the vapor flows, could have resulted in the higher hotwell pressure experienced.

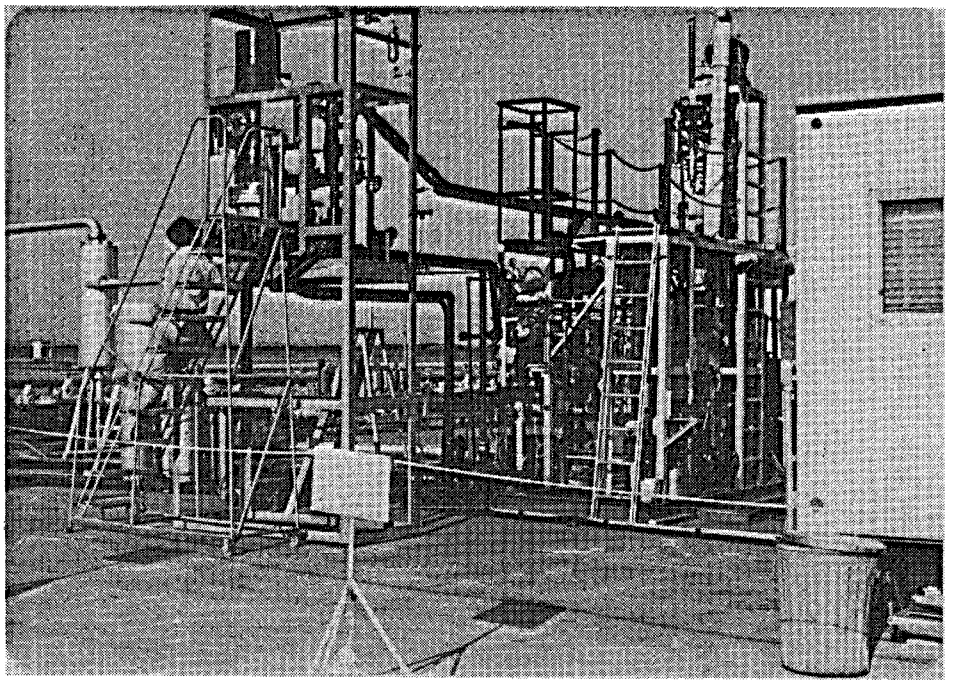
As a follow up condenser test program, DSS was contracted in May of 1978 by Lawrence Berkeley Laboratory (PO #4366002-Change#1, Task 10.0) to operate the DCHX - isobutane system in support of additional Oak Ridge condenser tests. This section of the report summarizes this proposed condenser test program and the problems encountered during attempts at executing this task.

8.2 Condenser Description and Loop Modification

The new Oak Ridge Condenser was a 40 tube stainless steel vertical shell-and-tube type. The tubes were fluted aluminum, four feet long, with an overall total heat transfer area of approximately forty square feet. The shell side (isobutane) of the condenser was designed to handle noncondensables by vapor sweeping across the tube bank in successively smaller flow areas to a purge point. Rubber drain-off tube sheets were used as baffles. The condenser was designed to handle an isobutane flow of 2000 lbs/hr at a condensing temperature of 110 F.

The condenser, together with piping and instrumentation, was delivered to the site as a pre-assembled module. The installation of the module is shown as Figures 8-3 and 8-4.

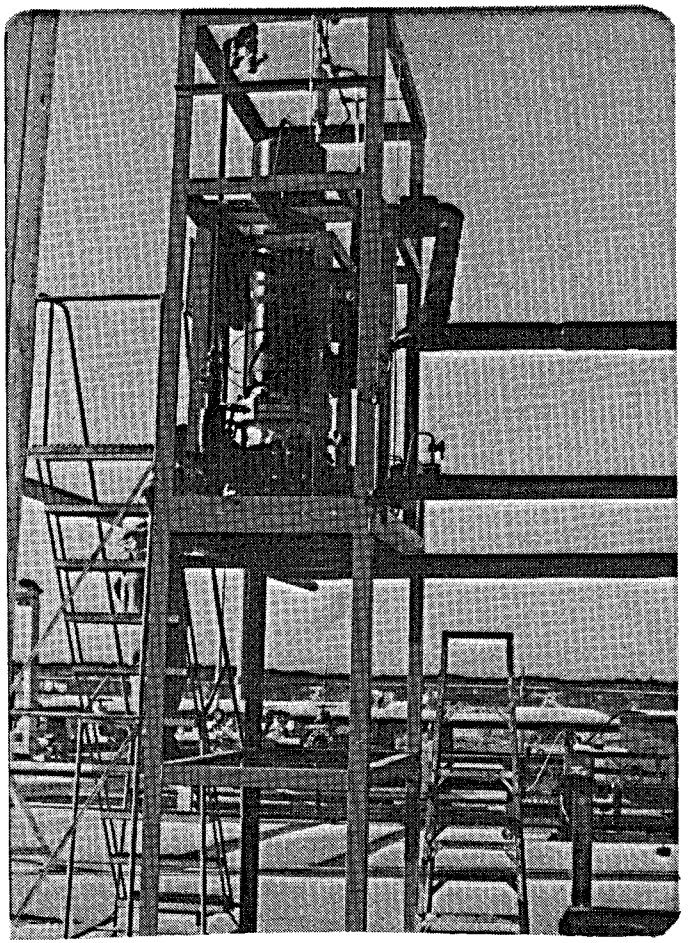
PHOTOGRAPHS OF THE OAK RIDGE NATIONAL LABORATORY
FORTY-TUBE VERTICAL SHELL AND TUBE ISOBUTANE CONDENSER



XBB 791-600

FIGURE 8-3

GENERAL LOCATION OF ORNL CONDENSER ON DCHX MODULE



XBB 791-601

FIGURE 8-4

ORNL CONDENSER. UPPERMOST HEADER IS ISOBUTANE VAPOR INLET. MIDDLE HEADER IS ISOBUTANE CONDENSATE RETURN TO HOTWELL. LOWER HEADER IS COOLING WATER

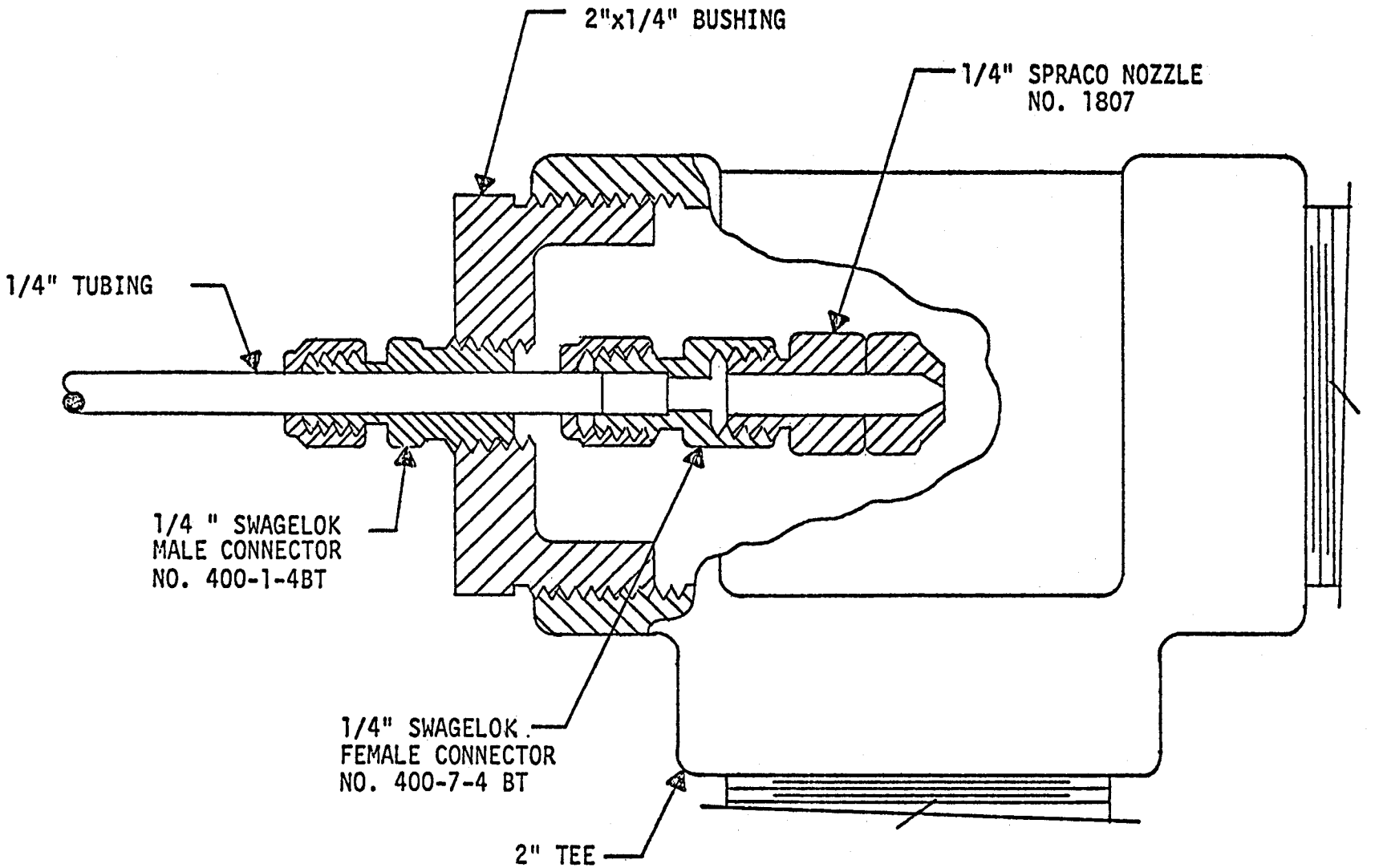
Minor modifications had to be made to the existing Direct Contact Heat Exchanger Loop to accommodate the ORNL condenser module. A two-inch tee and ball valve were installed at the DCHX condenser inlet and a length of two-inch pipe were fitted such that the isobutane vapor could be directed to either condenser. A "desuperheater" nozzle assembly was installed in this vapor line upstream of the Oak Ridge condenser. One-half inch stainless steel tubing was run between the nozzle and a port installed on the discharge piping of the isobutane pump. This setup was to regulate the amount of isobutane superheat entering the condenser by contacting liquid isobutane (at hotwell conditions) with the incoming isobutane vapor. Figure 8-5 shows a cut-a-way of the desuperheater nozzle assembly.

8.3 Proposed Test Procedure & Problems Encountered

A test program was devised by DSS and Oak Ridge Personnel for evaluating the performance of the Oak Ridge 40 tube condenser. This consisted of collecting "base line" data generated by evaporating isobutane in the "hairpin" exchanger and condensing the vapor in the Oak Ridge condenser. Then the DCHX would be operated to supply vapor at similar pressures and temperatures and the data compared. Isobutane vapor at both saturated and superheat conditions was to be run. However, because of numerous mechanical, design and operational problems, neither hairpin nor DCHX data could sufficiently be obtained. Some of the more prominent problems experienced were as follows:

a) Since bulk storage of isobutane at the site was discouraged by the California State Safety Officer (OSHA), operation down time was experienced on a number of occasions while makeup isobutane was being shipped from Los Angeles.

b) After installation of the condenser it was realized that the condensate return line was undersized. This caused flooding on a few occasions. The apparent maximum condensate flow rate was 4.5 gpm. This restricted the operation of both the hairpin and DCHX.



NOZZLE FOR DESUPER HEATER IN 2" TEE

FIGURE 8-5

c) Condenser "blow-by" was experienced on a number of occasions, causing excessive high pressures in the hotwell. This was similar to what had occurred during testing the two-tube condenser.

d) Downtime was experienced while waiting the arrival of spare parts necessary to rebuild the isobutane pump.

e) Performance data did not appear to be characteristic of expected isobutane system. Samples of working fluid and gas revealed that isobutane was contaminated with approximately 6% propane and at times excessive amounts of non-condensibles.

REFERENCES

1) "Study and Testing of Direct Contact Heat Exchangers for Geothermal Brines" - Final Report, DSS Engineers for ERDA Division of Geothermal Energy, January 1977, ORO-4893-1.

2) "Final Report - Direct Contact Heat Exchanger 10 K Power Loop Test Series No. 1", Barber Nichols Engineering Co., for Lawrence Berkeley Laboratory, December 15, 1977, LBL-7036.

3) "Conditioning Water for Boilers" Nalco Chemical Co., Chicago, 1962.

4) "Steam", the Babcock & Wilcox Co., 37th edition, New York, 1975.

5) "Fluid Thermodynamic Properties for Light Petroleum Systems" Starling, Gulf Publishing Co., Houston, 1973.

6) "Studies of Direct Contact Heat Transfer with Applications to Seawater Conversion" J. Winston Porter, PhD thesis, University of California, Berkeley, January 1965.

7) "The Mechanism of Heat Transfer in a Spray Column Heat Exchanger" Ruth Letan and Ephram Kehat, AIChe Journal, May 1968.

8) Minard, G.W. and Johnson, A.I., Chem. Engr. Progr, 48 (2), 62, 1952.

9) "Generalized Correlation of Flooding Rates" Sakiadis, B.C., Johnson, A.I., Industrial and Engr. Chemistry, June 1954.

10) M.W. Kellogg Co., Saline Water Conversion Engineering Data Book, 2nd edition Office of Saline Water, Washington, U.S. Government Printing Office, November 1971.

11) Hellstrom, G.W. Master Thesis, University of Utah, Utah, 1976.

12) Linke, William F., Solubilities of Inorganic and Metal Organic Compounds, American Chemical Society, 4th Edition 1958.

13) Rapier, P.M., The Vapor Composition of Boiling Immiscible Liquids, Engineering Notes, L.B.L., code GT1808, serial M5125, February 1, 1978.

14) Bechtel, Operations and Maintenance at East Mesa, USDI, August 1977.

15) Standard Methods for Examination of Water and Wastewater, American Public Health Association, Inc., 12th Edition, 1965.

16) Carbonate Chemistry at the East Mesa KGRA, H.A. Papazian L.B.L. excerpt from a technical report.

REFERENCES

APPENDIX A

APPENDIX A

COLUMN DIAMETER CORRELATIONS

Minard-Johnson Correlation

An empirical correlation has been presented by Minard and Johnson[8] for the relationship between the drop diameter and superficial velocities of the continuous and dispersed phases in a spray column at the flooding conditions. This equation is:

$$V_c^{0.5} = \left[47\mu_c^{-0.07}\Delta SG^{0.14}SG_c^{-0.5}\right] - \left[1.8d^{0.056}\mu_c^{-0.075}\left(\frac{SG_d}{SG_c}\right)^{0.5}V_d^{0.5}\right] \quad (2\text{-}1)$$

where:

d = droplet diameter, inch

SG_c = continuous phase specific gravity

SG_d = dispersed phase specific gravity

$\Delta SG = SG_c - SG_d$

μ_c = continuous phase viscosity, centipoise

V_c = continuous phase superficial velocity, ft/hr

V_d = continuous phase superficial velocity, ft/hr

The superficial velocity can be expressed as: mass flow rate/(density x column area). Therefore, the column diameter can be written as a function of droplet diameter by rearranging Eq. (2-1), i.e.

$$D = \left[\left(\frac{4M_c}{\pi\rho_c}\right)^{0.5} + 1.8d^{0.56}\mu_c^{-0.075}\left(\frac{SG_d}{SG_c}\right)^{0.5}\left(\frac{4M_d}{\pi\rho_d}\right)^{0.5}\right] \Big/ \left[47\mu_c^{-0.07}\Delta SG^{0.14}SG_c^{-0.5}\right] \quad (2\text{-}2)$$

where:

M_c, M_d = Mass flow rate of dispersed phase and continuous phase respectively. lb/hr

D = Column diameter, ft

If the constant average physical properties, mass flow rates and droplet size are defined, the spray column diameter can be determined.

Sakiadis-Johnson Model

Sakiadis and Johnson [9] have proposed a generalized theoretical equation for the flooding rate with respect to droplet size and superficial velocities. This equation has been used in the following form for correlation of published data on spray columns for the phase combinations solid-liquid, liquid-liquid, and gas-liquid.

$$1+1.8\left\{\left(\frac{\rho_d}{\rho_c}\right)^{1/4}\left(\frac{V_d}{V_c}\right)^{1/2}\right\}=0.565d^{1/4}\left\{\frac{V_c^2}{g_c}\,\frac{\rho_c}{\Delta\rho}\,\mu_c^{1/2}\right\}^{1/4} \qquad (2\text{-}3)$$

where:

ρ_d = density of dispersed phase, lb/cu-ft

ρ_c = density of continuous phase, lb/cu-ft

g_c = 4.17×10^8, ft/hr

$\Delta\rho$ = $\rho_c - \rho_d$,lb/cu-ft

μ_c = Viscosity of continuous phase, lb/ft-hr

For fixed mass flow rates of continuous phase and dispersed phase and a given droplet size, Eq. (2-3) can be rewritten and used to calculate the diameter of the spray column, i.e.:

$$1+1.8\left\{\left(\frac{\rho_d}{\rho_c}\right)^{1/4}\left(\frac{4M_d}{\pi D^2\rho_d}\right)^{1/2}\left(\frac{4M_c}{\pi D^2\rho_d}\right)^{-1/2}\right\}=0.565d^{1/4}\left\{\left(\frac{4M_c}{\pi D^2\rho_c}\right)^2\frac{\rho_c\mu_c^{1/2}}{g_c\Delta\rho}\right\}^{-1/4} \qquad (2\text{-}4)$$

Simplifying Eq. (2-4) and solving for D gives:

$$D=\left\{\left[1+1.8\left(\frac{\rho_c}{\rho_d}\right)^{1/4}\left(\frac{M_d}{M_c}\right)^{1/2}\right]\left[\left(\frac{4M_c}{\pi\rho_c}\right)^2\left(\frac{\rho_c\mu_c}{g_c\Delta\rho}\right)\right]^{1/4}\Big/0.565d^{1/4} \qquad (2\text{-}5)$$

Eq. (2-5) is used to calculate the column diameter with the assumption of constant average physical properties. Once the column diameter is determined, the throughputs of brine and isobutane may be obtained by $4M_c/(\pi D^2)$ and $4M_d/(\pi D^2)$ respectively.

APPENDIX B

Letan-Kehat Model

Letan and Kehat[7] have presented a mathematical model to describe the relationship between the height and temperature profiles in a spray column which is treated as a direct contact heat exchanger. These equations are:

$$\frac{T_d - T_{co}}{T_d - T_{co}} = \left\{ \frac{m}{r}\left[\frac{1+S}{\alpha_1}\left[1-\exp(\alpha_1 z)\right] - \frac{S}{\alpha_2}\left[1-\exp(\alpha_2 z)\right]+1 \right\} \exp\left(-\frac{M}{r}\right) \tag{2-6}$$

$$\frac{T_c - T_{co}}{T_{di} - T_{co}} = \left\{ \frac{m}{r}\left[\frac{1+S}{\alpha_1}\left[1-\left(\frac{r}{m}\alpha_1+1\right)\exp(\alpha_1 z)\right] - \frac{S}{\alpha_1}\left[1-\left(\frac{r}{m}\alpha_2+1\right)\exp(\alpha_2 z)\right]\right]+1 \right\} \exp\left(-\frac{M}{r}\right) \tag{2-7}$$

$$\alpha_{1,2} = \frac{m}{2}\left[\left(\frac{1}{M}+\frac{1}{r}-\frac{1}{p}\right) \pm \sqrt{\left(\frac{1}{M}+\frac{1}{r}+\frac{1}{p}\right)^2 - \frac{4}{mr}}\right] \tag{2-12}$$

$$S = \left\{\alpha_1 + \frac{M}{r} - \frac{rm}{pM}\left[\exp\left(\frac{M}{r}\right)-1\right]\right\} \Big/ \alpha_2 - \alpha_1$$

$$p = \frac{1}{R} + M$$

$$R = V_d / V_c$$

$$r = (\rho C_p)_d / (\rho C_p)_c$$

C_p = heat capacity, Btu/lb - degree F

z = height of spray column, ft

T_d = outlet temperature of dispersed phase, degree F

T_{di} = inlet temperature of dispersed phase, degree F

T_c = inlet temperature of continuous phase, degree F

T_{co} = outlet temperature of continuous phase, degree F

The value of M and m in Eq. (2-6) recommended by Letan and Kehat are 0.83 and 0.914 ft^{-1} respectively. Eqs. (2-6) and (2-7) are valid for the following conditions, (1) steady state, (2) no heat losses, (3) constant average physical properties, and (4) constant average droplet size. For fixed inlet and outlet temperatures of the dispersed phase and outlet temperatures of the continuous phase, the height of the spray column can be calculated by solving Eq. (2-6) using the Newton-Raphson iteration method.

APPENDIX C

APPENDIX C

RESULTS OF DEGASSING COLUMN EXPERIMENTS CONDUCTED DURING JANUARY AND FEBRUARY OF 1977

CONSIDERED INCONCLUSIVE

Isobutane Recovery Apparatus

The apparatus used in the isobutane recovery system is shown in Figure C-1. Vapor from the stripping column first enters a condenser to remove water vapor from the other gases. A hotwell to collect the condensate was installed under this water condenser. The remainder of the gas passes through a water trap into a compressor. The compressor used was a York Model 210 automotive air conditioning unit. The compressed gas mixture passes through an oil trap into a condenser where isobutane is removed from the mixture.

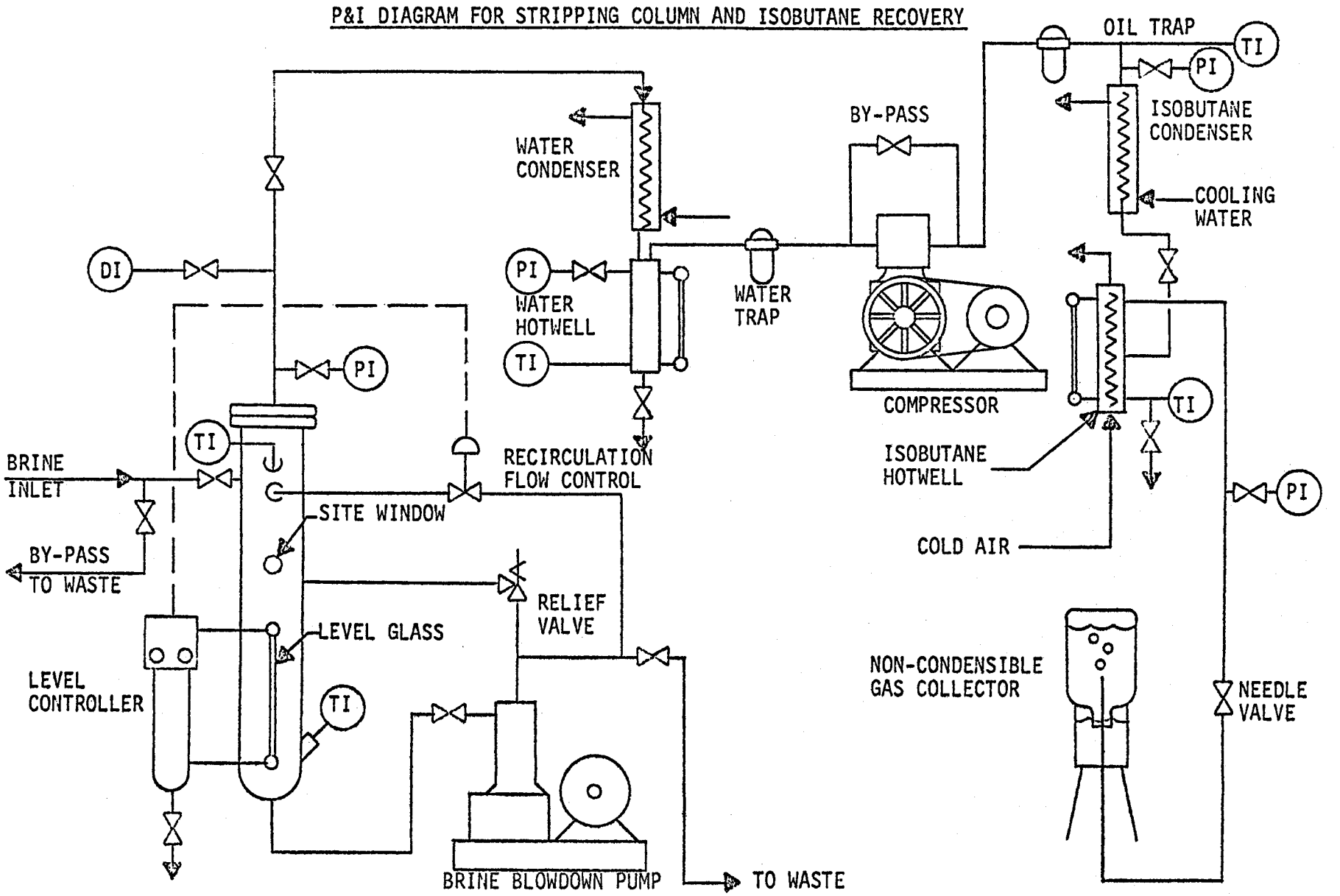
The condensed isobutane drops into the isobutane hotwell while the non-condensable gases are collected in a 5 gallon bottle under atmospheric pressure. The isobutane hotwell is cooled by cold air from a vortex tube.

Operating Procedure

The direct contact heat exchanger unit was started with the brine blowdown bypassing the stripping column. Once stable operating conditions for the unit had been established and the brine outlet temperature was down to approximately 150 F, the stripping column brine inlet valve was opened while closing the bypass valve. The gas inside the stripping column was vented to atmosphere through a gas sampling port at the top of the column. Except for this valve and the brine inlet, the stripping column was completely closed off while filling with brine. When the brine level in the stripping column reached the gas vent, the vent valve was closed, the blowdown pump

FIGURE C-1

P&I DIAGRAM FOR STRIPPING COLUMN AND ISOBUTANE RECOVERY



suction line was opened and the pump started. The positive displacement blowdown pump would create a vacuum of 12 to 14 in. Hg. in the column as the rate of vapor release from the brine would not keep pace with the liquid drawn down. With the vapor vent valve closed the pressure in the stripping column would eventually stabilize in the range between 2 to 14 psig in approximately 10 minutes.

After a period of steady operation of the unit with brine flow through the stripping column, temperatures and pressures at key locations around the unit were recorded. The bypass valve on the compressor was full open and the discharge valve was cracked. The vent valve on the stripping column was open and the compressor started. The compressor bypass and discharge valves were adjusted to establish the desired gas fow rate and stripping column pressure.

For consensing isobutane, a compressor discharge pressure of approximately 120 psig was used. Stripping column pressures were varied to analyze the effect of this variable on the amount of gas removed from the brine. Condensing temperatures varied between 55 F to 65 F depending on cooling water temperature.

It was noted that at 120 psig isobutane began condensing in the oil trap on the compressor discharge. Cold air from the vortex tube was then applied directly to this oil trap and the upstream tubing and the isobutane condenser and hotwell were bypassed. With proper oil level in the compressor, no accumulation of oil was noted in the isobutane. There was very little to no accumulation of water in this trap. The level of isobutane liquid in the trap was recorded periodically.

The non-condensable gases from the compressor discharge were collected in a 5 gallon glass bottle at atmospheric pressure. The 5 gallon bottle was

filled with water and inverted with the mouth of the bottle submerged in water. The non-condensible gases were allowed to bubble into this bottle. The rate of accumulation of gas in this bottle was noted and recorded.

Sampling Technique

Basically there were two different types of samples taken: (1) liquid and (2) gas. Brine sampling lines were run from four different locations around the unit: (1) boiler brine otlet; (2) separator outlet; (3) brine inlet into the unit; (4) discharge from the brine blowdown pump between the pump and downstream control valves.

When taking brine samples, a sample cylinder was mounted on the panel using swagelok fittings. The ball valve for the particular line being sampled was opened and the line purged by allowing brine to flow out the vent vales on the sampling manifold. The vent valve was then closed and the valves on the sampling cylinder were opened. These sample cylinders had been previously evacuated in the chemistry lab on the site to approximately 29 in. Hg of vacuum. The downstream throttling valve was observed to determine if any bubbles of gas were present. Approximately a 30 second quiet period without bubbles rising from the sample cylinder was allowed. On high pressure brine samples, such as the 300 psig samples from the separator outlet, the throttling valve was closed to permit flow at an intermediate pressure of 200 psig before closing the valve completely. Allowing the brine sample to flow at reduced pressure with the throttling valve full open allowed dissolved gas to bubble out of the brine. Flowing at the intermediate pressure suppressed the formation of bubbles. On all samples after the quiet period the valves on the sample cylinder were closed, the line pressure relieved, and the cylinder was removed from the panel, labeled and recorded.

A typical set of samples during the testing of stripping column performance consisted of the following samples: (1) stripping column brine inlet; (2) stripping column vent; (3) compressor discharge; (4) stripping column brine outlet. In addition to this routine set of samples, some brine inlet and boiler outlet samples were taken downstream of the separator. Initially the samples from the gas and brine outlets of the stripping column were taken first and were taken simultaneously. The compressor discharge and separator outlet samples were then taken successively. Later it was decided to try to better correlate the compressor discharge and separator outlet samples. At this point these two samples were taken first and simultaneously. These samples were then followed by the stripping column gas and brine samples taken simultaneously.

Discussion of Results

Although the chemistry lab at the East Mesa Site was very cooperative with the analysis of these samples, certain problems with the lab results for the first group of samples have been noted. First, accurate figures for the amount of air which was introduced into the low pressure gas and brine samples were not determined or recorded by the lab, and therefore it was assumed that the sample pressure was not a necessary variable in the analysis. While this assumption is true concerning the relative volume fractions of the constituents, the sample pressure is a siginificant factor in determining the total mole fractions of gases in a sample. It was assumed that the gases could be analyzed at atmospheric pressure because the gas chromatograph is vented to the atmosphere. An attempt was made to correct these reported figures to account for the amount of air introduced into the cylinders. For these corrections it was assumed that the cylinders had been pressurized to the service air pressure of the lab. THe validity of assuming that the sample cylinders were at this pressure when they were connected to the gas chromatograph is doubtful.

An additional problem arises from the fact that each time a sample was introduced into the gas chromatograph from a sample cylinder, the cylinder pressure would drop by an undetermined amount. For a particular sample cylinder a set of six or more samples may have been taken. This could result in a pressure drop of 10 psi in the sample. Therefore, confusion exists as to the actual pressure correction factors which should be applied to the sample analysis.

Although compound pressure gages were connected to the sample cylinders at the time the samples were flashed, no record was kept of the resulting pressure rise in the evacuated cylinders. This information would have been a valuable check on the quantity of isobutane and carbon dioxide which was collected in thse cylinders. Lack of knowledge of the final pressure after flashing of the brine samples prevents an accurate calculation of the solubilities of isobutane and carbon dioxide and determination of the residual amounts of these gases in the brine samples.

Another problem with this analysis results from the fact that a significant amount of carbon dioxide is left dissolved in the brine after it is flashed because of carbon dioxide's high solubility. The absence of pressure data at the time of flashing makes it impossible to determine the amount of carbon dioxide remaining in the brine.

"DEGASSING COLUMN DATA SUMMARY"

JANUARY - FEBRUARY 1978

DATE	TIME	DATA SET	LOCATION	P (psig)	LAB SAMPLE #	$\dot{m}$ BRINE (lb/hr)mea	compress. discharge (CFM)	IC4 HOTWELL (ml/hr)	PPM IC4 IN	PPM IC4 OUT	% IC4 recovered
2/7	17:50	4	TOP STRIPPER	1.5	400	3001	—	—	—	—	—
2/7	17:50	4	OUTLET STRIPPER	1.5	401	3001	—	—	—	—	—
2/7	17:57	4	COMP. DISCHARGE	105	402	3001	.0692	—	—	—	—
2/7	18:02	4	OUTLET SEPARATOR	300	403	3042	—	—	—	—	—
		4					$\dot{m}_{IB}$=.2029	57.7 $\dot{m}_{IB}$=.0719	60.6 $\dot{m}_{IB}$=.1843	4.6 $\dot{m}_{IB}$=.0138	92.9
2/8	13:12	5	TOP STRIPPER	1.5"	405	2876	—	—	—	—	—
2/8	13:12	5	OUTLET STRIPPER	10	406	2876	—	—	—	—	—
2/8	13:25	5	COMP. DISCHARGE	105	407	2876	.0306	—	—	—	—
2/8	13:40	5	OUTLET SEPARATOR	302	408	2824	—	—	—	—	—
		5					$\dot{m}_{IB}$=.1029	94 $\dot{m}_{IB}$=.1172	71.9 $\dot{m}_{IB}$=.2031	26.6 $\dot{m}_{IB}$=.0765	73
2/9	11:10	6	TOP STRIPPER	0.5	415	2930	—	—	—	—	—
2/9	11:10	6	OUTLET STRIPPER	12	416	2930	—	—	—	—	—
2/9	11:23	6	COMP. DISCHARGE	115	417	2930	.0222	—	—	—	—
2/9	11:28	6	OUTLET SEPARATOR	300	418	2930	—	—	—	—	—
		6					$\dot{m}_{IB}$=.0709	134 $\dot{m}_{IB}$=.1671	67 $\dot{m}_{IB}$=.1963	18.1 $\dot{m}_{IB}$=.0529	78.7

MADE BY W.A. LAVOIE
DATE 2-17-78
CHKD. BY
DATE
JOB NO. 068

DSS ENGINEERS, Inc.
FORT LAUDERDALE, FLORIDA

PROJECT DATA SUMMARY SHEET

SUBJECT DCHX STRIPPING COLUMN

SHEET NO. ___ OF ___

MADE BY W.A. LAVOIE
DATE 2-17-78
CHKD. BY
DATE
JOB NO. 068

DSS ENGINEERS, Inc.
FORT LAUDERDALE, FLORIDA

PROJECT DATA SUMMARY SHEET

SUBJECT DCHX STRIPPING COLUMN

SHEET NO. ____ OF ____

"DEGASSING COLUMN DATA SUMMARY"

JANUARY - FEBRUARY 1978

DATE	TIME	DATA SET	LOCATION	P (psig)	LAB SAMPLE #	$\dot{m}$ BRINE (lb/hr)mea	compress. discharge (CFM)	IC4 HOTWELL (ml/hr)	PPM IC4 IN	PPM IC4 OUT	% IC4 recovered
1/23	13:09	3	TOP STRIPPER	1.8	339	3046	—	—	—	—	—
1/23	13:09	3	OUTLET STRIPPER	1.8	340	3046	—	—	—	—	—
1/23	13:17	3	COMP DISCHARGE	125	341	3046	.07415	—	—	—	—
1/23	13:22	3	OUTLET SEPARATOR	305	342	3046	—	—	—	—	—
		3					— $\dot{m}_{IB}$=.2099	NO DATA	61.02 $\dot{m}_{IB}$=.1859	3.5 $\dot{m}_{IB}$=.01057	94.6
1/23	17:03	2	TOP STRIPPER	1.0	346	2935	—	—	—	—	—
1/23	17:03	2	OUTLET STRIPPER	0	347	2935	—	—	—	—	—
1/23	17:18	2	COMP. DISCHARGE	122	348	2935	.06921	—	—	—	—
1/23	17:20	2	OUTLET SEPARATOR	305	349	2935	—	—	—	—	—
		2					— $\dot{m}_{IB}$=.1660	36 $\dot{m}_{IB}$=.0444	47.2 $\dot{m}_{IB}$=.1385	3.73 $\dot{m}_{IB}$=.01015	92.7
1/4	10:14	1	TOP STRIPPER	8	265	3103	—	—	—	—	—
1/4	13:44	1	OUTLET STRIPPER	1.0	274	3049	—	—	—	—	—
1/4	NO DATA	1	COMP. DISCHARGE	NO DATA	NO DATA	NO DATA	NO DATA	—	—	—	—
1/4	13:44	1	OUTLET SEPARATOR	300	268	~~3049~~ 3104	—	—	—	—	—
		1					NO DATA	NO DATA	122 $\dot{m}_{IB}$=.38024	62.7 $\dot{m}_{IB}$=.1911	66

I

"DEGASSING COLUMN LABS DATA SUMMARY"

JANUARY & FEBRUARY 1978

D. S. S.

DATE:	Discription	# SAMPLE	% CO_2	% IC_4	% CH_4	% C_2H_6	% C_3H_8
1/4/78	—	264	77.5	17.4	1.54	.1	1.4
"	—	265	77.9	16.5	1.88	.09	1.3
"	—	266	14.0	2.12	.25	—	—
"	—	267	9.4	.91	.12	.005	.33
"	—	268	12.8	2.99	.34	—	—
"	—	274	12.2	2.2	2.9	.01	.008
"	—	275	27.5	5.1	.86	.033	.63
1/9/78	—	278	10.99	2.72	.34	—	.20
"	—	279	11.96	3.06	.37	—	.22
"	—	280	11.1	2.98	.36	—	.22
"	—	281	10.99	2.93	.35	—	.21
"	—	282	34.5	7.94	.96	—	.36
1/13/78	100 psig Vent GAS	299	76.2	16.3	1.35	.06	.87
"	~~15 psig~~ Stripping Column Gas.	300	76.4	16.7	1.39	.06	.89
1/16/78	20" VAC. Stripping Col. GAS	301	263 mg 7.16	6.3 mg .13	86.5 mg 6.5	.009 mg 2.9×10^{-4}	.2 mg .0055
"	5 lbs psig ← air Stripping Col. GAS.	302	72.5	18.8	1.5	.06	.88
"	305 psig Boiler Brine Outlet }	303	396 mg 10.8	40 mg .83	1.2 mg .09	— —	1.5 mg .042
"	305 psig Boiler Brine Outlet } air	304	339 mg 9.24	40 mg 1.24	2.0 mg .15	— —	2.2 mg .061
"	Seperator Outlet 305 psig)	305	613 mg 16.7	135 mg 2.8	4.5 mg .34	— —	4.8 mg .13
"	Seperator Outlet 305 psig } --?	306	631 mg 17.2	135 mg 2.8	4.7 mg .35	— —	5.1 mg .14
1/20	—	330	103 mg 2.8	2.4 mg .05	—	— —	—
"	—	331	587 mg 16.0	205 mg 4.24	—	— —	—
"	—	332	987 mg 26.9	343 mg 7.10	—	— —	—

"DEGASSING COLUMN LABS DATA SUMMARY"

JANUARY & FEBRUARY 1978

II

D. S. S.

DATE:	Discripition	# SAMPLE	% CO_2	% IC_4	% CH_4	% C_2H_6	% C_3H_8
1/20/78	—	333	411 mg 11.2	145 mg 3.0	—	—	—
1/23/78	Air FILTER	338	—	—	—	—	—
"	Top Stripper	339	498 mg 13.5	284 mg 5.89	—	—	—
"	outlet Stripper	340	198 mg 5.4	6.3 mg .132	—	—	—
"	Compresser outlet	341	288 mg 7.86	105 mg 2.18	—	—	—
"	Seperator Outlet	✓342	66.0	29.4	—	—	—
1/24/78	Compresser outlet	345	899 mg 24.5	529 mg 10.95	—	—	—
"	Top Stripper	346	596 mg 16.25	346 mg 7.16	—	—	—
"	Stripper outlet	347	212 mg 5.78	6.8 mg .14	—	—	—
"	Compresser discharge	✓348	68.7	24.3	—	—	—
"	Seperator outlet	349	188 mg 5.13	87 mg 1.8	—	—	—
2/6/78	Top Stripper	385	446 mg 12.5	445 mg 9.21	4.1 mg .31	—	14.8 mg .404
"	Stripper outlet	386	139 mg 3.8	8.0 mg .165	—	—	—
"	Compresser discharge	✓387	21.6	9.2	—	—	—
"	Seperator outlet	388	152 mg 4.15	117 mg 2.43	1.1 mg 8.07×10^{-2}	—	5.8 mg .103
"	Brine Inlet	389	128 mg 3.5	—	1.1 mg 8.25×10^{-2}	—	—
2/8/78	Top Stripper	400	576 mg 15.7	436 mg 9.03	4.1 mg .312	—	15.1 mg .413
"	Stripper outlet	401	154 mg 4.2	9.8 mg .203	—	—	—
"	Compresser discharge	✓402	65.4	30.4	—	—	—
"	Seperator outlet	403	195 mg 5.32	108 mg 2.23	.96 mg 7.2×10^{-2}	—	3.6 mg 9.72×10^{-2}
"	Brine Inlet	404	31 mg .85	.025 mg 5.3×10^{-4}	.088 mg 6.58×10^{-3}	—	.006 mg 1.65×10^{-4}
"	Top Stripper	405	343 mg 9.34	640 mg 13.26	3.3 mg 2.48×10^{-1}	—	21.6 mg .59
"	Stripper outlet	406	123 mg 3.34	12.3 mg .254	—	—	—

"DEGASSING COLUMN LABS DATA SUMMARY"

III

JANUARY & FEBRUARY 1978

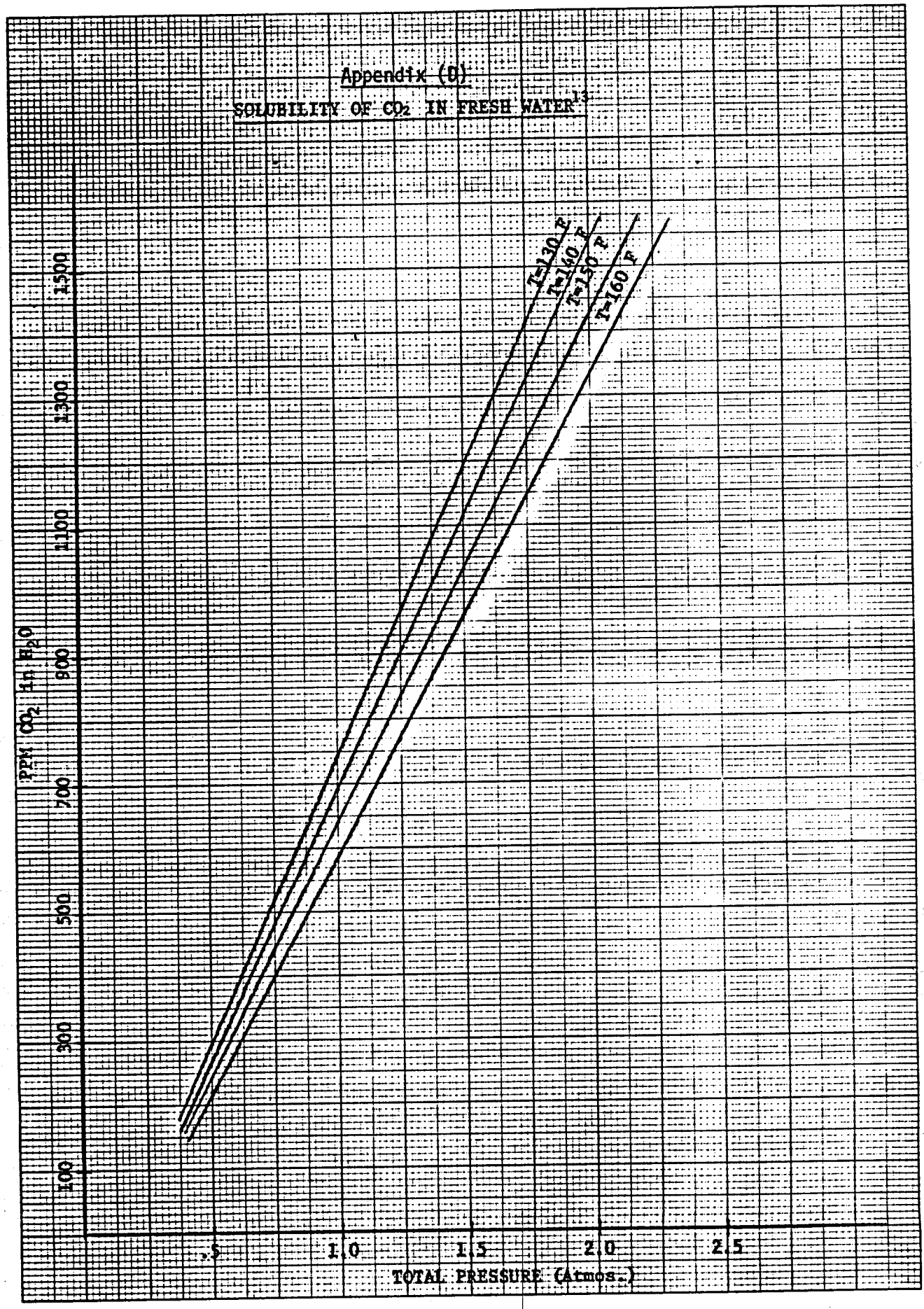
D. S. S.

DATE:	Discription	# SAMPLE	% CO_2	% IC_4	% CH_4	% C_2H_6	% C_3H_8
2/8/78	Compresser disharge ✓	407	56.8	32.2	—	—	—
"	Seperator Outlet	408	141 mg 3.85	119 mg 2.46	.6 mg 4.7×10^{-2}	—	3.9 mg .108
"	Brine Inlet	409	129 mg 3.51	.15 mg 3.68×10^{-3}	.5 mg 3.78×10^{-2}	—	—
"	Top of Condenser 45 psig	410	506 mg 13.8	2203 mg 45.6	40 mg 2.98	—	60.9 1.66
"	Top of Hot well 45 psig	411	191 mg 5.2	2947 mg 61.02	12 mg .92	—	70.5 mg 1.92
"	Icy Cylinder Sample	412	—	3893 mg 80.6	—	—	—
2/10/78	Stripper Vent	415	455 mg 12.4	901 mg 18.65	2.5 mg .19	—	27.7 mg .755
"	Stripper column bottom brine	416	52.5 mg 1.43	8.9 mg .184	—	—	—
"	Compresser disharge ✓	417	61.6	1640 mg 33.94	—	—	—
"	Seperater Outlet	418	147 mg 4.0	125 mg 2.59	.4 mg 2.82×10^{-2}	—	3.7 mg .102
"	Stripper vent	420	396 mg 10.8	480 mg 9.93	1.2 mg 9.35×10^{-2}	—	13.2 mg .341
"	Stripper Outlet	421	99.0 mg 2.69	9.6 mg .198	—	—	—
"	Seperater outlet	423	145 mg 3.95	108 mg 2.24	.23 mg 1.69×10^{-2}	—	2.9 mg .081
2/13/78	Stripping Col. Outlet	426	297 mg 8.08	6.8 mg .141	.13 mg 9.5×10^{-3}	—	.29 mg 7.92×10^{-3}
"	brine Inlet	427	626 mg 17.07	.05 mg 1.0×10^{-3}	1.8 mg .137	—	N.D.
"	Stripper outlet	428	411 mg 11.2	97 mg 2.0	.9 mg 70×10^{-2}	—	2.8 mg 7.74×10^{-2}
"	Compresser outlet ✓	429	462 mg 12.6	107 mg 2.22	1.0 mg .0768	—	5.3 mg .089
"	Seperater outlet	430	694 mg 18.9	145 mg 3.01	1.5 mg .118	—	4.6 mg .124
2/15/78	Seperater outlet brine 11:37	434	120 mg 3.27	68.6 mg 1.42	.13 mg 9.48×10^{-3}	—	1.9 mg .051
"	" " 11:40	435	214 mg 5.84	124 mg 2.57	.24 mg 1.82×10^{-2}	—	3.4 mg 9.32×10^{-2}
	" " 11:47	436	201 mg 5.49	113 mg 2.34	.24 mg 1.8×10^{-2}	—	3.2 mg 8.6×10^{-2}

APPENDIX D

Appendix (O)

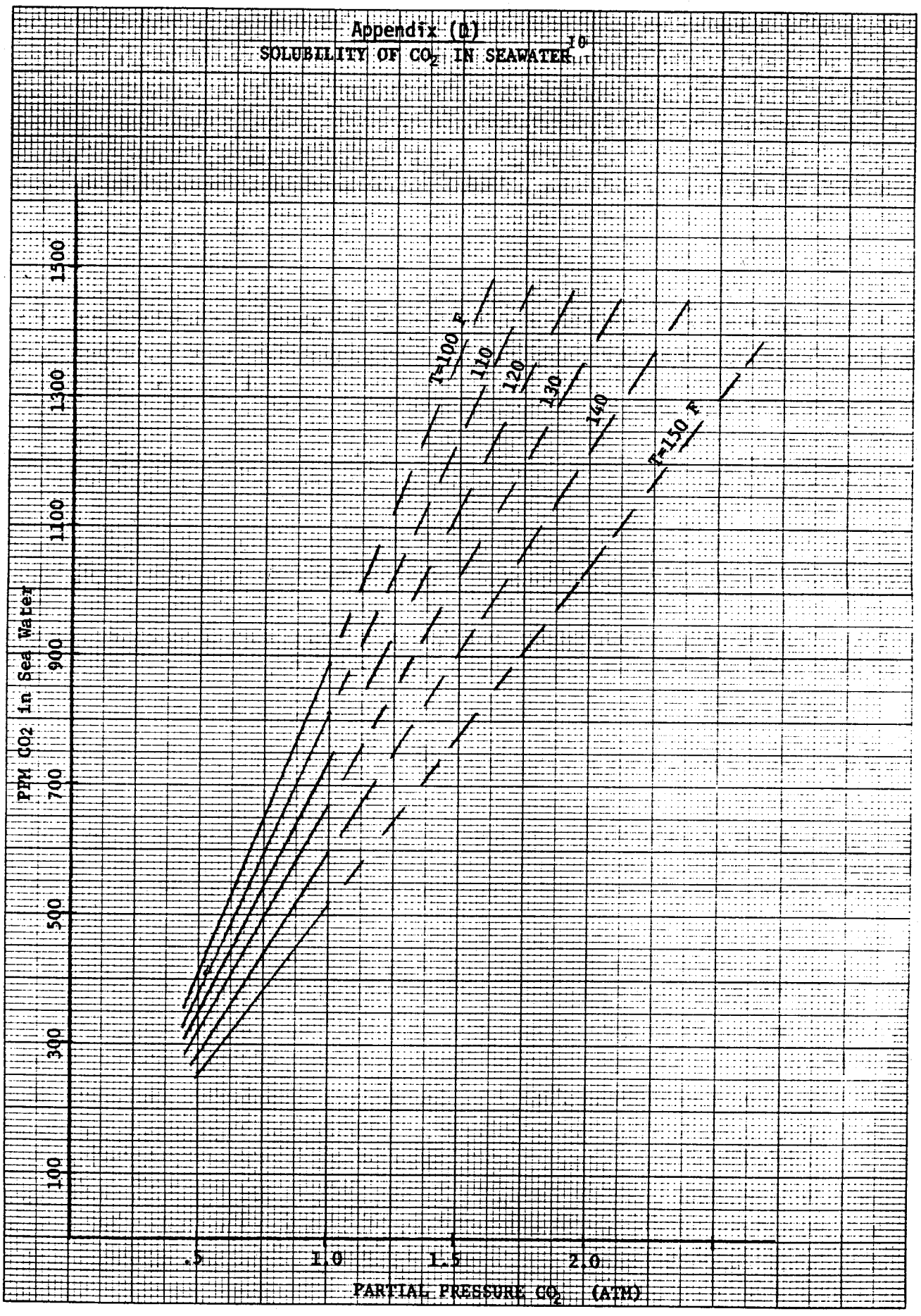
SOLUBILITY OF CO_2 IN FRESH WATER[13]



K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1322

Appendix (D)

SOLUBILITY OF CO_2 IN SEAWATER[10]



46 1322
K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.