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STUDY AND TESTING OF DIRECT CONTACT HEAT
EXCHANGERS FOR GEOTHERMAL BRINES

Phase II, August 1976—June 1977

By
W. B. Suratt
Chang-Ou Lee

November 1978

Work Performed Under Contract No. EY-76-C-05-4893

DSS Engineers, Inc.
Ft. Lauderdale, Florida

MASTER

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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EXCHANGERS FOR GEOTHERMAL BRINES

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ABSTRACT

The analytical and experimental studies completed under this project have explored several aspects of geothermal binary power cycles and column type direct contact heat exchangers between geothermal brine and isobutane.

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 tested on geothermal brine in order to correlate the experimental heat transfer data with the theoretical model for use in designing larger plants. Experiments also involved a small radial inflow turbine to produce electricity which marked the first generation of electricity from geothermal brine using a binary cycle.

In analytical studies, a comparison of the relationship between column diameter and droplet size was made for both Minard-Johnson and Sakiadis-Johnson model. The Letan-Kehat model for relating column height and temperature profile was analyzed and compared with experimental data. It appears that the experimental results are in good agreement with the theoretical models.

A detailed design of a 250 Kw pilot plant incorporating the direct contact heat exchanger was completed. This design with estimated costs for it and a 500 Kw pilot plant is incorporated in this report.

SECTION I

INTRODUCTION, SUMMARY AND CONCLUSIONS

1.1 INTRODUCTION

1.1.1 General

This research was conducted as part of the Department of Energy's continuing effort to develop the Direct Contact Heat Exchange/Binary Cycle for the extraction of energy from geothermal brines. Current efforts to economically extract significant amounts of power from medium-temperature, liquid dominated geothermal fields have focused on utilizing a secondary fluid in a Rankine power cycle. The major problems associated with the binary cycle are the costs associated with the heat exchangers, both capital costs and operating costs. The heat exchangers are required to evaporate the secondary fluid with heat extracted from the geothermal brine. Even if carbon steel can be used for this service instead of corrosion resistant alloys, surface type heat exchangers for this duty will be expensive. Capital costs of the heat exchangers would be prohibitive if corrosion resistant alloys are required. In addition, operating and maintenance costs for conventional heat exchangers would be expensive due to the additional cleaning required with many brines. Lower onstream factors would be expected for conventional heat exchangers because of the need for frequent cleaning. A means of reducing these costs, and the objective of this program, is the development and eventual deployment of direct contact heat exchangers.

1.1.2 Chronological Development

The program to develop direct contact heat exchangers began at DSS Engineers, Inc. in June, 1975 with the award of a contract to conduct preliminary studies, design, fabricate, and test an experimental direct contact heat exchanger and isobutane loop. The preliminary studies conducted prior to the experimental activities resulted in the selection of isobutane as the best working fluid, assuming a 330 F brine. Evaluation of various concepts for the direct contact heat exchanger resulted in the selection of a modified Elgin Tower to accomplish both preheating and boiling.

An experimental unit was built consisting of a direct contact preheater and boiler conventional surface condenser, hot well, isobutane feed pump, brine feed pump, and other equipment necessary to continuously circulate the fluids counter-currently through the direct contact heat exchanger. The equipment was installed on a concrete pad at a Government owned facility at Wrightsville Beach, North Carolina

and was tested there for six months. At design conditions, circulating brine was heated to 325 F in an auxiliary heat exchanger and pumped to the top of the boiler. Isobutane entered the bottom of the unit at 85 F, was heated to 220 F, and completely vaporized at that temperature, exiting at the top of the unit. The experimental unit operated with no major problems and demonstrated the potential of direct contact heat exchangers.

In January, 1977, the test equipment was modified to incorporate a taller combination direct contact preheater-vaporizer and some automatic controls. The equipment was arranged on an 8 ft. by 12 ft. skid and moved to the new East Mesa Geothermal component Test Facility. The unit was operated at design conditions with brine from well 6-2 for several months after arriving at East Mesa. In July, 1977, DSS was contracted by Lawrence Berkeley Laboratories to provide isobutane vapor from the direct contact heat exchanger to the LBL/Barber-Nichols Turbine experiment. The objective of that effort was to demonstrate the workability of a complete binary isobutane system, including a direct contact heat exchanger and turbine/alternator.

The direct contact heat exchanger at its present state of development is a single preheater-boiler column in which isobutane is dispersed at the bottom. The resemblance to a spray column is restricted to the lower portion, or preheating portion, of the column. There is no liquid-liquid separation of the dispersed isobutane from the continuous brine phases as in a spray column. Instead, the dispersed isobutane droplets vaporize completely and eventually disengage themselves at the free surface of the brine.

1.2 SUMMARY

1.2.1 General

The analytical and experimental program completed under this contract has explored several aspects of geothermal binary power cycles and direct contact heat exchange between geothermal brine and isobutane. A major design improvement of the heat exchanger was developed by the combination of the preheater and boiler into a single continuous column. The twelve (12) month program included test work on two separate cycle and heat exchanger configurations with both simulated brine and real geothermal brine. At Wrightsville Beach, North Carolina, the cycle was tested using a separate isobutane preheater and boiler with simulated geothermal brine. At East Mesa a new direct contact heat exchanger combining the preheater and boiler was tested on geothermal brine from Well 6-2. After completing preliminary heat transfer tests at East Mesa, experiments were conducted with a small radial inflow turbine to produce a small amount of electricity. This marked the first generation of electricity from geothermal brines using a binary cycle.

1.2.2 Analytical Studies

Analytical studies were conducted concurrently with the experimental activities in order to establish a theoretical model for use in designing larger plants as well as analyzing experimental data. A comparison of the relationships between spray column diameter and droplet size was made for both the Sakiadis-Johnson and Minard-Johnson correlations. The Letan-Kehat model for relating column height and temperature profile was analyzed and compared with experimental data.

Analysis of mass transfer rates between isobutane droplets and brine was completed which indicates an isobutane solubility near saturation will occur. The mass transfer rate is a function of droplet diameter and column height. Agreement with experimental data was obtained for liquid-liquid preheater column, but not for the combination preheater-boiler column.

1.2.3 Test Apparatus

The test unit used at Wrightsville Beach during the first months of testing was the same unit used during the previous test program a year earlier. This unit incorporated a separate direct contact preheater and separate direct contact boiler.

The brine was provided to the unit by heating raw sea water in a steam heated hairpin heat exchanger. After testing at Wrightsville Beach was completed the unit was removed from the concrete pad and installed on a steel skid. The boiler and preheater were combined at this point and a new hotwell and brine pump were also installed. The unit was then shipped to East Mesa. In both units isobutane was heated from 80 F to 220 F at which temperature it was vaporized. The isobutane and brine were circulated countercurrently through the direct contact heat exchangers. At

design conditions, the brine enters the boiler section at 325 F and is cooled by the isobutane to a temperature of 145 F. The isobutane vapor leaves the boiler with approximately 10 F superheat and is then throttled and condensed in a standard shell and tube heat exchanger. The liquid isobutane is pumped from the hotwell to the bottom of the direct contact exchange column, where it is injected through a distribution nozzle. It is dispersed as small .15 inch diameter droplets and rises upward through the brine.

1.2.4 Experimental Results

The experiments confirmed that the boiler section can be placed directly over the preheating section without any mechanical interface device. Boiling apparently takes place in a small section at the top of the column and does not disturb the performance of the preheating section below it. Unfortunately, without a mechanical interface it is difficult to measure the exact volume used for boiling and preheating and consequently volumetric heat transfer coefficients will have some error. Operation on real geothermal brine instead did not reveal any problems of any kind. No unusual corrosion or scaling has been noted. Foaming and sludge formation has not been observed at the interface or free surface of the brine in the direct contact heat exchanger. Isobutane dissolved in the brine leaving the direct contact heat exchanger was measured and the concentrations averaged 110 ppm. Water vapor fractions of the isobutane and water vapor leaving the boiler were measured at various temperatures. At 220 F the water vapor was 1.5% by weight of the mixture. The column diameter is apparently correctly sized for liquid-liquid direct contact heat exchange, but when combined with boiling the diameter of the column could be reduced. In other words higher throughputs are possible for the combined preheater-boiler combination.

1.3 CONCLUSIONS

The prospects for commercial development of direct contact heat exchangers appears very high at this time for geothermal brines or waste heat liquid streams, especially the more corrosive type brines. Our conclusions are summarized as follows:

- a) Operation with geothermal brine (Mesa 6-2) was accomplished and no unusual corrosion or scaling was observed.
- b) A combination preheater and boiler was developed with demonstrates higher heat transfer capacity and lower cost.
- c) Isobutane dissolved in the brine leaving the direct contact heat exchanger was measured to be 110 ppm.
- d) Water vapor in the isobutane leaving the boiler was measured to be 1.5% at design vapor outlet temperatures of 220 F.
- e) The height of the column necessary for liquid-liquid preheating agrees with the Letan-Kehat model.
- f) The height of the boiler section was not accurately determined. Visual and thermal methods for determining this were unsuccessful.
- g) The stability and resistance to corrosion and scaling was demonstrated by 24 hour per day operations with geothermal brine which accumulate a total of 500 hours.

SECTION 2

THEORY

2.1 GENERAL INTRODUCTION

The Elgin-type column was developed by Elgin and various co-workers; the paper of Blanding and Elgin² describes the detail of its evaluation. Originally, the spray column was designed for mass transfer operation such as liquid-liquid extraction. This operation depends on the immiscibility and difference in density of the two fluids. The spray column has been the subject of investigations as a direct contact heat exchanger for many years. Numerous theories have been proposed to describe the heat transfer mechanism between two phases. Sideman³ has presented an excellent review of these theories. The objective of this study is not to explore all of these theories, but to size the spray column for the geothermal cycle. However, the experimental data reported in Section 3 gives evidence to support the Letan-Kehat mathematical model and the Sakiadis-Johnson model which will be presented mainly in this section.

In the spray column, the heavier continuous phase, geothermal brine, is introduced into the column at the top, flows downward through a straight section and leaves at the bottom of the column. The working fluid, isobutane, is dispersed through nozzles as droplets at the bottom and rises through the straight section to a coalescence screen at the top of the column.

For a fixed flow rate of the continuous phase, as the flow rate of the dispersed phase is increased, the slowly rising droplets beneath the coalescence screen increase in concentration within the column to a point where more of the dispersed phase cannot be forced through the column. The column is completely filled with closely-packed droplets. 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. When the zone of concentrated droplets fills the column, the situation is referred to as a flooded column. The droplets cannot escape freely into the coalescence zone and tend to accumulate in the straight section with the characteristic appearance of closely packed spheres. The column can only operate satisfactorily at a lower flow rate.

In avoiding the flooded column and increasing the heat transfer efficiency, two factors are particularly important; the column diameter and the height of the column. The column diameter is determined by the maximum permissible velocity of the phases involved and the column height is determined from heat transfer consideration.

2.2

COLUMN DIAMETER

2.2.1

Minard-Johnson Correlation

An empirical correlation has been presented by Minard and Johnson⁴ 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:

$$v_c^{0.5} = \left[47\mu_c^{-0.07} \Delta SG^{0.14} SG_c^{-0.5} \right] - \left[1.8d^{0.56} \mu_c^{-0.075} \left(\frac{SG_d}{SG_c} \right)^{0.5} v_d^{0.5} \right] \quad (2-1)$$

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 = dispersed 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.

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

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.

2.2.2 Sakiadis-Johnson Model

Sakiadis and Johnson⁵ 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.

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

where:

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

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

$g_c = 4.17 \times 10^8$, 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.:

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

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

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

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.

2.2.3 Discussions

In Figure 2-1 the relationship between spray column diameter and droplet size is presented for both the Sakiadis-Johnson model and the Minard-Johnson correlation. The curve representing the Sakiadis-Johnson model shows that the column diameter decreases as the droplet size increases. In contrast, the Minard-Johnson curve indicates that the column diameter increases as the droplet size increases. However, the Minard-Johnson curve is quite flat in comparison with the Sakiadis-Johnson curve over the range 0.05-0.55 inch droplet diameter. In other words, the column diameter predicted by Minard-Johnson correlation is not affected very much by the droplet size at flooding. Also, the Minard-Johnson correlation is an empirical equation and was derived from only one specified spray column with various liquid-liquid systems. Therefore, the Minard-Johnson correlation is probably not in a general form.

The Sakiadis-Johnson model is derived theoretically from the point of view of fluid mechanics and has been correlated with 429 data sets of different size spray columns with various liquid-liquid, liquid solid and liquid-gas systems. Since for a given flow rate and column diameter the number of droplets is greater when smaller diameter droplets are used, one can visualize that the column may be more easily flooded when smaller droplet size is used. This follows from the fact that for any liquid-liquid pair, it is found that the terminal velocity of rising droplets will decrease if the drop diameter is made smaller. Therefore, the column diameter has to be enlarged to accommodate smaller droplets. The Sakiadis-Johnson model in Fig. 2-1 shows this trend for the relationship between the column diameter and droplet size.

In conclusion, the Sakiadis-Johnson model is probably a more general equation and may predict more reasonable results than the Minard-Johnson correlation. However, it may not introduce serious error to apply the Minard-Johnson correlation in the design of column diameter over the droplet size range 0.15 - 0.3 inch. In this droplet size range, both the Minard-Johnson correlation and the Sakiadis-Johnson model may predict the column diameter with equal satisfaction. If a smaller or larger droplet size is desired, the Sakiadis-Johnson model may give a better result.

Finally, it is important to note that the comparison made between Minard-Johnson correlation and Sakiadis-Johnson model in Figure 2-1 is based on the same conditions as stated on the top of this figure.

FIG. 2-1

COMPARISON OF COLUMN DIAMETER

2.3 COLUMN HEIGHT

2.3.1 Letan-Kehat Model

Letan and Kehat⁶ 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:

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

$$\frac{T_c - T_{co}}{T_{di} - T_{co}} = \left\{ \frac{m}{r} \left[\frac{1+S}{\alpha_1} \left[1 - \left(\frac{r}{m} \alpha_1 + 1 \right) \exp(\alpha_1 z) \right] - \frac{S}{\alpha_1} \left[1 - \left(\frac{r}{m} \alpha_2 + 1 \right) \exp(\alpha_2 z) \right] + 1 \right] \exp\left(-\frac{M}{r}\right) \right\} \quad (2-12)$$

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

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

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

$$R = V_d / V_c$$

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

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.

2.3.2 Volumetric Heat Transfer Coefficient and NTU

Letan and Kehat stated in their conclusions that the heat transfer in a spray column is controlled by the fluid dynamics of the system and not by the resistance to heat transfer inside or at the surface of the droplets. Volumetric heat transfer coefficients or heat transfer units do not fully correlate experimental data in spray column heat exchangers. Therefore, the Letan and Kehat model is the most promising method to predict the height of spray column instead of applying the value of volumetric heat transfer coefficients. However, the volumetric heat transfer coefficient which may be estimated from the log mean temperature difference, the volume of spray column and total heat transfer rate may be used to compare the performance of similar heat exchangers.

$$U_V = \frac{Q}{V \Delta T_{lm}} \quad (2-13)$$

where:

U_V = volumetric heat transfer coefficient, Btu/hr-ft³ - F

V = volume of spray column, cu ft

Q = total heat transfer rate, Btu/hr

ΔT_{lm} = log mean temperature difference, deg. F

Another parameter, the number of heat transfer units or NTU has also been used as a measure of the heat transfer size of an exchanger and is defined as:

$$NTU = \frac{Q}{\Delta T_{lm} c_f} \quad (2-14)$$

This is valid for c_f less than or equal to c_d , where c_f and c_d are the hourly capacity of the isobutane and brine streams, respectively. NTU may be taken as a dimensionless measure of the portion of the total working fluid temperature rise required for a binary cycle that can be economically provided in a particular heat exchanger. When scaling a direct contact heat exchanger up in size, NTU is probably more meaningful than volumetric heat transfer coefficient. NTU is used in this report because it is a convenient reference for the heat transfer correlation.

2.4 MASS TRANSFER

2.4.1 General

The isobutane losses in the brine rejected from the direct contact heat exchanger (DCHX) will have significant impact on the annual operating expense and the capital investment of recovering isobutane. As a result, a method based on mass transfer theory to predict the isobutane concentration in the rejected brine must be developed. If the mass transfer phenomenon in the DCHX can be better understood then methods for reducing isobutane losses may become possible.

As discussed in an earlier report¹, in the normal operating range of the direct contact heat exchanger, variations in the brine and isobutane flow rates do not influence the concentration of isobutane dissolved in the brine. Therefore, the flows are assumed to be steady state and only molecular diffusion is considered. For simplicity, it is assumed that the water does not diffuse into to the isobutane phase. Only the isobutane diffuses into the brine phase.

The film mass transfer coefficient on the isobutane side is assumed to be negligible. In other words the isobutane concentration in the brine side film is assumed to be saturated. Therefore, only the diffusion of the isobutane from the brine side film to the bulk brine is considered.

The physical properties are assumed to remain constant at an average temperature. Since only a very small amount of isobutane is present in the brine, the physical properties of this solution are assumed to be the same as that of the solvent, i.e. brine.

2.4.2 Diffusivity

An empirical correlation of Wailke and Chang to predict the diffusivity between liquids is recommended by Treybal⁸, i.e.

$$D = \frac{7.4 \times 10^{-8} (\phi M)^{0.5} T}{\mu \nu^{0.6}} \quad (2-15)$$

D = diffusivity of solute in dilute solution

T = temperature of solvent, K

M = molecular weight of solvent

μ = solution viscosity, cp

ν = solute molal volume at the normal boiling point
Cm³/g-mole

ϕ = association factor for solvent = 2.6 for water as solvent

The value of ϕ may be obtained from Table 2-1, thus, for isobutane (C_4H_{10}) $\nu = 4 \times 4.8 + 10 \times 3.7 = 92.2$, Witherspoon and Bonoli⁹ have performed experimental work on the diffusors of hydrocarbons into water and concluded that the Wilke-Chang correlation provides a reliable prediction of diffusivity of hydrocarbons in pure water.

2.4.3 Mass Transfer Coefficient

The mass transfer coefficient from swarms of liquid drops (dispersed phase) to another liquid (continuous phase) may be predicted by the Ruby and Elgin correlation which is recommended by Treybal¹⁰. This correlation is:

$$N_{Sh,c} = \frac{k_d}{D} = 0.725 N_{pe}^{0.57} N_{Sc,c}^{-0.15} (1-H) \quad (12-16)$$

where:

$N_{Sh,c}$ = Sherwood number of continuous phase = k_c / D , dimensionless

N_{pe} = Peclet number of a drop for molecular diffusion
 $= \frac{dV_s}{D}$ dimensionless

k = Mass transfer coefficient,
 $(lb-mole/hr-ft^2)/(lb-mole/ft^2)$

d = drop diameter, ft

D = diffusivity, ft^2/hr

V_s = slip velocity, ft/hr =

H = holdup with respect to dispersed phase

$N_{Sc,c}$ = Schmidt number of continuous phase
 $= \mu / V_s D$ dimensionless

2.4.4 Mathematical Model

From an isobutane material balance on the brine flow in a differential height, Z , of the column as shown in Figure 2-2, we obtain:

The change in rate of flow of isobutane in brine = the rate of diffusion of isobutane, i.e.

$$-U_c dC = N_a A dZ \quad (2-17)$$

TABLE 2-1

ATOMIC AND MOLECULAR MOLAL VOLUME AT NORMAL BOILING POINT

<u>Atomic Volume</u>		<u>Molecular Volume</u>	
Carbon	14.8	H ₂	14.3
Hydrogen	3.7	O ₂	25.6
Chlorine	24.6	N ₂	31.2
Bromine	27.0	Air	29.9
Iodine	37.0	CO	30.7
Sulfur	25.6	CO ₂	34.0
Nitrogen	15.6	SO ₂	44.8
Nitrogen in primary amines	10.5	NO	23.6
Nitrogen in secondary amines	12.0	N ₂ O	36.4
Oxygen	7.4	NH ₂	25.8
Oxygen in methyl esters	9.1	H ₂ O	18.9
Oxygen in higher esters	11.0	H ₂ S	32.9
Oxygen in acids	12.0	COS	51.5
Oxygen in methyl ethers	9.9	Cl ₂	48.4
Oxygen in higher ethers	11.0	Br ₂	53.2
Benzene ring: subtract	15	I ₂	71.5
Napthalene ring: subtract	30		

FIGURE 2-2

MATERIAL BALANCE IN DIFFERENCE SECTION
OF DCHX COLUMN

where

N = the mass transfer rate per unit interfacial area, lb-mole/hr-ft²

a = total interfacial area of dispersed phase ft²/ft³ =

C = concentration of isobutane in brine, lb-mole/ft³

A = the cross section area of column, ft²

z = the height of column, ft

U_c = volumetric flow rate, continuous phase, ft³/hr

the mass transfer rate may be determined by the following equation:

$$N = k(C^* - C) \quad (2-18)$$

where

C^* = concentration of isobutane at the interface of continuous phase side, lb-mole/ft³

Assuming, as stated previously, that the concentration, C^* , is the saturation concentration of isobutane, this concentration may be estimated from the correlation of the equilibrium solubility of isobutane in brine developed by Hellstrom¹¹, i.e.

$$\begin{aligned} \ln(X) = & -0.61424839 + \frac{7.0329254 \times 10^3}{T} \\ & + 15.946457 \ln\left(\frac{T}{1000}\right) \\ & + w_b \left[0.09582649 + \frac{0.0552885 \times 10^3}{T} \right. \\ & \left. + 0.29563845 \ln\left(\frac{T}{1000}\right) \right] \end{aligned} \quad (2-19)$$

where

T = temperature, K

w_b = weight percent of NaCl in brine

X = solubility, ppm/atm

Combining Eqs. (2-17) and (2-18), we may write

$$-U_c dC = kaA(C^* - C)dz \quad (2-20)$$

on separation of variables Eq. (2-20) becomes:

$$-\frac{dC}{C^* - C} = \frac{kaA}{U_c} dz \quad (2-21)$$

which on integration gives:

$$-\int_{C_0}^{C_i} \frac{dC}{C^* - C} = \int_0^Z -\frac{kaA}{U_c} dZ \quad (2-22)$$

At the bottom of the column (brine outlet) the height is zero and the isobutane concentration is C_0 . At the top of the column (brine inlet) the height is Z and the isobutane concentration is $C_i = 0$. Eq. (2-22) can be rewritten as:

$$\ln\left(\frac{C^* - C_0}{C^* - C_i}\right) = \frac{kaAZ}{U_c} \quad (2-23)$$

Rearranging Eq. (2-23), we get:

$$\frac{C_0}{C^*} = 1 - \exp\left(-\frac{kaAZ}{U_c}\right) \quad (2-24)$$

The isobutane concentration at the brine outlet may be predicted from equations (2-19) and (2-24). The validity of this method can only be proved by comparing the calculated values with the experimental values. As pointed out in an earlier report¹, it is very difficult to predict and measure the exact isobutane concentration accurately for a very large once-through system. However, this method would give the conceptual prediction of the isobutane concentration in the brine.

Calculations using Eq. (2-24), show that the isobutane concentration is mainly a function of droplet size and the height of the column. If an optimum choice of droplet size and column height can be achieved without sacrificing the heat transfer between brine and isobutane, the isobutane concentration will be reduced. However, the resulting isobutane concentration in brine predicted by the above method is very close to the isobutane saturation concentration. Further discussions about the isobutane loss will be presented later in sub-section 3.4.5.

SECTION 3

EXPERIMENTS

3.1 DESCRIPTION OF DIRECT CONTACT HEAT EXCHANGERS & ISOBUTANE LOOP

3.1.1 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 preheater and boiler. Other major components are the separator, condenser, hot well, stripper and two circulating pumps. The general relationship of these components is illustrated in the process flow sheet on drawing No. 064-5002.

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 control valve. 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 settled out. The high pressure brine is then reduced to atmospheric pressure and dumped into an open tank where any remaining dissolved isobutane in brine is flashed out. Finally, the brine is sent to the reinjection system.

3.1.2 Vessel Design

All test vessels were fabricated of carbon steel to Section VIII, Division I 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 300# screwed couplings. Construction details are shown on Drawing No. 051-2202. 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 predominantly 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.

3.1.3 Heat Exchanger

The preheater and boiler and 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 nine feet in length and with an inside diameter of six inches. At both ends a conical section with an included angle of 20 degrees flares to a ten

STREAM		DATE			REV.		DESCRIPTION	
							REVISIONS	
		1	2					
		ISO. FEED	ISO. BUTANE	ISO. CO.				
		FEED	14000	FROM				
			BOILER					
FLOW	LB/HR	2370	2390	2				
TEMPERATURE	°F	75	220					
PRESSURE	PSIA	315	315	1				
ENTHALPY	BTU/LB.	-787	-701	-				
SPECIFIC	LB/FT ³	33.61	3.85	2				

DSS engineers, inc.		DATE		REV.		DESCRIPTION	
APPROVALS		DATE		REV.		DESCRIPTION	
DESIGNED BY		7-99					
CHECKED BY							
DRAWN BY							
CALC. BY							
PROJECT MANAGER							
DSS engineers, inc.		064-5002		0			
P. E. REG. NO.							

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 3-1 and in detail by Drawing No. 071-2201.

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 oleophobic (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 making 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 "bullseyes") for viewing the dispersion, and three pairs of gage glass connections.

3.1.4 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 by Drawing 051-2203.

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

DIRECT CONTACT HEAT EXCHANGER

FIGURE 3-1

7-29-75 GENERAL REVISIONS NOTED Δ
8-14-75 DELETE CYCLONE SEPARATOR Δ

DSS ENGINEERS, Inc.			
FORT LAUDERDALE, FLORIDA			
APPROVALS		TITLE	
DESIGNED BY	7/75	PRESSURE VESSELS FOR DIRECT CONTACT TEST UNIT	
CHECKED BY	7/75		
DESIGNED BY	7/75		
CHECKED BY			
PROJECT NUMBER		051-2203	
P.E. REG. NO.		3	

3.1.5 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.

3.1.6 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 by Drawing 051-2208.

3.1.7 Stripping Column

The high-pressure brine leaving the separator still contained 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 ft 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 also shown on Drawing 051-2208.

3.1.8 Pumps

The isobutane is circulated by a four cylinder John Bean outside packed plunger pump (Model T-0410C) 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 of the pump. A relief valve is provided on the discharge line to prevent overpressure damage to the pump or test unit.

3.1.9 Instrumentation

Temperatures are measured with bi-metal thermometers and iron-constantan (J type) thermocouples. The specified accuracy is 0.5% of full scale for

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

OSS ENGINEERS, Inc.	
APPROVALS	DATE
DESIGNER	05/11/08
CHECKED	
APPROVED	
PRESSURE VESSELS FOR DIRECT CONTACT TEST UNIT	
051-2208	
P. E. REG. NO.	

bi-metal thermometers and ± 2 F for type J thermocouples. Thermocouple wires are connected to a Leeds & Northrup multipoint recorder which monitors temperature versus time. Since this recorder is not explosion proof or intrinsically safe, it is located in a trailer about 15 feet from the test unit.

Two calibrated rotameters with accuracies $\pm 1\%$ of full scale measure brine and isobutane flows. These are of armored design with magnetic indicators. Pressures in the vessels are indicated by calibrated gauges with a specified accuracy of $\pm 0.5\%$ of full scale. Level indications are shown by high pressure gauge glasses.

3.1.10 Safety Devices

Safety devices, such as relief valves, rupture disks, and pressure switches, are installed in order to protect operators and the test unit from any dangerous and unexpected situations. All safety devices and their settings locations and functions are listed in Table 3-1. Also these safety devices are shown in the P&I diagram, Drawing No.064-7101.

3.1.11 Automation

A free surface level between the liquid and vapor phases in the direct contact heat exchanger exists when the unit is operating. This level should be maintained automatically at the position shown in Figure 3-1, since an excessive brine flow may cause liquid phase flooding through the isobutane outlet at the top of the column. A Fisher displacer sensor (caged 249 series and type 2598) and a Fisher Level-Trol controller (Series 2500) are installed to send a pneumatic output signal when the liquid level is above the desired position. A Fisher type B valve with diaphragm actuator (type 315) accepts this signal and opens itself. This valve is located between the separator and stripper to control the brine flow and adjusts the liquid level automatically.

The vapor pressure inside the direct contact heat exchanger is automatically controlled by a Fisher pressure controller (Wizard II, series 4160). This unit is capable of being set at any desired pressure in the range of 0-600 psig. This controller sends a pneumatic signal to control the action of a Fisher Type B valve with diaphragm actuator (type 315), which is located at the isobutane vapor outlet.

3.1.12 Test Site Facilities

The geothermal brine used for the test unit is furnished by the Mesa 6-2 well at East Mesa Geothermal Component Test Site. The brine flows through the manifold and a gas separator which vents the non-condensable gases, such as H₂S and CO₂. During the testing period, the wellhead pressure usually varied from 135 to 152 psig and the well temperature varied from 300 to 330 F. Table 3-2 shows a typical chemical analysis report of brine from the Mesa 6-2 well.

TABLE 3-1
SAFETY DEVICES

<u>TYPE</u>	<u>SETTING (PSIG)</u>	<u>LOCATION</u>	<u>FUNCTION</u>
Pressure Switch	350 or 650	Isobutane pump discharge line	Shut down main electrical power on high pressure
Pressure Switch	350	Brine pump discharge line	Shut down main electrical power on high pressure
Rupture Disk	438	Bottom side of direct heat exchanger	Blow on high pressure
Rupture Disk	221	Condenser shell side	Blow on high pressure
Relief Valve	350	Down stream of the rupture disk of direct contact heat exchanger	Open to stack on high pressure
Relief Valve	165	Down stream of the rupture disk of direct contact heat exchanger	Open to stack on high pressure
Relief Valve	390	Brine pump discharge line	Open to air on high pressure
Relief Valve	350	Isobutane pump discharge line	Open to stack on high pressure
Relief Valve	800	Isobutane pump discharge line for turbine test	Open to stack on high pressure

TABLE 3-2

CHEMICAL ANALYSIS OF BRINE

Date: May 5, 1977

Sample: Mesa 6-2 wellhead unflashed

pH	5.9
Conductivity	53.50 μ mhos
Total dissolved solid	4092 ppm
Bicarbonate	639 ppm
Chloride	1778 ppm
H ₂ S	2.0 ppm
Silica (SiO ₂)	257 ppm
Sodium	1425 ppm
Calcium	8.75 ppm
Iron	<0.5 ppm

The used brine flows to an open-to-air flash tank which is used to drive out the residual isobutane from the brine and to avoid the accumulation of isobutane in the brine reinjection pipeline. The brine is then reinjected to the holding pond.

The cooling tower can supply a total of 800 GPM water at 90 degree F. This cooling water is used for the isobutane vapor condenser of the test unit.

Compressed air is supplied at 100 psig with a total flow rate of 50 SCFM for pneumatic control units.

Three-phase 480 VAC and single-phase 120 VAC electrical power are available to the test unit.

3.2

TEST OPERATION

3.2.1

General

One of the major tasks in this program was to make a total 13-foot high direct contact heat exchanger by adding 4 feet to the existing preheater column. This lengthened column with a 10-foot heat transfer section may be operated as a preheater or a single combined preheater and boiler. Part of the testing for this new column was conducted at the U. S. Department of the Interior's Office of Water Research and Technology test facility at Wrightsville Beach, North Carolina, under an inter-agency agreement with the ERDA. The piping and instrument diagram of the test unit at Wrightsville Beach is shown in Drawing No. 051-6101. Tests were conducted to determine combined preheating-boiling heat transfer performance for this 13-foot column. Fresh water was used for these tests.

Activities at Wrightsville Beach began in July 1976 and ended in March 1977. The test unit then was moved to ERDA Geothermal Component Test Facility, East Mesa Test Site of the Bureau of Reclamation, Department of the Interior, for the field test. The installation and modification was completed in late April. Since then, tests including the operation of the unit at design conditions using actual geothermal brine and turbine tests were performed.

3.2.2

Operating Procedures at Wrightsville Beach - Preheating Only

The following description of operating procedure may be more readily understood by reference to the Piping and Instrument Diagram (Drawing No. 051-6101). Brine is first slowly heated as it is circulated through the unit. Brine temperature is controlled by steam valve CV-106 and condensate valve CV-100A. Valves CV-100 and CV-123 control brine flow. Then, when temperature is reached, isobutane is introduced to the preheater, E-100, by opening recirculation valve CV-109 and starting the isobutane pump, P-100. After opening CV-108, CV-109 is closed until the desired flow is reached. During preheater operation the position of the isobutane-brine interface at the top of the preheater must be maintained by a pressure balance between isobutane and brine streams. This balance is held by manipulating either the isobutane outlet valve CV-112 or the brine outlet valve CV-100. To cause the position of the interface to rise, CV-112 is opened or CV-100 is closed. Conversely, the interface is lowered by closing CV-112 or opening CV-100. These two valves also control the total pressure in the preheater which must be kept higher than the saturation pressure of the isobutane to prevent it from boiling.

In the preheater only mode, valve CV-110 is shut and the heated isobutane liquid leaving the preheater bypasses the boiler and goes directly to the condenser E-102. The brine, however, flows through the boiler, E-101, which acts merely as a brine reservoir in this case. As the fraction of the preheater volume occupied by the isobutane liquid (hold-up) varies, so too does the brine level in the boiler since the brine loop is closed. Should it be necessary to add to or subtract from the brine inventory, the surge tank provides this capacity. It is pressurized with nitrogen gas to add make-up brine or vented to allow removal of excess brine.

Each heat transfer test usually lasted for about five hours. During this time, the unit was allowed to reach several steady state points at which data was taken. Since all controls are manual and no supervisory instrumentation is incorporated, the unit required constant attention and was, therefore, operated only during day shifts.

3.2.3 Operating Procedures at Wrightsville Beach - Combination of Preheating and Boiling

In sub-section 3.2.2, the direct contact heat exchanger is treated as a preheater. This single column was also operated as a combined preheater-boiler. The operating procedures are the same as those described in sub-section 3.2.2. The only difference is that there is no isobutane-brine interface. However, there is a free surface level between the liquid and vapor phase. The control procedures for level and pressure are the same as in the preheating operation procedures.

3.2.4 Operating Procedures at East Mesa - Combination of Preheating & Boiling

Since the wellhead pressure of brine is 150 psig, the brine is first circulated through the system without running the brine pump. The brine level inside the DCHX is maintained at a fixed position by the level control unit and control valve (LCV100) as shown in drawing No. 064-7101. Once the desired brine level is established, a stable brine flow rate is obtained. The isobutane pump is turned on and isobutane is slowly fed into the DCHX. Since the column is full of hot brine, the isobutane is vaporized and consequently the vapor pressure builds up. The brine pump is turned on immediately since the vapor pressure is higher than 150 psig.

Both brine and isobutane flows can be controlled by manual control valves. A pressure controller and a valve (PCV100) are used to adjust the isobutane vapor flow rate in order to control the vapor pressure. The desired steady-state conditions of DCHX may be accomplished through the adjustments of the brine and isobutane flows and the isobutane vapor pressure.

3.2.5 Miscellaneous Operating Problems

The isobutane pump was probably the greatest single source of operating problems and unplanned shutdowns. One of the most persistent problems was the repeated failure of the pump packing. Another problem was the isobutane vapor binding of the isobutane pump resulting from the marginal suction conditions.

3.3 TEST RESULTS - PREHEATER ONLY (Wrightsville Beach)

3.3.1 Test Designation

Experimental runs are designated by an alphabetic prefix followed by two numbers. The meanings of the letters are stated as follows:

C, combined preheating and boiling, fresh water, 6' height preheater tower; E, combined preheating and boiling, 6' height preheater tower, simulated geothermal brine; f, preheating only, 10' height preheater tower, actual geothermal brine. The experimental data under the prefix C and E are selected from the previous report (Phase I)¹. The first digit is the test number and the second digit means the data point number.

3.3.2 Heat Losses

Because of the fire hazard posed by the use of the isobutane, the test unit was operated out-of-doors. Although the column was insulated with half inch thick plastic foam (except some areas such as the flanges), there was some heat loss from the column surface to the ambient. Therefore, a heat loss test was performed by circulating geothermal brine through the test unit without isobutane flow. The inlet and outlet temperatures of hot brine in direct contact heat exchanger were recorded. Using the ambient temperature, total heat transfer rate and the column surface area, the overall heat transfer coefficient for heat loss was estimated at about 3.58 Btu/hr-ft-F.

The heat loss, the difference between the heat lost from the brine and the heat transferred to the isobutane, is usually about 5-20% of the total heat leaving the brine. After correcting the heat transfer coefficient, most heat transfer differences between the brine and isobutane have been reduced to 0-10% of the total heat transferred from the brine. This portion of the imbalance in heat transfer still remains unexplained. Therefore heat transfer results are based on the isobutane total heat transfer rate determined from isobutane temperature measurements and flow rates. Brine temperatures have been used only for heat transfer calculations which may not introduce serious error.

3.3.3 Data Analysis

The experimental data for the preheater is listed in Table 3-3. All this test data has been reduced according to the same method outlined in the previous report, Phase I¹.

The Letan-Kehat model, which is presented in sub-section 2.3.1, has been used to predict the isobutane temperature rise in the preheater under the experimental conditions. These conditions include the brine outlet and isobutane inlet temperatures, the flow rates, average densities and average heat capacities of both fluids and the column height. For comparison, the calculated isobutane temperature rise agrees very well with the observed isobutane temperature rise as shown in Figure 3-2. Points representing preheaters with either 6' or 10' distance between distributors in Figure 3-2 confirm the validity of the Letan-Kehat model for predicting the relationship between the column height and the temperature approach. The superficial velocity ratio between isobutane and brine vs. the temperature difference ratio between the isobutane inlet and outlet with respect to the brine

TABLE 3-3
PREHEATER TEST RESULTS

M_f	=	Mass flow rate of isobutane, lb/hr
M_b	=	Mass flow rate of brine, lb/hr
T_{bi}	=	Brine inlet temperature, F
T_{bo}	=	Brine outlet temperature, F
T_{fi}	=	Isobutane inlet temperature, F
T_{fo}	=	Isobutane outlet temperature, F
θ	=	$\frac{T_{fo} - T_{bo}}{T_{pi} - T_{bo}}$
ΔT_{LM}	=	Log mean temperature difference, F
$Q_{\bar{f}}$	=	Total heat transfer rate of isobutane, lb/hr
ΔT_{fo}	=	Observed isobutane temperature rise, F
ΔT_{fc}	=	Calculated isobutane temperature rise by Letan-Kehat Model, F
U_v	=	Volumetric heat transfer coefficient, Btu/ F-hr-ft ³
NTU	=	Number of transfer units
H	=	Isobutane holdup, %
V_f/V_b	=	The ratio of superficial velocities between isobutane and brine

TABLE 3-3
PREHEATER TEST RESULTS (Con't)

TEST	M _f	M _b	T _{bi}	T _{bo}	T _{fi}	T _{fo}	θ	ΔT _{LM}	Q _f	ΔT _{fo}	ΔT _{fc}	U _v	NTU	H	V _f /V _b
C-2-1	793	2105	131.5	119	69.0	128.0	-0.18	17.5	28099	59.0	59.9	1339	3.37	5.0	0.66
C-2-7	768	2211	140.5	128	69.0	132.0	-0.07	26.0	29036	63.0	69.8	928	2.42	5.0	0.62
C-2-8	768	2207	145	131	68.5	136.0	-0.08	27.6	31628	67.5	74.1	954	2.45	5.0	0.60
C-2-9	751	2092	152.5	142	97.0	144.0	-0.04	21.1	21663	47.0	53.7	854	2.20	5.0	0.64
C-2-10	752	2092	152.5	140	97.5	145.0	-0.12	20.9	22395	47.5	50.7	892	2.30	5.0	0.64
C-2-11	751	1925	151.0	142	98.5	145.5	-0.08	18.4	21896	47.0	52.6	993	2.55	5.0	0.79
C-2-12	751	1812	149.0	140	99.5	142.5	-0.06	18.6	20032	43.0	49.5	898	2.31	5.0	0.74
C-2-13	729	2369	155.5	145	94.0	148.5	-0.07	22.1	24629	54.5	59.6	926	2.47	5.0	0.55
C-2-15	895	2088	153.0	142	106.5	148.0	-0.17	15.6	23038	41.5	43.6	1234	2.66	6.5	0.78
C-3-3	521	2263	170.0	158	111.0	159.5	-0.03	24.3	15927	48.5	53.1	545	2.00	3.0	0.42
C-3-5	496	2206	172.5	161	111.0	163.5	-0.05	23.9	16419	52.5	58.2	572	2.20	3.0	0.41
C-3-7	494	2085	191.0	174	118.0	178.0	-0.07	29.4	19263	60.0	63.6	545	2.04	3.0	0.43
C-4-6	743	2211	170.5	144	70.0	153.0	-0.12	39.2	37595	83.0	87.5	799	2.12	5.0	0.59
C-4-8	692	2209	171.5	145	68.0	155.0	-0.13	39.3	36742	89.0	90.2	779	2.21	4.5	0.55
C-6-12	1534	2191	165.0	124	71.0	147.0	-0.43	32.4	69954	76.0	79.6	1799	2.35	14.5	1.20
C-4-14	1585	2245	166.5	127	71.0	148.0	-0.38	33.8	74458	77.0	82.9	1833	2.28	15.0	1.21
C-4-16	1583	2187	167.5	124	74.0	149.0	-0.50	31.7	72419	75.0	74.5	1905	2.37	15.0	1.24
C-4-23	1513	2242	176.0	135	89.0	164.0	-0.59	25.3	70366	75.0	67.5	2317	2.96	14.5	1.18
C-5-6	1566	2172	170.0	127	64.0	150.0	-0.37	37.5	80826	86.0	92.9	1797	2.30	15.0	1.20
C-5-7	1541	2230	172.0	129	66.0	152.0	-0.37	37.5	79501	86.0	91.4	1768	2.30	14.5	1.16
C-5-10	1534	2175	172.0	134	73.0	159.0	-0.41	31.0	80478	86.0	90.0	2160	2.77	14.5	1.19
C-5-15	2010	2219	174.0	130	94.0	159.0	-0.81	24.0	80991	65.0	59.5	2814	2.71	26.0	1.56
C-6-5	1955	2050	160.0	134	127.5	152.0	-2.77	10.2	27533	24.5	11.1	2454	2.40	26.0	1.71
C-6-12	1927	2046	170.0	147	142.0	162.0	-7.40	7.2	21294	18.0	8.6	2590	2.50	26.0	1.72
C-7-4	999	2132	157.0	130	70.0	144.0	-0.23	30.7	44338	74.0	74.1	1202	2.41	7.0	0.80
C-7-9	1529	2213	170.0	136	100.0	156.0	-0.56	23.3	53083	56.0	52.8	1899	2.40	14.5	1.15
C-7-12	2007	2094	169.0	136	112.0	156.0	-0.83	17.9	55647	44.0	40.7	2585	2.45	27.0	1.66
C-7-17	2171	2037	174.5	153	145.0	163.0	-1.25	9.6	25405	18.0	15.0	2195	1.88	19.5	1.93
C-8-9	1939	2186	196.0	158	138.0	182.0	-1.20	16.8	56318	44.0	33.3	2790	2.62	26.0	1.57
C-8-11	1925	1870	194.5	162	146.0	180.0	-1.13	15.2	43853	34.0	28.8	2398	2.23	26.0	1.85
C-8-14	1415	1329	200.0	167	151.0	182.0	-0.94	17.0	29394	31.0	28.3	1442	1.83	13.5	9.91
C-8-17	983	1276	208.0	173	150.0	186.0	-0.57	22.5	23720	36.0	35.8	879	1.60	8.0	1.38
C-11-4	2499	2144	160.5	141	138.0	150.0	-0.97	6.0	19195	12.0	5.9	2672	2.00	40.0	2.09
C-11-5	2561	2367	172.0	140	128.0	157.0	-0.96	13.4	47540	29.0	23.5	2945	2.16	41.0	1.93
C-11-7	2566	2192	176.0	142	131.0	162.0	-1.81	12.4	50920	31.0	22.3	3411	2.50	41.0	2.06

TABLE 3-3
PREHEATER TEST RESULTS (Con't)

TEST	M _f	M _b	T _{bi}	T _{bo}	T _{fi}	T _{fo}	θ	ΔT _{LM}	Q _f	ΔT _{fo}	ΔT _{fc}	U _v	NTU	H	V _f /V _b
E-1-3	665	2213	142.5	127	75.0	134.0	-0.14	24.0	23487	59.0	62.1	815	2.46	4.0	0.61
E-1-6	1005	2371	162.5	137	93.0	134.0	-0.25	26.5	34265	55.0	55.9	1074	2.08	7.5	0.87
E-1-9	1460	2474	171.0	150	132.0	160.0	-0.56	14.2	26162	28.0	27.5	1534	1.97	17.0	1.26
E-1-12	1954	2498	178.5	152	136.0	163.0	-0.69	15.7	34301	27.0	27.7	1815	1.72	26.0	1.62
E-1-14	2469	2726	176.5	151	140.0	163.0	-1.10	12.2	36908	23.0	21.6	2519	1.89	40.0	1.92
E-1-16	2565	2717	178.5	151	140.0	165.0	-1.27	12.9	25014	25.0	22.7	2533	1.94	42.0	1.97
E-2-4	2069	2443	167.0	145	134.0	154.0	-0.82	11.9	26485	20.0	20.6	1843	1.68	30.0	1.77
E-2-7	1976	2443	183.0	161	134.0	167.0	-0.22	21.0	42816	33.0	48.0	1697	1.57	27.0	1.74
E-2-10	2026	2453	198.5	161	135.0	180.0	-0.37	22.0	60007	45.0	45.6	2269	2.04	28.0	1.65
E-3-3	2058	2489	191.0	160	140.0	191.0	-1.48	17.9	47547	51.0	37.3	2210	1.96	30.0	1.73
E-3-6	1958	2287	203.0	165	141.0	184.0	-0.79	21.4	56419	43.0	42.1	2197	2.01	26.5	1.65
E-3-10	2304	2658	195.0	164	150.0	180.0	-1.14	14.5	46308	30.0	27.2	2662	2.07	30.0	1.84
E-4-3	1982	2377	176.0	146	127.0	159.0	-0.68	18.0	40594	32.0	33.5	1881	1.78	26.5	1.71
E-4-6	2002	2658	198.0	164	145.0	182.0	-0.95	17.4	44692	37.0	32.9	2320	2.12	28.0	
F-2-9	2563	3339	168.0	141	118.0	159.0	-0.78	15.3	65592	41.0	42.4	2605	2.69	36.4	1.42
F-2-11	2863	3394	170.0	142	117.0	159.0	-0.68	17.1	74991	42.0	49.0	2667	2.46	44.2	1.55
F-2-41	1414	3895	170.0	146	123.0	165.0	-0.83	11.8	37478	42.0	30.0	1927	3.56	12.8	0.67
F-2-45	2253	3392	174.5	151	126.0	170.0	-0.76	12.0	63097	44.0	42.8	3201	3.68	29.4	1.23
F-2-59	2453	2948	175.5	156	138.0	177.0	-0.86	8.9	53129	24.0	35.9	3639	3.78	35.2	1.57
F-2-63	2312	3173	170.5	151	135.0	166.0	-0.91	9.5	45101	31.0	39.0	2892	3.23	21.4	1.37
F-3-1	1691	1896	155.0	126	119.0	133.0	-1.0	13.1	14482	14.0	14.0	670	1.07	17.5	1.65
F-3-5	1727	2174	162.0	134	131.0	135.0	-0.33	10.9	4270	3.3	3.3	2371	0.37	18.6	1.49
F-3-9	2120	3617	145.0	121	113.0	125.0	-0.50	13.1	15434	12.0	13.7	714	0.92	25.8	1.30
F-4-8	2539	2764	205.0	161	132.0	189.0	-0.50	21.9	94945	57.0	63.1	2634	2.61	36.9	1.68
F-4-12	2535	3151	204.0	162	134.0	188.0	-0.97	21.4	89923	54.0	55.3	2543	2.52	26.9	1.49
F-4-13	2562	3318	203.0	163	133.0	188.0	-0.93	21.6	92431	55.0	57.5	2591	2.54	37.5	1.43
F-4-34	2253	3382	187.0	142	102.0	173.0	-0.83	24.8	99666	71.0	67.7	2441	2.87	28.5	1.21
F-4-36	2103	3380	190.0	144	101.0	175.0	-0.78	26.6	97054	74.0	70.2	2214	2.78	25.2	1.13
F-6-6	2567	2594	210.0	140	115.0	175.0	-1.36	30.2	95667	59.0	55.9	1923	1.96	36.3	1.79
F-6-8	2562	3031	216.0	146	119.0	174.0	-1.26	31.3	99781	61.0	55.1	1934	1.95	36.4	1.53
F-6-11	2737	3035	211.0	145	118.0	180.0	-1.15	30.8	100816	58.0	56.4	1984	1.88	40.9	1.64
F-7-8	2584	3188	188.0	147	121.0	180.0	-1.27	15.3	97556	41.0	50.6	3874	3.86	37.1	1.49
F-7-32	2176	2833	179.0	150	128.0	160.1	-0.86	15.2	56840	41.0	41.1	2265	2.69	27.8	1.43
F-7-35	2228	2834	178.0	150	126.0	168.0	-0.75	16.0	59436	42.0	45.4	2254	2.60	78.9	1.46
F-8-17	2830	3200	211.0	145	122.0	192.0	-2.04	20.9	128796	70.0	48.3	3731	3.30	43.7	1.61

TABLE 3-3
PREHEATER TEST RESULTS (Con't)

TEST	M _f	M _b	T _{bi}	T _{bo}	T _{fi}	T _{fo}	θ	ΔT _{LM}	Q _f	ΔT _{fo}	ΔT _{fc}	U _v	NTU	H	V _f /V _c
F-8-22	2880	3252	215.5	145	122.0	196.0	-2.22	21.2	139252	74.0	48.6	2983	3.5	45.1	1.61
F-8-26	3036	3142	215.0	142	118.0	196.0	-2.25	21.4	153946	78.0	54.1	4362	3.6	49.1	1.75
F-8-34	3061	3078	227.0	148	118.0	200.0	-1.73	28.5	164001	82.0	69.6	3494	2.3	49.9	1.79
F-9-10	1127	2225	169.0	128	100.0	160.0	-1.14	16.7	41593	60.0	41.3	1507	3.6	8.3	0.92
F-9-24	2329	2384	185.0	124	100.0	173.0	-2.02	17.6	104947	73.0	52.3	3610	4.1	30.1	1.77
F-9-27	2378	2384	187.0	120	102.0	175.0	-1.81	18.1	108367	73.0	57.8	3630	4.0	31.3	1.81
F-9-39	2504	2374	206.0	127	101.0	187.0	-2.31	22.3	135866	86.0	61.2	3693	3.9	34.3	1.90
F-11-4	2447	2538	210.0	144	111.0	182.0	-1.15	30.4	110202	71.0	72.6	2196	2.3	33.2	1.74
F-11-6	2720	2317	212.0	140	112.0	183.0	-1.52	28.7	121855	71.0	72.9	2571	2.5	40.1	2.12
F-11-8	2724	2371	213.0	138	108.0	181.0	-1.43	31.0	125631	73.0	76.2	2458	2.4	40.1	2.07

FIG 3-2

COMPARISON OF OBSERVED AND CALCULATED
TEMPERATURE RISE IN PREHEATER FROM
THE LETAN-KEHAT MODEL

outlet, which is calculated in Eq. (2-6), is plotted in Figure 3-3. The two curves in this figure represent the theoretical predictions by Letan-Kehat model for a 6' and 10' preheater height. These curves appear to be in good agreement with the experimental data points. Figure 3-3 not only gives further confirmation of the Letan-Kehat model application but also furnishes a very useful chart to estimate the height of the preheating zone in a spray column with predetermined temperature approach and superficial velocities of both fluids.

In the above presentations, the knowledge of local heat transfer coefficient is not required in sizing the height of spray column, since the Letan-Kehat model assumes negligible resistance to heat transfer at the drops. The heat transfer performance in a spray column is controlled by the fluid dynamics. The heat transfer coefficient or NTU should not be used for the correlation of experimental data in the spray column heat exchanger as stated by Letan and Kehat. However, the volumetric heat transfer coefficient and NTU have been calculated for reference purposes and listed in Table 3-3. Many efforts have been made to correlate any possible relationship among the hold-up, superficial velocities, NTU and volumetric heat transfer coefficient. Unfortunately, none has been discovered.

In the previous report (Phase I¹), a relationship between the isobutane holdup and isobutane volumetric flow rate has been established. The hold-up calculated in this study is based on the above relationship. The drop size of isobutane is 0.15 inch which remains the same as the previous measurements in Phase I, since the same isobutane distributor is used for this phase of experimentation.

FIG. 3-3

VERIFICATION OF LETAN-KEHAT MODEL
BY EXPERIMENTAL DATA

3.4

TEST RESULTS - COMBINATION OF PREHEATER AND BOILER

3.4.1

Data Reduction

All heat transfer in the preheating zone takes place between liquid brine and liquid isobutane drops. In contrast, the mechanisms of heat transfer in the boiling zone is much more complicated than in the preheating section and is described in the following paragraph.

When hot brine is sprayed near the top of the direct contact heat exchanger, a certain amount of steam is produced at a temperature which is higher than the surrounding isobutane vapor temperature and is unable to be determined simply because of an unpredicted amount of steam. For simplicity, this steam temperature is assumed to be the same as the brine inlet temperature. This steam mixes with isobutane vapor and reaches an equilibrium temperature which is the isobutane vapor outlet temperature. The high temperature of the steam is decreased and some of the steam condenses. At equilibrium, the mole fraction of steam is theoretically equal to the ratio of water vapor pressure to the total pressure of the mixture. The amount of water vapor in the vapor phase can be estimated from the mole fraction of steam in the mixture. Part of this steam, leaves the heat exchanger with the isobutane vapor and condenses to water in the hotwell, resulting in water carryover into the isobutane. The heat associated with this carryover, the respective sensible and latent heat given off by the steam as it cools and condenses should be counted in the brine total heat transfer rate.

When the column is treated only as a preheater, the total heat transfer area is difficult to define because the direct contact surface area between isobutane and brine is continuously formed and eliminated. Fortunately, the liquid level in a preheater is easily fixed by a level controller and the preheater volume can be determined. When the single column is used for a combination of preheating and boiling, the boiling zone cannot be distinguished from the preheating zone clearly. Even if an intermediate position between these two zones exists inside the column, this position varies with the operating conditions. However, the ability of Letan-Kehat model to estimate the height of the preheater with the knowledge of the isobutane inlet and outlet temperature and brine outlet temperature can be verified in sub-section 3.3.3. The height of the boiling section can be calculated by subtracting the preheating distance from the total column height.

The intermediate brine temperature between the preheating and boiling zones is indeterminable not only because it is very difficult to install a thermometer to measure this temperature at the exact intermediate position, but also because this position varies with the operating conditions. Usually, this brine temperature can be estimated from the heat balance between isobutane and brine. Realistically, the heat transfer rates of brine and isobutane are not balanced with each other because of heat losses due to the ambient and other unaccountable reasons. Therefore, the intermediate brine temperature calculated from the heat balance may not give a satisfactory result. The intermediate brine temperature is assumed to be the brine inlet temperature of the preheater. One equation (Eq.2-7) in Letan-Kehat model is used to calculate the brine intermediate temperature from the preheating zone distance and both fluid outlet temperatures. Although this may not be the ideal method to solve the problem, it does give a reasonable result.

After the volume of each zone and brine intermediate temperatures are determined, the log mean temperature difference and volumetric heat transfer coefficient are calculated. All the reduced results are shown in Table 3-4.

3.4.2 Data Analysis

Since a combination column of preheating and boiling involves more variables than a single preheater, it is easier to analyze a group of experimental data by selecting one independent variable and keeping other variables or conditions unchanged. Two types of experiments have been performed to meet the above requirement.

In the first type of experiment the total vapor pressure is maintained at 315 psia and the correspondent isobutane saturation temperature at 220 F. The flow rates of both fluids are varied. The flow rate ratio between these two fluids is held constant in order to maintain a constant isobutane pressure and temperature. The free surface level inside the column is always fixed at one position. The fluctuation of the brine inlet temperature, which is beyond the operator's control, effects the brine outlet temperature and isobutane outlet temperature. The purpose of this type experiment is to evaluate the influence of flow rate upon the heat transfer performance. The flow rate may be termed as mass flow rate, volumetric flow rate, and superficial velocity. Since mass flow rate is independent of temperature and pressure, it is selected to express the flow rate. The test number of this type of experiment is assigned under the prefix G-1 as shown in Table 3-4.

The volumetric heat transfer coefficient is plotted against the isobutane mass flow rate for both preheating and boiling as shown in Figure 3-4.

After examining Table 3-4 and Figure 3-4, several interesting facts have been discovered as follows:

- 1) The heat transfer performance U_v is increased linearly with increasing flow rates of both fluids in the preheating zone.
- 2) In the boiling zone, the volumetric heat transfer coefficient is increased exponentially as both brine flow and isobutane flow increase.
- 3) For these particular saturation conditions, which are at 220 F and 315 psia, a fixed isobutane-to-brine mass flow ratio is obtained under a specified brine inlet temperature and isobutane inlet temperature. This leads one to believe that there is a correspondent mass flow ratio between two fluids for the heat exchanger under specified conditions.
- 4) As both fluid flow rates increase, the vertical distance ratio of preheating and boiling tends to reach a constant value. The limit of these flow rates for this constant distance ratio is probably the flow rates at flooding point. For instance, this ratio is 1.6 for the test Group G-1.

TABLE 3-4

RESULTS OF COMBINATION OF PREHEATING AND BOILING TESTS

T_i	= Isobutane inlet temperature, F
T_{fo}	= Isobutane outlet temperature, F
T_{bi}	= Brine Inlet temperature, F
T_{bo}	= Brine Outlet temperature, F
T_{bm}	= Brine intermediate temperature between preheating and boiling, F
P	= Pressure, Psia
$\dot{M}_i$	= Mass Flow rate of isobutane, lb/hr
$\dot{M}_b$	= Mass flow rate of brine, lb/hr
Q_{fp}	= Total heat transfer of isobutane in preheating, Btu/lb
Q_{fb}	= Total heat transfer rate of isobutane in boiling, Btu/lb
ΔT_{LMp}	= Log mean temperature difference in preheating, F
ΔT_{LMb}	= Log mean temperature difference in boiling, F
U_{vp}	= Preheating volumetric heat transfer coefficient, Btu/ F-hr-ft ³
U_{vb}	= Boiling volumetric heat transfer coefficient, Btu/ F-hr-ft ³
NTU_p	= Number of transfer units in preheating
H	= Isobutane Holdup, %
z_p	= Distance of preheating zone, ft
z_b	= Distance of boiling zone, ft
V_b/V_f	= Ratio of superficial velocities between brine and isobutane

TABLE 3-4

RESULTS OF COMBINATION OF PREHEATING AND BOILING TESTS
(Con't)

TEST	T _{fi}	T _{fo}	T _{bi}	T _{bo}	T _{bm}	P	M _f	M _b	Q _{fp}	Q _{pb}	T _{MP}	T _{LMB}	U _{vp}	U _{vb}	NTU _p	H	T _p	T _b	V _b /V _f
G-1-1	87	220	307	168	244	315	1012	1184	89073	85024	46.9	48.9	2205	1451	2.84	7.6	4.2	6.1	0.70
G-1-2	94	220	307	163	238	315	1383	1706	118951	116185	33.4	43.8	3628	2535	3.77	13.4	5.0	5.3	0.73
G-1-3	90	220	316	160	237	315	1643	2025	142902	137974	37.5	45.6	3737	3001	3.47	18.0	5.2	5.1	0.74
G-1-4	95	220	318	156	235	315	1885	2289	160194	158310	32.8	44.2	4013	4415	3.81	23.2	6.2	4.1	0.71
G-1-5	92	220	321	155	235	315	2139	2589	183971	179693	28.8	45.1	5333	4797	4.45	29.0	6.1	4.2	0.69
G-1-6	98	220	322	154	230	315	2261	2660	187699	189960	26.7	39.6	5188	7121	4.57	32.0	6.9	3.4	0.73
G-1-7	95	220	325	155	232	315	2386	2981	207821	200435	29.8	42.9	5587	5764	4.19	35.3	6.2	4.1	0.68
G-2-1	87	225	320	155	236	315	1391	1537	128011	112705	31.3	39.0	3206	3877	4.41	13.4	6.5	3.8	0.66
G-2-2	85	212	317	155	226	295	1396	1492	115895	127066	34.8	45.2	3089	2977	3.65	13.4	5.5	4.8	0.64
G-2-3	83	206	316	149	218	275	1399	1471	111880	128662	31.7	44.2	2998	3445	3.88	13.4	6.0	4.3	0.63
G-2-4	83	201	316	144	211	255	1396	1419	106286	132858	28.2	43.0	2823	4496	4.18	13.4	6.8	3.5	0.61
G-2-5	85	190	316	140	198	235	1336	1401	92158	141029	24.4	42.8	2790	4936	4.31	13.4	6.9	3.4	0.60
G-2-6	85	183	315	135	188	215	1396	1304	85176	146615	19.5	38.8	2552	12028	5.02	13.4	8.7	1.6	0.56

FIG. 3-4

VOLUMETRIC HEAT TRANSFER COEFFICIENT VS.
ISOBUTANE AND BRINE FLOW RATES

The second type test is to keep a constant isobutane flow rate and to vary brine flow rate. The total vapor pressure and temperature change as the brine flow rate varies. The vapor pressure and temperature are always at the isobutane saturation condition. Again the free surface level is operated at the same fixed position. The goal of this kind of experiment is to investigate the heat transfer performance at different saturation conditions. The test number of this group experiment is designated under the prefix G-2.

The brine-to-isobutane superficial velocity ratio vs. the volumetric heat transfer coefficient for both the boiling and preheating zones are plotted in Figure 3-5. The preheating line shows that the volumetric heat transfer coefficient increases linearly with increasing superficial velocity ratio. In other words, the volumetric heat transfer coefficient depends on the brine flow rate since the isobutane flow rate is constant. The boiling curve indicates that the heat transfer performance is increased as the brine flow rate is reduced. This is in contradiction to the boiling curve shown in Figure 3-5. In order to explain this discrepancy, the heat transfer in the preheating zone is discussed. A certain quantity of sensible heat required to heat the liquid isobutane to its desired saturation temperature and pressure is fixed because of the constant isobutane flow rate. If the brine flow rate is reduced, the heat supplied to the isobutane is also reduced. Therefore, a larger preheating zone is required to meet the isobutane saturation conditions. The space for the boiling zone in the column is diminished simply because the height of the column is fixed. Consequently, the value of the volumetric heat transfer coefficient in the boiling zone becomes larger. Also the isobutane latent heat of vaporization at higher temperatures is less than that at lower temperatures. This definitely increases the volumetric heat transfer coefficient in the boiling zone since the calculation of heat transfer coefficient is based on the isobutane total heat transfer rate. When the brine flow rate is further reduced, the heat supplied by the brine can only vaporize isobutane partially. Thus the liquid isobutane liquid is accumulated at the top of the column and the boiling zone disappears. This situation has actually occurred when low brine flow rates were used during the test period.

In Figure 3-6, the UA factor of the boiling zone is plotted against the isobutane reduced pressure. The UA factor in the boiling zone is defined as

$$U_A = \frac{Q_{fB}}{\Delta T_{LMB}} \quad (3-1)$$

Where Q_{fB} is the heat transferred to the isobutane and ΔT_{LMB} is the logarithmic mean temperature difference of boiling zone. The straight line in Figure 3-6 indicates that the UA factor increases with higher isobutane pressure. Again this suggests that isobutane latent heat of vaporization is higher at lower temperature. The UA factor also may be influenced by LMTD to a less extent. The relationship between UA factor and volumetric heat transfer coefficient can be expressed as $U = UA/V$, where V is the volume of boiling zone. The UA factor instead of U is used in Figure 3-6, only because the boiling zone volume depends on the brine flow rate and is independent of the isobutane reduced pressure.

FIG. 3-5

BRINE-TO-ISOBUTANE SUPERFICIAL VELOCITY RATIO
VOLUMETRIC HEAT TRANSFER COEFFICIENT

FIG. 3-6

UA FACTOR IN BOILING ZONE
VS. ISOBUTANE REDUCED PRESSURE

3.4.3 Column Diameter

In section 2.2, theories have been presented to correlate the relationship among mass flow rates of both fluids, drop diameter and column diameter at the flooding point. A comparison between the Sakiadis-Johnson model and the Minard-Johnson correlation has also been discussed.

As shown in Figure 3-4 a saturation condition for the isobutane vapor at 315 psia and 220 F for this six-inch diameter spray column can be established by operating with an isobutane-to-brine mass flow ratio of 0.83. If this column is ever flooded under the same mass flow ratio and conditions, the flow rates predicted by Sakiadis-Johnson model should be 2332 and 2810 lb/hr for isobutane and brine respectively. The estimation of isobutane flow rate by the Minard-Johnson correlation is 2688 lb/hr which is correspondent to a brine flow rate of 3238 lb/hr at a mass flow ratio of 0.83. However, no experimental runs in this study have operated at those predicted flow rates because of the limitation of pump capacity. Also the column has not been flooded since no high isobutane concentration in brine outlet has been discovered. It is very interesting to note that the maximum flow rates for isobutane and brine among all test runs to date are 2386 and 2981 lb/hr respectively.

The predicted column diameter corresponding to these mass flow rates is 5.5 inches by the Sakiadis-Johnson model and is 5.2 inches by the Minard-Johnson correlation. All the above results are based on an isobutane drop size of 0.15 inch diameter.

3.4.4 Water Vapor Carryover

The steam in the vapor phase in the heat exchanger accompanies the isobutane vapor to the condenser and is condensed in the hotwell. Two liquid phases are formed in the hotwell, the water sinks to the bottom. The volume of water collected from the hotwell was measured with respect to time at steady-state. Those measurements were performed at various vapor pressures and isobutane outlet temperatures of the direct contact heat exchanger as shown in Figure 3-7. In Figure 3-8 it shows that the water vapor weight percentage in isobutane vapor is a function of the vapor pressure and temperature of the vapor phase inside the heat exchanger. However, it was discovered that the amount of this experimental water carryover is about 8-21% less than that of the theoretical water carryover. This could be explained as: 1) incomplete steam vaporization from the brine because the vapor pressure is at least three times higher than the steam saturation pressure or/ and 2) condensation of part of the steam before leaving the heat exchanger.

The water collected from the hotwell has been chemically analyzed. This water has a pH value of 5.9 and conductivity of 550/mhos and contains 70 ppm of chlorides. In comparison with geothermal brine (Table 3-2), it shows that the solid content in the watery carryover may not be a problem in direct contact heat exchangers.

3.4.5 Isobutane Loss

The brine sample at the brine outlet of the direct contact heat exchanger was collected in order to measure the isobutane concentration in the brine and to estimate the isobutane loss in the brine reinjection system. The brine was taken into a stainless steel sampling bottle with the air purged out. This bottle is filled with brine. Then the brine sample was analyzed by the East Mesa site chemistry laboratory.

FIG. 3-7

WATER VOLUME COLLECTED HOTWELL VS TIME

FIG. 3-8

WATER VAPOR WEIGHT PERCENTAGE VS

ISOBUTANE OUTLET TEMPERATURE

According to the test report, the first step in the brine analysis was to collect a brine sample at 150 F and 295 psig. This brine sampling bottle was then connected to another bottle which was evacuated to 26.5" Hg vacuum as shown by an attached pressure gauge. The brine bottle was then opened into this evacuated bottle and the pressure rose to 15" Hg vacuum. Therefore, this 11.5" Hg pressure difference must be accounted for in this analysis.

The gas chromatograph analysis of the isobutane indicated 110 ppm of isobutane in brine as it leaves the heat exchanger. This quantity of isobutane will yield 1.39" Hg pressure in the collecting bottle. The vapor pressure of water at room temperature is about 1" Hg. Therefore, $11.5 - 1.39 - 1 = 9.1$ " Hg must be accounted for. Assuming this is due to CO_2 dissolved in the brine at the collecting temperature of 150 F, the solubility of CO_2 is 1.2×10^{-2} Molar. Literature results show that equilibrium solubility at 150 F is 1.1×10^{-2} Molar.

The test results are shown in Table 3-5. The fourth column in this table is the isobutane equilibrium solubility which is reported by the University of Utah¹¹. The isobutane concentration is far below the isobutane equilibrium solubility in brine. However, two tests, which are also in the East Mesa site chemistry laboratory report and not listed in Table 3-5, show inconsistent results of very high isobutane concentration. One is 1660 ppm at 297 psig and 157 F and the other one shows 940 ppm at 350 psig and 154 F. This inconsistency is probably due to an isobutane drop trapped in the brine sample accidentally.

In Section 2.4.3, a method is developed for the prediction of isobutane concentration at the brine outlet of the spray column. Apparently, the assumption made for this method may not fit this situation. The experiment data indicates that the isobutane concentration at the interface of the brine side is not saturated.

3.4.6 Isobutane Vapor Quality

When the isobutane leaves the heat exchanger, it passes through a globe needle valve in lieu of a throttling calorimeter and then returns to the condenser and hotwell. Several measurements of pressure and temperature have been made immediately after the throttling of various mass flow rates. The quality of isobutane vapor has been obtained and is ranged from 98.77 to 100%. This quality is increased as the mass flow rate increases.

TABLE 3-5

MEASUREMENT OF ISOBUTANE CONCENTRATIONS AT THE BRINE OUTLET
OF DIRECT CONTACT HEAT EXCHANGER

Sampling Conditions		Isobutane Concentration	Equilibrium Solubility*
Temperature, F	Pressure, PSIG	PPM	PPM
150	293	110.0	375.8
163	306	120.0	357.3
157	295	103.0	359.4
156	300	49.0	367.1
164	300	80.5	347.1
167	315	89.2	356.1

*Estimation of the isobutane saturation solubility is based on reference¹¹ .

3.5 TURBINE EXPERIMENT

3.5.1 Introduction

In 1977 DSS was contracted by Lawrence Berkeley Laboratories (via sub-contract with Barber-Nichols) to provide isobutane vapor from the direct contact heat exchanger to the LBL/Barber-Nichols turbine experiment. The objective of this effort was to demonstrate the workability of a complete binary isobutane cycle fueled by geothermal brine to obtain operating experience, and to identify potential problem areas. The goal established was to run the power loop for 500 hours or 30 days, whichever came first, at a subcritical condition of 300 psig and 220 F at the turbine inlet.

3.5.2 Modification to the Test Unit for Turbine Experiment

Several piping and control changes were made to the test unit to accommodate the turbine experiment as shown in drawing No.064-7101. These changes were made so that the system could provide isobutane liquid at supercritical and subcritical pressures to the surface heat exchanger for calibration

Piping from the isobutane pump to the direct contact heat exchanger was provided with tees and shut-off valves to direct isobutane to either the surface heat exchanger or to the direct contact heat exchanger. Since calibration with the surface heat exchanger was at both sub-critical and super-critical conditions, two safety relief valves were provided on the pump discharge. Either safety valve could be selected: 650 psi for supercritical or 350 psi for sub-critical.

Piping from the surface heat exchanger to the turbine inlet was provided for isobutane vapor. Also connected to the turbine inlet by means of appropriate isolating valves and tees was the vapor line from the DCHX. As a result of these changes, the mode of operation could be changed from calibration with the surface heat exchanger to operation with the DCHX without requiring a major shutdown and gas freeing to make piping changes.

A vapor line was provided between the turbine exhaust and the condenser. This line was tied into the original vapor line from the DCHX to the condenser. The original pressure control valve (PCV 100) between the DCHX and condenser remained operable to allow the turbine to shut down while the DCHX was still running. This provided a "short circuit" around the turbine directly to the condenser.

Separate brine supply and return pipes were installed to provide the surface heat exchanger with brine. The flow of brine to the heat exchanger was manually controlled.

All piping was hydrotested to 900 psi before testing began. Hot pipes were insulated with asbestos lagging.

An electrical relay was installed linking the turbine stop valve to the DCHX system. A signal closing the turbine stop valve also shut off the power to the DCHX pumps and opened the pressure control valve (PCV 100) between the boiler and condenser. This allowed the isobutane vapor in the DCHX to be vented to the condenser when the turbine inlet valve closed for any reason.

3.5.3 Performance of DCHX and Isobutane Loop During 500 Hour Endurance Test

In discussing performance of equipment here, it is necessary to make the distinction between the experimental item and the supporting equipment. The direct contact heat exchanger is the experimental item being tested, not the equipment used to conduct the experiment.

The Direct Contact Heat Exchanger maintained the same level of heat transfer performance throughout the 500 hour endurance test. The capacity to transfer heat was not affected by the corrosive or scaling properties of the geothermal brine. Inspection of the internals of the heat exchanger showed no significant buildup of scale. The only scale formation noticed was a 3/4" x 1" ring of material found between the O.D. of the demister mesh pack and the I.D. of the vessel. This had no effect, however, on performance. The remainder of the vessel was quite clean.

Malfunctions of the supporting equipment, i.e. the other components in the isobutane loop, caused the endurance run to be interrupted numerous times. The following discussion outlines some of the problems experienced with the loop components. In defense of the loop, or in praise of it, depending on your outlook, it should be pointed out that the loop was put together on a "crash" basis nearly two years ago for a series of short heat transfer tests not lasting more than a few hours each.

The most troublesome pieces of equipment in the loop were the isobutane and brine booster pumps. These pumps are both outside packed plunger pumps. They were selected because of 1) quick delivery 2) high head ability (2000 psi) 3) low flow capacity and 4) cost. The problem with both pumps was the leakage around the packing and the very short life of the packing. In some instances the packing lasted less than 100 hours. These pumps would not normally be chosen for this service in a large commercial power plant using the same process. There are numerous large centrifugal pumps available that would give good service in a commercial plant.

SECTION 4
PILOT PLANT DESIGN

4.1 INTRODUCTION

4.1.1 Summary

During a previous contract detailed designs and specifications were completed for a 250 KW Direct Contact Heat Exchanger/Binary cycle pilot plant. The present task updated and reviewed the designs in conjunction with the latest test data and field operations experience. Cost estimates were revised by obtaining updated quotations from equipment manufacturers. In addition, a cost estimate for a 500 KW unit was prepared and is shown in section 4.6. The pilot plant design consists of a complete secondary fluid power cycle utilizing direct contact heat exchangers and a turbine generator. Process flow and piping and instrument diagrams were prepared.

4.1.2 Design Basis

Through discussions with the ERDA and other ERDA contractors and DSS Engineers, Inc., the following design ground rules were established.

- a. Site location - East Mesa, California.
- b. Geothermal brine supply temperature 325 F, at a salinity equal to 30,000 ppm.
- c. Isobutane boiling temperature 260 F
- d. Isobutane condensing temperature 110 F. (Isobutane return temperature to boiler, with 5 subcool, 105 F).
- e. Experimental turbine-generators up to 250 KW
- f. Equipment efficiencies
 - turbine - 77%
 - gearbox - 98%
 - generator - 90%
- g. Surface type condenser for condensing isobutane vapor exhaust from turbine.

Based on the desirability of obtaining additional test data on a unit having a hydraulic diameter that is significantly larger than the old test apparatus and allowing the pilot plant flexibility for moving to other sites, the following features were incorporated:

- a. Total brine flow of 100 GPM (isobutane vapor production equivalent to approximately 250 KW total).
- b. Incorporate an atmospheric stripping column to reduce working fluid losses.
- c. Design boiler for 260 F boiling at East Mesa but provide a structural design suitable for supercritical operation in the event that higher temperature brines are made available.

- d. A brine surge vessel is incorporated in the design to allow control of brine flow and adjust temperature and pressure, as well as strip non-condensibles if required.
- e. The direct contact boiler is designed as a single straight column for preheating and vaporizing. No internal distribution plates are incorporated. Heating will be done for an NTU of 9 (pinch point temperature difference of approximately 5°F).

4.2 Process Description

4.2.1 General

The process flow diagram for the plant at rated design capacity is given in Drawing No.51-5004. This can be referred to while reading the following general description.

Geothermal brine is supplied to the unit from any one of three wells, identified as Mesa 6-1, 6-2 and 8-1. Design geothermal flow rate to the boiler is 100 GPM at 325°F. Unflashed brine flow at the East Mesa location will be limited to 100 GPM or less from each well at a temperature up to 338°F. A surge vessel is provided to control the flow to the brine pump and allow trapped gas to be vented off. The brine feed pump takes its suction from the surge vessel and boosts the supply pressure from 150 psig to the boiler operating pressure of 496.7 psig.

Brine from the boiler flows to the stripping column where isobutane is stripped from the brine stream, prior to being pumped to waste or reinjection by the brine waste pump.

At the design brine flow rate of 100 GPM (at 325°F), vapor will be generated in the boiler at a rate of 40,940 lbs/hr at 260°F and 497 psia. Of this total flow rate 10,880 lbs/hr are required at the turbine. The remainder would by-pass the turbine, and be piped directly to a dump condenser.

Vapor exhaust from the turbine (at 135°F and 86 PSIA) is condensed in a conventional shell and tube heat exchanger. Cooling water flow to this condenser is approximately 335 GPM.

The vapor by-passing the turbine generator is condensed and then cooled in air cooled heat exchangers. Vent condensers are provided at each condenser to minimize isobutane losses.

4.2.2 Heat Rejection System Selection

At 110°F condensing temperature the total heat rejection load of the pilot plant is approximately 6.33×10^6 BTU/hr. The cooling water required for this condensing load would be 1265 GPM (cooling water supply temperature at 90°F). This is considerably above the cooling water availability at the East Mesa site. Therefore, it was established that the practical maximum availability of cooling water be set in the neighborhood of 350-450 GPM. This cooling water flow is sufficient for condensing the turbine exhaust only (i.e. for 10,876 lbs/hr vapor flow 350 GPM of cooling water is required).

STREAM	MATERIAL BALANCE																		
	PROCESS STREAM NUMBER																		
PARAMETER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
GEOTHERMAL BRINE SUPPLY	44.530	40.937	10.876	10.876	10.876	166.474	166.474	30.061	30.061	0.8*/H.R	40.966	43.416	43.416	27.83*/H.R	43.416	.296	.818	40.966	27.83
ISOBUTANE VAPOR FROM BOILER																			
ISOBUTANE VAPOR TO TURBINE																			
ISOBUTANE VAPOR TO MAIN CONDENSER																			
MAIN CONDENSER ISOBUTANE CONDENSATE																			
COOLING WATER SUPPLY																			
COOLING WATER RETURN																			
ISOBUTANE VAPOR TO DUMP CONDENSER																			
DUMP CONDENSER ISOBUTANE CONDENSATE																			
ISOBUTANE MAKE UP																			
ISOBUTANE FEED																			
BRINE FROM BOILER																			
BRINE STRIPPER INLET																			
ISOBUTANE FROM STRIPPER																			
BRINE TO WASTE																			
WATER FROM MAIN CONDENSER																			
WATER FROM DUMP CONDENSER																			
ISOBUTANE FROM DUMP CONDENSER																			
ISOBUTANE FROM VENT COOLER																			
ISOBUTANE FROM VENT CONDENSER																			
ISOBUTANE FEED PUMP																			
ISOBUTANE MAKE-UP PUMP																			
ISOBUTANE BOOSTER PUMP																			
AIR COOLED DUMP CONDENSER																			
AIR COOLED CONDENSATE COOLER																			
ISOBUTANE STORAGE																			
TO WASTE POND																			

Various systems were investigated for condensing the remainder of the vapor flow (40,937 lbs/hr turbine by-pass). These systems were:

1. Elevate the condensing temperature to reduce the cooling water requirements in the range 350-450 GPM.
2. Condensing at 110°F and corresponding saturation pressure using air cooled condensers.
3. a. Condensing at 260°F and cooling to 110°F at boiler pressure using shell and tube heat exchangers.
b. Condensing at 260°F and cooling to 110°F at boiler pressure using an air cooled condenser and air cooler.

Each of the above alternates were thoroughly investigated from the technical and economic aspects. The use of additional cooling tower capacity was not investigated because the use of this equipment would limit the transportability of the pilot plant should it be desirable to operate the plant at different sites.

Equipment capital cost estimates were developed for each of the above arrangements and appear in Table 4-1. Although case 1 is the most advantageous from the economical viewpoint, the return temperature to the boiler would be too high and the turbine exhaust conditions change. The addition of a shell and tube cooler to reduce this temperature to 110°F would result in an additional 90 GPM of cooling water and of course, increased costs.

Only cases 1 and 3b meet all the ground rule requirements. On the basis of economics and technical merit therefore, case 3b (air condenser and air cooler) was selected for the pilot plant system design.

4.3 COMPONENT DESIGN AND SPECIFICATION

4.3.1 Pressure Vessels

All pressure vessels are designed and are to be fabricated in accordance with the latest edition of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, for the requisite design pressures and temperatures shown on the drawings (ASME code stamps are required). The vessels will be fabricated from seamless carbon steel pipe to ASME SA106 Grade C, or welded carbon steel to ASME SA515, Grade 70, or equal. This material has a specified minimum tensile strength of 70,000 psi (the allowable stress used in the design of these vessels is 17,500 psi). A corrosion allowance of 3/8" minimum was used in developing the total wall thickness required for the vessels in geothermal brine service. For the vessels in isobutane service a corrosion allowance of 0.05" minimum was employed. Except for the direct contact boiler, radiography inspection of butt welded joints is not required for these vessels. At the completion of fabrication, all vessels will be hydrostatically tested in accordance with Code requirements.

PILOT PLANT DESIGN

TABLE 4-1

HEAT REJECTION SYSTEMS
CAPITAL COST SUMMARY

<u>CASE</u>	<u>DESCRIPTION</u>	<u>CAPITAL COST ESTIMATE</u> <u>(\$)</u>
1.	Elevate the condensing temperature to 135 F at Saturation Pressure (exhaust condition 147 F at 116 psia)	78,770
2.	110 F Condensing at Pressure (exhaust) condition 125 F at 83 psia)	114,730
3.	Condensing at high pressure and cooling the condensate to 110 F using:	
	a. shell and tube condenser and cooler	93,470
	b. air cooled condenser and cooler	85,270

Table 4-2 (Bill of Materials), contains a summary of the important features of the pressure vessels.

The surge vessel (TV101), has been provided to enable precise control of the geothermal brine supply to the pilot plant and to act as a non-condensable gas separator. It has been designed for operation at 150 psig at 350 F brine temperature. Brine leaving this vessel is piped to the brine feed pump. The vessel has been sized for a flow retention time of 1.5 minutes. Drawing No. 051-2212 shows the general arrangement and fabrication requirements for this vessel. The brine inlet has been designed for easy access and inspection of the vessel internals.

The isobutane stripping column (SR100) has been provided for removing dissolved isobutane from the geothermal brine prior to being discharged. Drawing No. 051-2212 shows the general arrangement and fabrication requirements for this vessel. It has been designed for sub-atmospheric operation (2.5 psia at 135 F) but is also suitable for operation up to 210 psig. The brine inlet contains a spray nozzle to assist in liberating the isobutane. The vessel will be filled with 1" raschig rings or an equivalent. A flow retention time of 2.0 minutes has been provided to facilitate plant operations.

The isobutane storage tank (TV102) has been provided for the storage of isobutane required for make up purposes and for the storage of operating fluid in the event of a plant shut-down requiring the unit to be drained. The construction of this vessel is shown on Drawing No. 051-2214. The total capacity of this vessel is 465 gallons which is sufficient for the initial charge of 340 gallons plus a 2 week supply of isobutane.

The vent vessel (TV103) will be provided to ensure that isobutane which is either normally vented, or from relief lines during emergency operation, is vented away from the pilot plant pad. This vessel would be located a minimum of 30 feet from the plant proper and off the pad. Drawing No. 051-2214 shows the general arrangement and fabrication requirements for this vessel. The vessel is designed with an open top of sufficient height to allow the escape of hot vapors without endangering operating personnel and is provided with vents at the bottom to prevent the buildup of isobutane gases within the shell. The vessel has been designed for atmospheric pressure operation at a temperature of 350 F.

The main hot well (TV106) has been furnished to allow accurate control of isobutane flow to the boiler. Drawing No. 051-2209 shows the general arrangement and fabrication requirements for this vessel. The total capacity provided is 56 gal. The design operating pressure and temperatures are 100 psig and 135 F respectively. At normal design flow conditions a 1 minute flow retention time will be available.

The bypass hotwell (TV107) is considerably larger than the main condenser hotwell. A total capacity of 400 gal. is required for this vessel. Also, the design operating conditions are higher at 325 psig and 220 F. Flow retention time will be one minute. Drawing No. 051-2213 shows the general arrangement and fabrication requirements for this vessel.

TABLE 4-2
BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: VESSELS

Page 1 of 1

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
1	SURGE VESSEL	TV101	GEO THERMAL BRINE	VERTICAL	DRY WEIGHT 1054 lbs.	24" OD X 72" LONG*	100 psig 350°F	SA 515 GR 70	0.500" WALL, CAPPED ENDS
2	ISOBUTANE STRIPPING COLUMN	SR100	GEO THERMAL BRINE	VERTICAL	2284 lbs.	24" OD X 96" LONG*	2.5 psia 135°F	SA 515 GR 70	0.625" WALL CAPPED ENDS
3	ISOBUTANE STORAGE	TV102	ISOBUTANE STORAGE	HORIZONTAL	1289 lbs.	36" OD X 96" LONG*	65 psig 90°F	SA 515 GR 70	0.25" WALL CAP ENDS
4	VENT VESSEL	TV103	ISOBUTANE VENTS	VERTICAL	496 lbs.	12.75"OD X 120" LONG*	0 psig 350°F	SA 515 GR 70	0.25" WALL OPEN TOP
5	MAIN CONDENSER HOTWELL	TV106	ISOBUTANE HOTWELL	HORIZONTAL	337 lbs.	18" OD X 42" LONG*	100 psig 135°F	SA 515 GR 70	0.25" WALL CAPPED ENDS 1.5 MIN.RETENTION
6	BY PASS HOTWELL	TV107	ISOBUTANE HOTWELL	HORIZONTAL	2500 lbs.	36" OD X 84" LONG*	325 psig 220°F	SA 515 GR 70	0.25" WALL CAPPED ENDS 1.5 MIN.RETENTION

NOTES: VESSELS FABRICATED IN ACCORDANCE WITH ASME PRESSURE VESSEL CODE, DIV.1, SECTION VIII
ALL WELDED CONST., NOT SPOT EXAMINED.
*CYLINDRICAL SECTION

GENERAL NOTES

1. THE NOTES SHOWN ON DRAWING NO. 051-2209 APPLY TO THIS DRAWING.
2. RADIOGRAPHIC EXAMINATION OF BUTT WELDED JOINTS NOT REQUIRED FOR THESE VESSELS (TV101 & SR100).

TOP VIEW
1 1/2" = 1'-0"

TOP VIEW
1 1/2" = 1'-0"

NOTE
SEE REINFORCING PAD DETAILS DWG. NO. 051-2210, 2" CONN. (DETAIL A) & 3" CONN. (DETAIL E)
3.3125"

DSS ENGINEERS, Inc.		FORT LAUDERDALE, FLORIDA	
APPROVALS		TITLE	
DRAWN P.S.	DATE 2/22	STRIPPING COLUMN & SURGE VESSEL FOR DCHX PILOT PLANT	
CHECKED J.M.	DATE 3/77		
DESIGN J.M.	DATE 3/77		
PROJECT MANAGER	DRAWING NO. 051-2212	REV. 0	
P.E. REG. NO.	SCALE	SHEET 1 OF 1	

GENERAL NOTES

1. THE NOTES SHOWN ON DRAWING NO. 051-2209, APPLY TO THIS DRAWING.
2. RADIOGRAPHIC EXAMINATION OF BUTT WELDED JOINTS NOT REQUIRED FOR THESE VESSELS (TV102 & TV103)

DSS ENGINEERS, Inc.		FORT LAUDERDALE, FLORIDA	
APPROVALS		TITLE	
DRAWN	P.S.	DATE	2/77
CHECKED	OJ MORIN	DATE	3/77
MECH	Quon	DATE	5/77
ELECT			
CIVIL			
PROJECT MANAGER		DRAWING NO.	
P.E. REG. NO.		051-2214	
SCALE AS NOTED		SHEET 1 OF 1	

VENT VESSEL & ISOBUTANE STORAGE FOR DCHX PILOT PLANT

DSS ENGINEERS, Inc.		FORT LAUDERDALE, FLORIDA	
APPROVALS		TITLE	
DRAWN <i>P.S.</i>	9-17-77 1-31-77	MAIN HOTWELL FOR DCHX PILOT PLANT	
CHECKED <i>QJ Mearin</i>	3/77		
INCH <i>QJ Mearin</i>	3/77		
SELECT			
CIVIL			
PROJECT MANAGER		DRAWING NO. 051-2209	REV. 0
P.E. REG. NO.		SCALE	SHEET 1 OF 1

GENERAL NOTES

1. THE NOTES SHOWN ON DRAWING NO. 051-2209 APPLY TO THIS DRAWING.
2. RADIOGRAPHIC EXAMINATION OF BUTT WELDED JOINTS NOT REQUIRED FOR THIS VESSEL (TV-107).

END VIEW
1/4" = 1'-0"

3/4" END CAP - SCH. 160 W/ 0.625" WALL - ASTM A234 (2 REQUIRED)

BY-PASS HOTWELL - (TV107)
1/4" = 1'-0"

DESIGN PRESSURE = 325 PSIG
DESIGN TEMPERATURE = 220°F

REINFORCEMENT PAD DETAIL
N.T.S.

DSS ENGINEERS, Inc.			
FORT LAUDERDALE, FLORIDA			
APPROVALS		TITLE	
DESIGNER	P.S.	DATE	7-1-77
CHECKED	OJMOEN	DATE	5-77
BY	CHUBBY	DATE	3-77
DATE			
PROJECT NUMBER	051-2213		
P.E. REG. NO.	1		

BY-PASS
HOTWELL FOR
DCHX PILOT
PLANT

4.3.2 Heat Exchangers

This pilot plant design incorporates the use of direct contact, shell and tube, and air cooled condensers and coolers. Fabrication of the direct contact isobutane boiler will be in accordance with the latest edition of the ASME Boiler and Pressure Vessel Code, Section VIII, Division I, for the requisite design pressures and temperatures (ASME code stamp required). The shell and tube heat exchangers are all to be designed and fabricated in accordance with the latest requirements of the Tubular Heat Exchanger Manufacturers Association, Class "R".

Table 4-3 (Bill of Materials), contains a summary of the important features of these heat exchangers.

The direct contact boiler is depicted in Drawing No. 051-2210. This vessel has been designed for operation at 650 psig and 350 F. The overall size of the vessel has been set at 28" OD (26.75" ID) by 30' in length. These dimensions were determined from the results obtained from the test apparatus operations. The required vessel ID is based on throughput of the fluids and hold up (amount) of isobutane in the vessel. The vessel length was set to satisfy the heat transfer required for heating and boiling the isobutane. Test data has shown that the length required to attain the necessary heat transfer is 30 feet which includes the required volume for placement of inlet devices, sufficient vapor space and vapor separator volume.

The internal vessel equipment consists of inlet flow distribution devices for the brine and isobutane and a vapor separator (mesh pack). The brine inlet device shown in Drawing No. 051-2210 is a full cone spray nozzle as manufactured by SPRAYCO and is designed for a 11.32 psi pressure drop at the design brine flow rate of 100 GPM. This device is removable so that other inlet devices may be tested, such as injection of the brine below the free surface. The isobutane inlet device (dispersion plate) has been designed for an isobutane droplet size of .25" diameter. This device is also removable. The vapor separator is constructed of stainless steel wire grade 316, woven to a density of 7.3 lb/ft², mesh pack thickness is 6". The vessel is supported on a skirt type support of 0.5" wall thickness

6". The vessel is supported on a skirt type support of 0.5" wall thickness

The main condenser (E103) is the largest of the shell and tube condensers. This heat exchanger is a two pass "U" tube, single pass shell design. At an overall heat transfer coefficient of 250 BTU/hr. - F - ft², the surface area required to condense the turbine exhaust is approximately 500 ft². Using 3/8" tubes the resulting overall size is 7' -6" length by 20" shell diameter.

Vent condensers are furnished for each of the following services:

- a. Main condenser (vent condenser (E104))
- b. By-pass condenser (Vent Condenser (E105))

In addition to these heat exchangers, a vent condenser is provided at the stripping column to recover isobutane stripped from the brine outlet of the boiler.

The air cooled exchangers are furnished for condensing and cooling the turbine by-pass vapor flow. The general design characteristics of these units are listed following:

TABLE NO. 4-3
BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: HEAT EXCHANGERS

Page 1 of 1

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
1	ISOBUTANE BOILER	E100	ISOBUTANE BRINE BOILER	DIRECT CONTACT	7405 lbs.	28.00" OD X 360" L	325 psig 350°F	SA 515 GR 70	0.625" WALL CAPPED ENDS
2	STRIPPING COLUMN VENT CONDENSER	E102	CONDENSE ISOBUTANE	SHELL & TUBE	0.2 Ft ²	--	2.5 psia 135°F SHELL	AL.BR. TUBES STEEL SHELL	FRESH WATER COOLING - 90°F
3	MAIN CONDENSER	E103	CONDENSE ISOBUTANE	SHELL & TUBE	500 Ft ²	--	86 psia 150°F SHELL	AL.BR. TUBES STEEL SHELL	FRESH WATER COOLING - 90°F
4	MAIN CONDENSER VENT CONDENSER	E104	CONDENSE ISOBUTANE	SHELL & TUBE	5 Ft ²	--	86 psia 150°F SHELL	AL.BR. TUBES STEEL SHELL	FRESH WATER COOLING - 90°F
5	BY-PASS VENT CONDENSER	E105	CONDENSE ISOBUTANE	SHELL & TUBE	2.5 Ft ²	--	325 psig 220°F	AL.BR. TUBES STEEL SHELL	FRESH WATER COOLING - 90°F
6	BY-PASS CONDENSER	E106	CONDENSE ISOBUTANE	AIR COOLED	410 Ft ²	8'x8' Face area	325 psig 220°F	STEEL TUBES AL. FINS	AIR COOLING 10HP F.D. FAN
7	BY-PASS COOLERS	E107	COOL ISOBUTANE	AIR COOLED	800 Ft ²	8'x16' Face area	325 psig 220°F	STEEL TUBES AL. FINS	AIR COOLING 15HP F.D. FAN

NOTES: 1. ISOBUTANE BOILER FABRICATED IN ACCORDANCE WITH ASME PRESSURE VESSEL 100E, DIV. 1, SECTION VIII, ALL WELDED CONSTRUCTION, FULLY RADIOGRAPHED.
2. E102, E103, E104 HEAT EXCHANGERS FABRICATED IN ACCORDANCE WITH TEMA STANDARDS.

- a. Type - air cooled, forced draft.
- b. Tube size and arrangement - 1" OD, .060" wall steel (ASTM A214), on a 3-3/8" triangular pitch, with aluminum fins at 0.625" height (10 fins per inch).
- c. Overall design U value - condensing and cooling 87.5 BTU/hr F ft .
- d. Static pressure across bundle 0.5" water.
- e. Overall face dimensions - Condenser 8' by 8', cooler 8' by 16'.
- f. Motor size - Condenser 6.5 BHP., cooler 12.5 BHP.

4.3.3 Pumps and Drivers

The general design features of the pumps and drivers for the pilot plant are given in Table 4-4.

The brine and isobutane feed pumps are high speed vertical pumps equipped with suction inducers to meet the low available NPSH requirements. Specific design features of these pumps are listed below:

- a. Type - single stage, vertical, centrifugal
- b. Materials of Construction - carbon steel casing; 316 stainless steel impeller, diffuser, sleeve, and seal parts; 4140 steel shaft.

The brine blowdown and isobutane booster are single stage, horizontal, centrifugal pumps with the same materials of construction as the brine and isobutane feed pumps.

Positive displacement metering type pumps have been specified for the stripping vent condenser pump, make up and fill pumps due to the very low flows for these services. Materials of fabrication are all 316 stainless steel.

The total pumping power required for the pilot plant is 55 BHP.

4.3.4 Controls & Instruments

The control valves and instrumentation required for automatic/manual control of the plant are given in Tables 4-5 and 4-6 respectively.

The materials of construction of the control valves are all 316 stainless steel for those valves in brine service and carbon steel or cast iron for those in isobutane and fresh water service as noted in the table. Linear plugs are specified for those valves in level control service and equal percentage plugs for pressure, temperature or flow control service.

Control valves are furnished for the following services:

- a. Surge vessel level control (geothermal brine supply).
- b. Geothermal brine flow to the boiler (boiler pressure control).

TABLE 4-4
BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: PUMPS

Page 1 of 1

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
1	CENTRIFUGAL PUMP	P100	GEOTHERMAL FEED	VERTICAL		3"x2"	100 GPM 605 Ft TDH	C.S.CASING 316 SS TRIM	RATED AT 120 GPM MOTOR HP = 50
2	CENTRIFUGAL PUMP	P102	ISOBUTANE FEED	VERTICAL			47 GPM 1164 Ft TDH	C.S.CASING 316SS TRIM	RATED AT 56 GPM MOTOR HP = 15
3	CENTRIFUGAL PUMP	P103	BRINE BLOWDOWN	HORIZONTAL		3"x2"	91 GPM 56 Ft TDH	C.S.CASING 316SS TRIM	RATED AT 109 GPM MOTOR HP = 5
4	POSITIVE DISPLACEMENT	P101	VENT CONDENSER	PLUNGER SIMPLEX			2GPH 374 Ft. TDH	All 316 SS CONSTRUCT- ION	RATED 5 GPH MOTOR HP = 1/2
5	POSITIVE DISPLACEMENT	P104	ISOBUTANE MAKE UP	PLUNGER SIMPLEX			0.1 GPH 95 Ft. TDH	ALL 316 SS CONSTRUCT- ION	RATED 0.25 GPH MOTOR HP = 1/2
6	POSITIVE DISPLACEMENT	P105	ISOBUTANE FILL PUMP	PLUNGER SIMPLEX			185 GPH 95 Ft. TDH	ALL 316 SS CONSTRUCT- ION	RATED 222 GPH MOTOR HP = 1/2
7	CENTRIFUGAL PUMP	P106	ISOBUTANE BOOSTER	HORIZONTAL			198 GPM 270 Ft TDH	C.S. CASING 316 SS TRIM	RATED 240 GPM MOTOR HP = 15

NOTES: Pumps to be fabricated in accordance with the Hydraulic Institute Standards.

TABLE 4-5
BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: CONTROL VALVES

Page 1 of 1

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
1	SURGE TANK LEVEL CONTROL	CV100	GEO THERMAL SUPPLY	GLOBE	LINEAR PLUG	2" Ø FLG. 300 LB.ASA	100 GPM $\Delta P = 32.3$	316SS BODY 316SS TRIM	$C_{VDES} = 16.8$
2	MAIN PRESSURE CONTROL	CV101	BRINE TO BOILER	GLOBE	EQUAL PERCENTAGE PLUG	2" Ø FLG. 300 LB.ASA	100 GPM $\Delta P = 20.1$	316SS BODY 316SS TRIM	$C_{VDES} = 21.3$
3	BOILER LEVEL CONTROL	CV102 A	BRINE FROM BOILER	GLOBE	LINEAR PLUG	1" Ø FLG. 300 LB.ASA	91 GRP $\Delta P = 216$	316SS BODY 316SS TRIM	$C_{VDES} = 6.21$
4	BOILER LEVEL CONTROL VALVE	CV102 B	BRINE FROM BOILER	GLOBE	LINEAR PLUG	1½" Ø FLG. 300 LB.ASA	91 GPM $\Delta P = 83$	316SS BODY 316SS TRIM	$C_{VDES} = 10.03$
5	STRIPPER LEVEL CONTROL	CV103	BRINE FROM BOILER	GLOBE	LINEAR PLUG	2½" Ø FLG. 150 LB.ASA	91 GPM $\Delta P = 8.1$	316SS BODY 316SS TRIM	$C_{VDES} = 32.1$
6	BY-PASS CONTROL	CV112	ISOBUTANE FROM TV107	GLOBE	LINEAR PLUG	2" Ø BODY 300 LB.ASA	42,272 lbs./hr $\Delta P = 15$	CS BODY 316SS TRIM	$C_{VDES} = 33.4$ BELLOWS SEAL
7	ISOBUTANE FLOW CONTROL	CV107	ISOBUTANE TO BOILER	GLOBE	EQUAL PERCENTAGE PLUG	1" Ø BODY 300 LB.ASA	47 GPM $\Delta P = 20$	CS BODY 316SS TRIM	$C_{VDES} = 7.7$ BELLOWS SEAL
8	CW FLOW CONTROL	CV108	CW FROM MAIN CONDENSER	GLOBE	EQUAL PERCENTAGE PLUG	4" Ø BODY 150 LB.ASA	407 GPM $\Delta P = 15$	CI BODY	$C_{VDES} = 104.9$

NOTES: C_{VDES} = DESIGN C_V

TABLE 4-6
BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: BOARD MOUNTED INSTRUMENTS

Page 1 of 2

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
1	LEVEL CONTROLLER	LIC 100	SURGE TANK LEVEL	INDICATING CONTROLLER	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-100% LEVEL	PHENOLIC	AUTO/MANUAL SWITCHING W/ HI ALARM
2	TEMPERATURE RECORDER	TR100	PROCESS TEMPERATURE	RECORDING	L & N SPEEDOMAX	12-POINT	0-400°F SCALE RANGE		5 ALARM PER CONTACTS
3	PRESSURE CONTROLLER	PRC100	BOILER PRESSURE	RECORDING CONTROLLER	TAYLOR TRANSSCOPE	4" CHART	0-400 psig	PHENOLIC	AUTO/MANUAL SWITCHING W/HI/LO ALARM CONTACTS
4	LEVEL CONTROLLER	LRC100	BOILER LEVEL CONTROL	RECORDING CONTROLLER	TAYLOR TRANSSCOPE	4" CHART	0-100% LEVEL	PHENOLIC	AUTO/MANUAL SWITCHING
5	FLOW CONTROLLER	FRC100	BRINE TO BOILER	RECORDER	TAYLOR QUICK-SCAN 400 SERIES	6" X 6"	0-150 GPM	PHENOLIC	
6	FLOW CONTROLLER	FRC101	BRINE FROM BOILER	RECORDING CONTROLLER	TAYLOR TRANSSCOPE	4" CHART	0-150 GPM	PHENOLIC	
7	FLOW INDICATING CONTROLLER	RIC100	BUTANE/BRINE RATIO	INDICATING CONTROLLER	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-300 0-150	PHENOLIC	WITH HI-LO CONTACTS
8	LEVEL CONTROLLER	LIC102	BRINE FROM STRIPPER	INDICATING CONTROLLER	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-100%	PHENOLIC	AUTO/MANUAL SWITCHING W/HI & LO ALARM
9	LEVEL CONTROLLER	FRC102	ISOBUTANE TO & FROM BOILER	INDICATING CONTROLLER (2 POINT)	TAYLOR TRANSSCOPE	4" CHART	0-7500 lb/HR 0-300 GPM	PHENOLIC	RECORDING CONTROL ISOBUTANE TO BOILER RECORD ISOBUTANE FROM BOILER
10	LEVEL INDICATOR	LIC104	ISOBUTANE BY-PASS	INDICATING CONTROLLER	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-400 psig	PHENOLIC	AUTO/MANUAL SWITCHING W/HI ALARM CONTACT
11	LEVEL INDICATOR	L1103	VENT CONDENSER LEVEL	INDICATOR	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-100%	PHENOLIC	WITH HI ALARM CONTACT

NOTES:

TABLE 4-6 (cont'd)

BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT EQUIPMENT

EQUIPMENT: BOARD MOUNTED INSTRUMENTS

Page 2 of 2

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
12	INDICATING CONTROLLER	HIC 100	P101 STROKE ADJUSTMENT	INDICATOR LOADER	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-100%	PHENOLIC	
13	FLOW RECORDER	FR 103	VAPOR TO TURBINE	RECORDER	TAYLOR TRANSSCOPE	4" CHART	0-25,000 LBS/HR.	PHENOLIC	
14	LEVEL INDICATOR	LI 104	HOTWELL LEVEL	INDICATOR	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-100%	PHENOLIC	WITH ALARM CONTACTS
15	TEMPERATURE CONTROLLER	TRC 104	CW RETURN TEMPERATURE	INDICATOR CONTROLLER	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-200°F	PHENOLIC	AUTO/MANUAL SWITCHING
16	PRESSURE INDICATOR	PI 102	INSTRUMENT AIR	INDICATOR	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-150 psig	PHENOLIC	WITH LO ALARM CONTACT
17	LEVEL INDICATOR	LI 105	ISOBUTANE STORAGE	INDICATOR	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-100%	PHENOLIC	WITH HI & LO CONTACTS
18	INDICATING CONTROLLER	HIC 101	P104 STROKE CONTROL	INDICATOR LOADER	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-100%	PHENOLIC	
19	INDICATING CONTROLLER	HIC 102	P105 STROKE CONTROL	INDICATING LOADER	TAYLOR QUICK-SCAN	3" X 6" VERTICAL SCALE	0-100%	PHENOLIC	

NOTES: INSTRUMENTS AS SPECIFIED, OR EQUAL.

- c. Boiler level control (two valves in series are required due to the large available pressure drop).
- d. Stripping column level control
- e. Isobutane by-pass, hotwell level control.
- f. Main condenser cooling water temperature control.
- g. Isobutane make up flow control (solenoid valve on/off service).
- h. Isobutane flow control feed to boiler.

Local and board mounted instrumentation is provided so that the plant can be operated either fully automatically or manually from the control board. In addition, manual operators are provided with each valve to allow local manual operation. Board mounted indicating type instruments are of the vertical edgewise type, recorders are of the miniature strip chart type. A twelve (12) point temperature recorder, is also included with the board mounted instruments to automatically monitor critical process temperatures throughout the plant. An annunciator system is also included and equipped to alarm and identify process points that vary from pre-determined set points.

The control panel is a free standing conventional, fully enclosed cabinet suitable for out-of-doors operation. It is fabricated of 3/16" steel plate and equipped with positive forced fan ventilation. A full process mimic diagram is included on the front of the panel.

The local instrumentation includes the necessary pneumatic transmitter, orifice plates, pressure gages, bi-metallic dial thermometers, etc., required to fully monitor plant operation. Tables 4-7 and 4-8 respectively contain the design features of the thermometers and pressure gages.

4.3.5 Piping, Valves and Fittings

The major piping and manual valves for the plant are listed in Table 4-9 and 4-10 respectively.

All piping is to be fabricated and installed in accordance with the ASA code for pressure piping and Pipe Fabrication Institute. Piping shall be schedule 40, carbon steel in accordance with the following:

- a. ½" to 1½" size - seamless, to ASTM A106, Grade B, plain end.
- b. 2" to 10" size - Electric Resistance Welded, to API 5L, Grade B, Open Hearth, beveled ends.

4.4 PROCESS OPERATION

4.4.1 Piping and Instrument Diagram

The piping and instrumentation diagram for the pilot plant is presented in Drawing Nos. 051-6104, 051-2215 and 051-2246. These drawings contain the majority of all equipment, instrumentation, controls, piping and valves, required for the proper installation and operation of the pilot plant. The following paragraphs review the plant operation and the piping and instrument diagram should be referred to while reading these descriptions.

TABLE 4-7

BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: THERMOMETERS

Page 1 of 2

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
1	BRINE SUPPLY	TI 100	GEO THERMAL BRINE	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-400°F 2 1/2" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
2	BRINE TO BOILER	TI 101	GEO THERMAL BRINE	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-400°F 2 1/2" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
3	BRINE FROM BOILER	TI 102	GEO THERMAL BRINE	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-400°F 2 1/2" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
4	BRINE FROM SR-100	TI 103	GEO THERMAL BRINE	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-400°F 6" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
5	BRINE BLOWDOWN	TI 104	GEO THERMAL BRINE	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-400°F 2 1/2" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
6	ISOBUTANE FROM BOILER	TI 105	ISOBUTANE VAPOR	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-300°F 2 1/2" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
7	ISOBUTANE TO BOILER	TI 106	ISOBUTANE LIQUID	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-200°F 2 1/2" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
8	ISOBUTANE BY-PASS		ISOBUTANE VAPOR	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-300°F 4" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
9	E102 VENT	TI 109	ISOBUTANE VAPOR	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-200°F 2 1/4" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
10	CW TO/FROM E102	TI 110 TI 111	FRESH WATER	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-125°F 2 1/2" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
11	P101 DISCHARGE	TI 112	ISOBUTANE LIQUID	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-200°F 2 1/2" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
NOTES: THERMOMETERS AS SPECIFIED OR EQUAL									

TABLE 4-7 (Cont'd)

BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: THERMOMETERS

Page 2 of 2

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
12	COOLING WATER SUPPLY	T1113	FRESH WATER	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-125°F 4" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
13	COOLING WATER SUPPLY & RETURN	T1115 T1116	FRESH WATER	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-125°F 4" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
14	E103 VENT	T1117	ISOBUTANE VAPOR	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-200°F 4"STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
15	MAIN HOTWELL OUTLET	T1119	ISOBUTANE LIQUID	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-200°F 6" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
16	BY-PASS HOTWELL TV107	T1120	ISOBUTANE LIQUID	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-250°F 6" STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
17	E107 COOLER OUTLET	T1121	ISOBUTANE LIQUID	BI-METAL DIAL	ASHCROFT EH	5" DIAL 1/2" NPT BACK	0-250°F 2 1/2"STEM	304SS CASE STEM	GLASS COVER EXTERNAL ADJ.
NOTES:									

TABLE 4-8

BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: PRESSURE GAGES

Page 1 of 2

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
1	BRINE SUPPLY	PI100	GEO THERMAL BRINE	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-200 psig	316SS TUBE & SOCKET	WITH PIGTAIL
2	SURGE TANK	PI101	GEO THERMAL BRINE	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-200 psig	316SS TUBE & SOCKET	WITH PIGTAIL
3	P100 DISCHARGE	PI102	GEO THERMAL BRINE	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-400 psig	316SS TUBE & SOCKET	WITH PIGTAIL
4	BOILER	PI103	GEO THERMAL BRINE	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-400 psig	316SS TUBE & SOCKET	WITH PIGTAIL
5	STRIPPING COLUMN	PI104	GEO THERMAL BRINE	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	150 psig & 30"	316SS TUBE & SOCKET	
6	P103 DISCHARGE	PI105	GEO THERMAL BRINE	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-100 psig	316SS TUBE & SOCKET	
7	BOILER OUTLET	PI106	ISOBUTANE VAPOR	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-400 psi	STEEL TUBE & SOCKET	
8	E102 SHELL	PI107	ISOBUTANE VAPOR	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	150 psig & 30"	STEEL TUBE & SOCKET	
9	P101 DISCHARGE	PI108	ISOBUTANE LIQUID	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-160 psig	STEEL TUBE & SOCKET	
10	ISOBUTANE BY-PASS	PI109	ISOBUTANE VAPOR	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-200 psi	STEEL TUBE & SOCKET	
11	ISOBUTANE TO TURBINE	PI111	ISOBUTANE VAPOR	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-400 psi		

NOTES: PRESSURE GAGES AS SPECIFIED OR EQUAL

TABLE 4-8 (Con't)
BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: PRESSURE GAGES

Page 2 of 2

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
12	E103 SHELL	P1112	ISOBUTANE VAPOR	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-160 psig	STEEL TUBE & SOCKET	
13	INSTRUMENT AIR SUPPLY	P1113	COMPRESSED AIR	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-160 psig	STEEL TUBE & SOCKET	
14	COOLING WATER SUPPLY	P1114	FRESH WATER	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-160 psig	STEEL TUBE & SOCKET	
15	P102 DISCHARGE	P1115	ISOBUTANE LIQUID	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-160 psig	STEEL TUBE & SOCKET	
16	TV102 STORAGE	P1116	ISOBUTANE LIQUID	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-160 psig	STEEL TUBE & SOCKET	
17	P104 DISCHARGE	P1117	ISOBUTANE LIQUID	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-160 psig	STEEL TUBE & SOCKET	
18	P105 DISCHARGE	P1118	ISOBUTANE LIQUID	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-160 psig	STEEL TUBE & SOCKET	
19	BY-PASS HOTWELL TV107	P1119	ISOBUTANE LIQUID	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-400 psig	STEEL TUBE & SOCKET	
20	P106 DISCHARGE	P1120	ISOBUTANE LIQUID	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-400 psig	STEEL TUBE & SOCKET	
21	BY-PASS TO ISOBUTANE FEED	P1121	ISOBUTANE LIQUID	BOURDON TUBE	ASHCROFT 1279	4½" DIAL ¼" BOTTOM	0-400 psig	STEEL TUBE & SOCKET	
NOTES:									

TABLE 4-9

BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: MAJOR PIPING

Page 1 of 2

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
1	WELDED AND FLANGED PIPE		GEO THERMAL	API 5L GR.B, BE	300 LBS. ASA	3" OD SCH.40	150 psig 350°F	CARBON STEEL	470 psig at 700°F MAX. RATING 0.216" WALL
2	WELDED AND FLANGED PIPE		GEO THERMAL SUPPLY	API 5L GR.B, BE	300 LBS. ASA	3" OD SCH.40	350 psig 350°F	CARBON STEEL	470 psig at 700°F MAX. RATING 0.216" WALL
3	WELDED AND FLANGED PIPE		BRINE BLOWDOWN	API 5L GR. B, BE	150 LBS. ASA	3" OD SCH.40	50 psig 150°F	CARBON STEEL	110 psig at 700°F MAX. RATING 0.216" WALL
4	WELDED AND FLANGED PIPE		ISOBUTANE VAPOR FROM BOILER	API 5L GR.B, BE	300 LBS. ASA	2 1/2"OD SCH.40	325 psig 200°F	CARBON STEEL	470 psig at 700°F MAX. RATING 0.203" WALL
5	WELDED AND FLANGED PIPE		ISOBUTANE CONDENSATE TO BOILER	API 5L GR.B, BE	300 LBS. ASA	4" OD SCH.40	350 psig 350°F	CARBON STEEL	470 psig at 700°F MAX. RATING 0.237" WALL
6	WELDED AND FLANGED PIPE		COOLING WATER SUPPLY	API 5L GR.B, BE	125 LBS. ASA	3"-6"OD SCH.40	50 psig 150°F	CARBON STEEL	175 psig at 167°F MAX RATING .216-.280" WALL
7	WELDED AND FLANGED PIPE		COOLING WATER RETURN	API 5L GR.B, BE	125 LBS. ASA	3"-6"OD SCH.40	50 psig 150°F	CARBON STEEL	175 psig at 167°F MAX RATING .216-.280"WALL
8	WELDED AND FLANGED PIPE		INSTRUMENT AIR HEADER	API 5L GR.B, BE	125 LBS. ASA	2"OD SCH.40	100 psig 150°F	CARBON STEEL	150 psig at 150°F MAX RATING 0.154" WALL
9	WELDED AND FLANGED PIPE		VAPOR TO TURBINE	API 5L GR.B, BE	300 LBS. ASA	1 1/2"OD SCH.40	325 psig 220°F	CARBON STEEL	470 psig at 700°F MAX. RATING 0.145" WALL
10	WELDED AND FLANGED PIPE		VAPOR FROM TURBINE	API 5L GR.B, BE	150 LBS. ASA	3"OD SCH.40	70 psig 135°F	CARBON STEEL	110 psig at 700°F MAX. RATING 0.216" WALL
11	WELDED AND FLANGED PIPE		CONDENSATE FROM MAIN CONDENSER	API 5L GR.B, BE	150 LBS. ASA	4"OD SCH.40	70 psig 110°F	CARBON STEEL	110 psig at 700°F MAX. RATING 0.322" WALL

NOTES: Smls. = Seamless

TABLE 4-9 (Con't)
BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: MAJOR PIPING

Page 2 of 2[illegible]

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TABLE 4-10
BILL OF MATERIALS

PROJECT: DCHX PILOT PLANT

EQUIPMENT: MAJOR MANUAL VALVES

Page 1 of 2

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ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
1	P100 SUCTION ISOLATION	V102	GEOTHERMAL BRINE	WEDGE GATE	CRANE NO. 33½ X R	6" Ø BW	300 LB.ASA	CARBON STEEL	COMBINATION TRIM
2	P104 DISCHARGE ISOLATION	V104	GEOTHERMAL BRINE	WEDGE GATE	CRANE NO. 33½ X R	3" Ø BW	300 LB.ASA	CARBON STEEL	COMBINATION TRIM
3	P103 SUCTION ISOLATION	V108	GEOTHERMAL BRINE	WEDGE GATE	CRANE NO. 47½ X R	6" Ø BW	150 LB.ASA	CARBON STEEL	COMBINATION TRIM
4	P103 DISCHARGE ISOLATION	V110	GEOTHERMAL BRINE	WEDGE GATE	CRANE NO. 47½ X R	3" Ø BW	150 LB.ASA	CARBON STEEL	COMBINATION TRIM
5	STRIPPING COLUMN VENT CONTROL	V121	ISOBUTANE VAPOR	GLOBE	VOGT NO. SW-803-8	3/4" Ø SW	600 LB.ASA	CARBON STEEL	F6 + TRIM
6	P101 SUCTION ISOLATION	V113	ISOBUTANE LIQUID	WEDGE GATE	CRANE NO. 3604 X U	3/4" Ø SCRWD.	600 LB.ASA	CARBON STEEL	F6 + TRIM
7	P101 DISCHARGE FLOW CONTROL	V129	ISOBUTANE LIQUID	GLOBE	VOGT NO. SW-803-8	3/4" Ø SW	600 LB.ASA	CARBON STEEL	F6 + TRIM
8	IT100 INLET FLOW	V131	ISOBUTANE VAPOR	GATE	CRANE NO. 3605 XU	1½" Ø SW'	600 LB.ASA	CARBON STEEL	F6 + TRIM
9	V131 BYPASS WARM-UP	V132	ISOBUTANE VAPOR	GLOBE	VOGT.NO. SW-803-8	3/4" Ø SW	600 LB.ASA	CARBON STEEL:	F6 + TRIM
10	COOLING WATER SUPPLY ISOLATION	V117	FRESH WATER	WEDGE GATE	CRANE NO. 465½	6" Ø FLG. FF	125 LB.ASA	CAST IRON	BRASS TRIM
11	COOLING WATER RETURN ISOLATION	V118	FRESH WATER	WEDGE GATE	CRANE NO. 465½	6" Ø FLG. FF	125 LB.ASA	CAST IRON	BRASS TRIM

NOTES. FURNISH AS SPECIFIED OR EQUAL.

TABLE NO. 4-10 (Con't)
BILL OF MATERIALS

PROJECT:

EQUIPMENT:

Page 2 of 2

ITEM	DESCRIPTION	TAG	SERVICE	TYPE	MODEL	SIZE	DESIGN CONDITIONS	MATERIALS	REMARKS
12	P102 SUCTION ISOLATION	V119	ISOBUTANE LIQUID	WEDGE GATE	CRANE NO. 47½ x R	8" ø BW	150 LB.ASA	CARBON STEEL	COMBINATION TRIM
13	P102 DISCHARGE ISOLATION	V121	ISOBUTANE LIQUID	WEDGE GATE	CRANE NO. 33½ x R	4" ø BW	300 LB.ASA	CARBON STEEL	COMBINATION TRIM
14	MAIN CONDENSER VENT	V136	ISOBUTANE VAPOR	GLOBE	VOGT NO. SW-803-8	1" ø SW	600 LB.	CARBON STEEL	F6+ TRIM
15	BY-PASS INLET	V131	ISOBUTANE VAPOR	WEDGE GATE	CRANE NO. 33½ X R	3" ø BW	300 LB.ASA	CARBON STEEL	COMBINATION TRIM
16	P106 SUCTION	V132	ISOBUTANE LIQUID	WEDGE GATE	CRANE NO. 33½ X R	4" ø BW	300 LB.ASA	CARBON STEEL	COMBINATION TRIM
17	PUMP DOWN LINE	V137	ISOBUTANE LIQUID	GLOBE	VOGT SW-803-8	2" ø SW	600 LB.ASA	CARBON STEEL	F6+ TRIM
18	P100 PUMP DISCHARGE	NR100	GEO THERMAL BRINE	SWING CHECK	CRANE NO. 159½ X	3" ø BW	300 LB.ASA	CARBON STEEL	F6 TRIM
19	P103 PUMP DISCHARGE	NR101	GEO THERMAL BRINE	SWING CHECK	CRANE NO. 147½ X	3" ø BW	150 LB.ASA	CARBON STEEL	F6 TRIM
20	P101 PUMP DISCHARGE	NR102	ISOBUTANE LIQUID	BALL CHECK	VOGT NO. SW5-4853-8	3/4" ø SW	600 LB.ASA	CARBON STEEL	F6 TRIM
21	P102 PUMP DISCHARGE	NR106	ISOBUTANE LIQUID	SWING CHECK	CRANE NO. 159½ X	4" ø BW	300 LB.ASA	CARBON STEEL	F6 TRIM

NOTES: FURNISH AS SPECIFIED OR EQUAL

- GENERAL NOTES**
1. ALL PNEUMATIC DISTRIBUTION LINES ARE 1/2" COPPER TUBING.
 2. ALL PRESSURE GAGE LINES ARE 1/2" CARBON STEEL SPEC. B.
 3. SEE SYMBOL SHEET FOR ABBREVIATIONS DWG. NO. 051-6104.
 4. LEVEL GAGE & LEVEL CONTROL LINES 3/4" CARBON STEEL SPEC. B.

REVISIONS

DSS ENGINEERS, Inc.			
FORT LAUDERDALE, FLORIDA			
APPROVALS		TITLE	
DRAWN	P.S.	DATE	7-2-77
CHECKED	MORIN	DATE	2/7/77
MECH	WILSON	DATE	2/7/77
ELECT			
CIVIL			
PROJECT MANAGER		DRAWING NO.	
		051-6104	
P. E. REG. NO.		SCALE	
		NONE	
		SHEET	
		1 OF 3

GENERAL NOTES
REFER TO SHEET NO. 1 FOR NOTES.

REVISIONS

DSS ENGINEERS, Inc.			
FORT LAUDERDALE, FLORIDA			
APPROVALS		TITLE	
DRAWN	P.S.	DATE	2/17/77
CHECKED	O.J. MOEN	DATE	2/17/77
RECH		DATE	2/17/77
ELECT			
CIVIL			
PROJECT MANAGER		DRAWING NO.	
		051-6104	
P.E. REG. NO.		SCALE	
		NONE	
		SHEET	
		2 OF 3	

GENERAL NOTES
REFER TO SHEET NO. 1 FOR NOTES

LEGEND
--- = EXISTING
— = NEW
AS = FROM AIR SUPPLY

REVISIONS

APPROVALS			TITLE P&I DIAGRAM DCHX PILOT PLANT-110°F CONDENSING
DRAWN	P.S.	DATE 7-7-76	
CHECKED	OT MOON	DATE 2/1/77	
RECH	OT MOON	DATE 2/1/77	
ELECT			
CIVIL			
PROJECT MANAGER			DRAWING NO. 051-6104
P.E. REG. NO.			SCALE NONE SHEET 3 OF 3

The turbine inlet design operating condition is 260 F at 497 psia. This operating condition is to be maintained at brine flowrates from 20% to 100% of design and will be accomplished by varying the heat input (geothermal brine supply) while at the same time adjusting the isobutane flowrate to the boiler. This is accomplished by the master pressure controller PRC-100. During normal operation, the turbine governor will adjust the turbine control valves (isobutane flow to the turbine) dependent upon generator load. The master pressure controller interprets changes in turbine/generator load then, as pressure changes and adjusts both the brine flowrate and isobutane flowrate to the boiler. A ratio relay controller assures that the isobutane flowrate is larger than the brine flowrate. It is important that when boiler load increases that the geothermal brine flow lead the isobutane flow and the opposite occurs on load decreases. Instrumentation is provided to accomplish this (not shown on the piping and instrument diagram). This procedure must be followed to assure that all butane entering the boiler is subsequently vaporized.

The boiler level is automatically controlled by the geothermal brine outlet control valves CV102A and CV102B. Two valves have to be furnished to meet the severe pressure drop to be absorbed between the boiler and stripping column operating pressure. Separate level switches are provided at the level controller to alarm if level exceeds pre-selected high or low limits.

Normal load changes are not anticipated as being rapid and will approximate normal load changes as experienced in conventional power plant installations. As mentioned above the control system is capable of maintaining automatic control between the range 20% to 100%. However, the brine and isobutane feed pumps selected can not be continuously operated below approximately 35% of design capacity. This will therefore, limit the actual operating range.

Emergency shut down is provided and arranged to be activated either in the automatic or manual mode. This system when activated secures all control valves and pump motors. In the automatic mode the shut down is initiated by PS100 shown in Drawing No.051-6104 of the piping and instrument drawing. Normal operational sequence will be:

- a. Alarm only on high pressure exceeding approximately 490 psig.
- b. Secure plant on high pressure exceeding 500 psig.

The 500 psig setting will be below the safety valve settings to prevent loss of isobutane due to high pressure operation.

Flow to the vapor by-pass system is controlled by level in the by-pass hotwell. Final temperature of the by-pass flow will be regulated by air damper control on the by-pass cooler.

The cooling water flow to the main condenser will be automatically controlled by the temperature of the isobutane condensate leaving the main condenser.

4.4.3 Vent Systems

In any condensing heat exchanger, the condensing side must be continuously vented of non-condensable gases or the resultant buildup of these products will seriously limit overall heat transfer. To prevent this, condensers are vented, normally to the atmosphere, assuming such loss is not detrimental to process economics. In the case of the pilot plant, these losses would be substantial and seriously affect the operating economics. For example, in a conventional steam condenser, design venting flow rates will be in the order of .5 to 1.0 percent of condensed liquid. In the pilot plant by-pass condenser, this represents a minimum isobutane loss of 210 lbs/hour or over \$116,000.00/year. The vent condenser (E105) provided for the bypass condenser reduces this loss to approximately 1 lb/hr.

4.4.4 Isobutane Make-up System

The isobutane make-up system is depicted in Drawing No.051-6104 of the piping and instrument diagram. The make up system is composed of a storage tank TV102, a make-up pump P104 and start up/emergency fill pump P105.

During normal operation, the required isobutane make up will be transferred from the storage tank to the hotwell (RV106) via the make up pump P104. The system provided is an on/off type, energized by level control switches mounted on the hotwell. At a pre-determined low hotwell level control valve CV109 and the make up pump are simultaneously energized. The make up pump continues to pump until it is de-energized by the high level cut off switch. The normal make up rate will be 0.30 gallons per hour and the pump has been sized at approximately twice this value.

Pump P105 has been provided for start-up (plant filling) and to satisfy periods where large isobutane flows will require flow rates in excess of normal make-up pump flow capacity. This pump has been sized at 5 GPM.

4.4.5 Plant Draining

There will be periods when, due to inspection, maintenance, etc., it will be desirable to drain the unit of all brine and isobutane. To prevent the loss of butane, a drain system (identified as pump down system on the piping and instrument diagram) has been provided. Its operation is discussed below.

With the unit secured, isobutane is drained from the boiler by opening either V106 or V107 as appropriate, allowing isobutane to drain to the main hotwell. This fluid can then be pumped to the storage tank by the isobutane feed pump P102 via, CV137. Isobutane in the bypass system can be pumped to the storage tank by the isobutane booster pump. The remaining vaporous isobutane would then be vented through the vent vessel TV103.

4.5 EQUIPMENT LAYOUT AND ARRANGEMENT

4.5.1 General

The plant layout is shown on the general arrangement drawings, plan and elevation views, Drawing Nos. 051-2215 and 051-2216, respectively.

DSS ENGINEERS, Inc.			
FORT LAUDERDALE, FLORIDA			
APPROVALS		TITLE	
DRAWN	P.S.	DATE	3/7/77
CHECKED	OTMORIN	DATE	3/7/77
MECH	OTMORIN	DATE	3/7/77
ELECT			
CIVIL			
PROJECT MANAGER		DRAWING NO.	051-2215
P.E. REG. NO.		SCALE	AS NOTED

DSS ENGINEERS, Inc.			
FORT LAUDERDALE, FLORIDA			
APPROVALS		TITLE	
DRAWN	P. S.	DATE	3/23/77
CHECKED	J. MORIN	DATE	3/17
MECH	J. MORIN	DATE	3/17
ELECT			
CIVIL			
PROJECT MANAGER		DRAWING NO.	051-2216
P. E. REG. NO.		SCALE	AS NOTED
		SHEET	1 OF 1

The total plan area required by the pilot plant is 2360 ft² (38 feet wide by 62 feet in length). This plant size will "fit" on any one of the designated test pads at the East Mesa Test Facility (test pads at 40' by 80'). The vent vessel should be mounted off the test pad at a minimum distance of 25 feet from the unit proper.

The plan view shows the control panel location 25 feet from the unit since it would be impractical to fabricate this panel and equipment to meet explosion proof requirements.

The elevation view shows the unit arranged in two decks above the grade elevation. The elevation of the main and by-pass hotwells is fixed by the net positive suction head (NPSH) requirements of the pumps for these services. In this case each pump will require an NPSH availability of approximately 10 feet (above pump centerline). This results in locating the hotwell operating level at 12' -0". The turbine/generator, main condenser and bypass condenser are mounted above the hotwell. Access to these operating platforms is provided by stairways.

All locally mounted level controllers, level gages, thermometers and pressure gages are arranged for viewing from the south side (control panel side) of the unit to facilitate plant operations. Control valves are arranged for easy access for maintenance purposes.

4.6 COST ESTIMATE

4.6.1 Equipment Costs

The equipment cost estimate was prepared from actual equipment quotations and reliable cost estimating procedures. An average of three (3) quotations were received for each item of equipment. Table 4-11 contains the equipment cost estimate for the 250 Kw unit and Table 4-12 for the 500 Kw unit. The costs shown are FOB manufacturer's plant.

In addition to the equipment shown in the table, quotations were also obtained for control valves and instrumentation. This equipment does not appear in the table as it is considered to be field installation material, and is included in the total cost estimate.

4.6.2 Capital Cost Estimate

The total cost estimate is based on the module concept of cost estimating. Each module includes the cost of the equipment (FOB) together with the requisite field installation materials, direct field labor for installation and indirect construction costs. Modules are then combined to determine the total estimated capital cost. Table 4-13 contains the cost estimate summary for the 250 Kw unit and Table 4-14 for the 500 Kw unit.

The major factors and considerations that were used in compiling the cost estimate are discussed below:

- a. Major Process Equipment - The cost of this equipment was estimated based on quotations from equipment manufacturers as discussed above.

TABLE 4-11
250KW PILOT PLANT DESIGN
EQUIPMENT COST SUMMARY

<u>TAG</u>	<u>EQUIPMENT</u>	<u>COST (\$)</u>
E100	Direct Contact Boiler	\$ 15,180
TV101	Surge Vessel	4,340
SR100	Isobutane Stripping Column	3,900
E103	Main Condenser	9,400
E102	Stripping Column Vent Condenser	100
E104	Main Condenser Vent Condenser	350
E105	By Pass Vent Condenser	350
TV106	Main Condenser Hotwell	2,780
TV102	Isobutane Storage Tank	3,350
E105	By Pass Condenser	6,400
TV107	By Pass Hotwell	3,950
E107	By Pass Cooler	12,500
P100	Geothermal Brine Feed Pump	6,100
P103	Geothermal Brine Blowdown Pump	1,560
P102	Isobutane Feed Pump	7,000
P106	Isobutane Booster Pump	3,670
P104	Isobutane Make Up Pump	1,170
P105	Isobutane Emergency Make Up Pump	2,400
P101	Stripping Column Vent Pump	1,500
TV103	Vent Vessel	650
		<hr/>
		\$ 86,650

TABLE 4-12
500 kW PILOT PLANT DESIGN
EQUIPMENT COST SUMMARY

<u>Tag</u>		
E-101	Heater/Boiler	20,792
TV-100	Stripping Column	4,434
TV-101	Surge Vessel	4,175
TV-102	I/B Storage	4,218
TV-103	Vent Vessel	766
TV-106	Main Hot Well	5,078
TV-107	Knockout Drum	1,926
E-102	Vent Condenser	3,495
E-103	Trim Condenser	13,185
E-106	Air Cooler @ 80°F (Water cooled \$32,000 less)	76,700
E-107	Isobutane Cooler	900
P-101	Brine Feed, 196 GPM @ 998' TDH	11,524
P-102	Isobutane Feed 307 GPM @ 1860' TDH	17,204
P-103	Brine Blow-down, 176 GPM @ 60' TDH	3,000*
P-104	Isobutane Make-up, 1.0 GPH @ 81 psi	1,500
P-105	Isobutane Fill, 4.2 GPM @ 80 psi	1,500
TOTAL EQUIPMENT		<u>170,397</u>

* Estimates

TABLE 4-13
PILOT PLANT DESIGN

COST ESTIMATE SUMMARY
(250KW)

TOTAL EQUIPMENT COSTS (FOB Mfgs. Plant)	86,650	
TOTAL CONSTRUCTION MATERIALS*	<u>92,240</u>	
TOTAL EQUIPMENT & MATERIALS		<u>178,890</u>
INSTALLATION DIRECT LABOR*	65,950	
INSTALLATION INDIRECT COSTS*	<u>70,700</u>	
TOTAL LABOR & INDIRECTS		<u>136,650</u>
TRANSPORTATION	16,870	
CONTRACTORS' FEE (3%)	9,900	
START UP EXPENSES	30,000	
CONTINGENCY (10%)	<u>33,100</u>	
TOTAL OTHER COSTS		<u>89,870</u>
TOTAL INSTALLED COST 1977		<u>405,410</u>
ESCALATION TO END 1978 (7%)		<u>28,300</u>
TOTAL INSTALLED COST 1978		<u>433,710</u>

*Includes Turbine/generator foundations and installation, but not equipment cost.

TABLE 4-14

500 KW PILOT PLANT DESIGN

CONSTRUCTION COST SUMMARY

Total Main Equipment Cost	\$ 171,000	
Control Valves	8,000	
Instr., Controls & Control Valves	52,000	
Starters & Electrical Controls	22,000	
Piping, Manual Valves & Struct. Mat.	<u>96,000</u>	
Total Material Costs		\$ 349,000
Shop Fabrication & Assembly		150,000
Field Installation, Labor & Material		75,000
Equipment & Material Transportation		20,000
Miscellaneous & Contingency		<u>60,000</u>
Total Costs Ready for Start-up		\$ <u>654,000</u>

Notes:

1. Above based on shop fabricated modules
2. Cost of Turbine Generator and associated controls not included but installation labor and materials is included
3. Costs are based on completing work by October, 1978

4.6.2 Capital Cost Estimate (Con't)

- b. Construction Materials - This is the material required for the installation of the equipment at site and includes the following:

- .piping, valves and fittings
- .control valves
- .instrumentation
- .electrical
- .civil work (foundations, no piling and major steel work)
- .insulation
- .painting

In large dollar magnitude projects, construction materials normally range from 50% to 75% of equipment costs, with the norm being 68%. For the pilot plant, construction materials averaged 107.2% of equipment costs. This resulted in the main from:

- .High instrumentation costs in proportion to total equipment cost. In the normal module, instrumentation costs will range from 3% to 12%, of equipment costs, whereas the pilot plant instrumentation is 10% to 40%. This high ratio will decrease to normal levels with increases in plant size.

- .Turbine/generator installation (equipment costs not included).

- c. Direct Construction Labor - Direct field labor normally represents from 54% to 66% of total equipment costs. The norm being 58%. The pilot plant direct labor will be 77% of equipment costs. This is due primarily to the high proportion of vertical pressure vessel installation (direct labor rate of 99% of equipment costs) and the turbine/generator installation.

The construction labor for the pilot plant has been estimated at 172 man weeks. This is based on an average hourly direct labor rate of \$8.88 and assumes a 40 hour work week.

- d. Construction Indirects - This item includes all contractor costs for construction engineering and procurement, field supervision, and general overhead expenses. Construction overhead is based on 20% of direct material and labor costs, made up as follows:

Fringe Benefits	2.6
Labor Burden	4.0
Field Supervision	5.2
Temporary Facilities	1.6
Construction Equipment	2.6
Small Tools	0.6
Miscellaneous	3.4
Total Construction Overhead	20.01

Contractor engineering is based on 11% of direct material and labor costs and is composed of engineering direct labor; construction and office indirects and overhead.

- e. Transportation and Insurance - This item was estimated at 9% of equipment and construction materials costs. No sales or use tax is included.
- f. Start-up Costs - Initial start-up has been assumed at one month's time. The costs shown include contractors' labor, materials and consumables.
- g. Escalation - Escalation was assumed at 7% per year. A cost break-down has been presented in Tables 4-15 through 4-18. Costs for each section of work have been included. Review of the data presented in Tables 4-15 through 4-18 reveals that the costs are made up as follows:

<u>Item (installed)</u>	<u>% Total</u>
Vessels (includes boiler)	34%
Heat exchangers	20%
Pumps and Drivers	20%
Miscellaneous Equipment	8%
Other Costs	18%
	<u>100%</u>

TABLE 4-15

PILOT PLANT DESIGN

COST ESTIMATE

VESSELS

<u>ITEM</u>	<u>FOB COST</u>	<u>FIELD MATERIALS</u>	<u>DIRECT LABOR</u>	<u>INDIRECT COST</u>	<u>TRANS. COST</u>	<u>TOTAL COST</u>
1. Boiler E100	15,180	21,140	15,060	14,530	3,270	69,180
2. Surge Vessel TV101	4,340	6,020	4,340	4,150	930	19,780
3. Stripping Column SR100	3,900	5,430	3,870	3,650	840	17,690
4. Main Condenser Hotwell TV106	2,780	2,940	1,700	1,920	520	9,860
5. Isobutane Storage TV102	3,350	3,540	2,050	2,320	620	11,880
6. By-Pass Hotwell TV107	3,950	4,160	2,410	2,710	730	13,960
7. Vent Vessel TV103	650	680	400	440	120	2,290
TOTAL	34,150	43,910	29,830	29,720	7,030	144,640

TABLE 4-16

PILOT PLANT DESIGNCOST ESTIMATEHEAT EXCHANGERS

<u>ITEM</u>	<u>FOB COST</u>	<u>FIELD MATERIALS</u>	<u>DIRECT LABOR</u>	<u>INDIRECT COST</u>	<u>TRANS. COST</u>	<u>TOTAL COST</u>
1. Main Condenser E103	9,400	10,170	5,920	6,700	1,760	33,950
2. SR100 Vent Condenser E102	100	110	60	70	20	360
3. E103 Vent Condenser E104	350	380	220	250	70	1,270
4. By-Pass Condenser E106	6,400	2,940	2,040	3,100	840	15,320
5. By-Pass Cooler E107	12,500	5,740	3,980	6,060	1,640	29,920
6. E-106 Vent Condenser E105	350	380	220	250	70	1,270
TOTALS	29,100	19,720	12,440	16,430	4,400	82,090

TABLE 4-17

PILOT PLANT DESIGNCOST ESTIMATEPUMPS & DRIVERS

<u>ITEM</u>	<u>FOB COST</u>	<u>FIELD MATERIALS</u>	<u>DIRECT LABOR</u>	<u>INDIRECT COST</u>	<u>TRANS. COST</u>	<u>TOTAL COST</u>
1. Geothermal Feed Pump P100	6,100	5,040	4,250	4,500	1,000	20,890
2. Brine Blowdown Pump P103	1,560	1,290	1,090	1,150	260	5,350
3. Isobutane Feed Pump P102	7,000	5,780	4,880	5,160	1,150	23,970
4. Isobutane Booster Pump P106	3,670	3,030	2,560	2,700	600	12,560
5. Isobutane Make-up Pump P104	1,170	970	820	860	190	4,010
6. IB.Emergency/Fill Pump P105	2,400	1,980	1,670	1,770	390	8,210
7. Vent Condenser Pump P101	1,500	1,240	1,050	1,110	250	5,150
TOTALS	23,400	19,330	16,320	17,250	3,840	80,140

TABLE 4-18

PILOT PLANT DESIGN

COST ESTIMATE

MISCELLANEOUS

<u>ITEM</u>	<u>FOB COST</u>	<u>FIELD MATERIALS</u>	<u>DIRECT LABOR</u>	<u>INDIRECT COST</u>	<u>TRANS. COST</u>	<u>TOTAL COST</u>
1. Turbine/Generator Install.	--	8,260	6,970	7,280	1,640	24,150
2. Platforms/Stairways	--	2,940	1,760	1,340	260	6,300
TOTALS	--	11,200	8,730	8,620	1,900	30,450

APPENDIX A

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