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TEST RESULTS FROM THE 500 kW DIRECT CONTACT PILOT PLANT AT EAST MESA

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MASTER

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Kenneth E. Nichols, Robert G. Olander and James L. Lobach
Barber-Nichols Engineering Company
Arvada, Colorado 80002

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REA

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Kenneth E. Nichols, Robert G. Olander
and James L. Lobach

Barber-Nichols Engineering Company
Arvada, Colorado 80002

ABSTRACT

A 500 kW power plant utilizing direct contact heat exchange (DCHX) between the geothermal brine and the isobutane (IC_4) working fluid is being operated at the East Mesa test facility. The power plant incorporates a 40-inch-diameter direct-contactor approximately 35 feet tall. The purpose of the pilot plant is to determine the feasibility of large-scale direct-contact heat exchange and power plant operation with the DCHX. The binary cycle offers higher conversion factors (heat energy transformed to electrical energy) than the flashed steam approach for geothermal brines in the 300°F to 400°F range and preliminary results indicate the DCHX system may have higher performance than the conventional tube-and-shell binary approach. This performance advantage results from the absence of any fouling and the very close pinch temperatures achieved in the DCHX itself.

The baseline performance tests for the plant were completed in January, 1980. The results of these tests and follow-on testing are covered in this summary. A complete description of the plant is presented in References 1 and 2.

INTRODUCTION

The pilot plant is to be used to establish design criteria for large direct contactors and evaluate the overall performance levels of direct contact binary power systems. The pilot plant includes all of the significant functions felt to be necessary in a complete direct contact binary power plant. The system includes a downhole pump to provide unflashed brine to the plant, a brine conditioning module used to eliminate excess undissolved gases that may be in the brine, a direct-contact heat exchanger, a power turbine and generator, condensers and reservoir for the working fluid and a recovery system to control the working-fluid losses in the effluent brine.

Testing began with the downhole REDA pump and continued through the brine delivery system including the sand trap and brine pump. The DCHX and hydrocarbon loop was then operated with vapor flow bypassing the power turbine module. During this period the instrumentation and control loops were set up and checked out and operator training was initiated. Safety systems such as the hydrocarbon gas detectors, fire system and vent systems were completely checked during this phase of testing.

Preliminary performance data were obtained for the hydrocarbon and brine pumps, DCHX, and condensers. The head and flow rates produced by the pumps were proper to support operation of the power plant. The brine temperature delivered to the plant by well 8-1 was 326°F, which is 14° below the design value of 340°F. At this lower brine temperature the DCHX met or exceeded performance specifications. At design brine flow rates (225 gpm), pinch temperature differences between the brine and isobutane were in the range of 1 or 2°F. This result indicates that high-performance direct-contact spray columns in this size range can be accomplished. The evaporative condensers showed no problem in providing design heat-transfer rates at reasonable temperature differences between ambient wet bulb and condensing isobutane.

PLANT PROCESS AND PERFORMANCE

The process flow diagram and selected cycle state points are shown in Figure 1. The plant brings the 340°F incoming brine through a sand and CO_2 separating vessel. The brine boost pump then increases the pressure of the brine to 453 psia for injection into a spray column configuration DCHX. The brine is cooled to 145°F and, after passing through a working-fluid recovery system, is returned to a facility pond for re-injection. The isobutane working fluid is pumped from the hotwell to a pressure of 485 psia for injection at the bottom of the DCHX. As the IC_4 flows to the top of the DCHX through the descending brine, the IC_4 is heated to a temperature of 250°F, boiled, superheated to a temperature of 255°F, and taken off the top of the heat exchanger as a vapor. The IC_4 vapor, along with small amounts of water vapor, passes through a single-stage radial-inflow turbine and to the condenser where the mixture is condensed at a temperature of 94°F and then returned to the hotwell. The hotwell separates the water and IC_4 liquid phases. The water fraction is directed to the recovery system and the IC_4 returns to the feed pump, completing the cycle.

A study of thermodynamic cycles for this direct contact geothermal pilot plant was made during the design definition of this pilot plant (Ref. 2). The fluids examined were isobutane, isopentane, and N-pentane. Isobutane showed the highest utilization factor at brine temperatures of 340°F.

The 500 kW pilot plant was designed to produce a net output of 500 kW with a brine inlet temperature of 340°F at an ambient wet-bulb temperature of 64°F. Total plant parasitic losses were calculated to be 306.9 kW, resulting in a gross plant output of 806.9 kW. Design brine flow rate is 222 gpm, resulting in a predicted net plant output of 5.1 watt-hr/lb of brine. The power levels developed for the plant and its components are:

Component	Efficiency	kW
Condensers		77.7
IC_4 organic pump	$\eta_p = 75\%$	
	$\eta_m = 90\%$	96.7
Brine pump	$\eta_p = 76\%$	
	$\eta_m = 90\%$	54.4
Discharge pump	$\eta_p = 70\%$	
	$\eta_m = 85\%$	2.1
Recovery system		15.0
	Subtotal	245.9
Gearbox	$\eta_{gb} = 97\%$	
Alternator	$\eta_{alt} = 95\%$	61.0
	Subtotal	306.9
Power turbine	$\eta = 83\%$	776.7
Hydraulic turbine	$\eta = 81\%$	30.2
	Total output	806.9
	Net output	500.0 kW

Three major factors influencing plant performance and cost are 1) the control of noncondensibles that contaminate the power cycle condenser, 2) the equipment required to limit working-fluid losses, and 3) the control of scaling or performance robbing deposits in critical components. These factors are not unrelated and control of one often impacts control of the other two. The 500 kW pilot plant has been designed to investigate and demonstrate viable solutions to all three factors.

MAJOR COMPONENT DESCRIPTION

The DCHX configuration is one of a spray tower, with the hot (335°F) brine injected at the top of the vessel and allowed to flow to the bottom, forming a continuous column of liquid approximately 30 feet high. Cold isobutane (94°F) is injected near the bottom of the vessel through a perforated plate, forming small "bubbles" of dispersed liquid. The isobutane is less dense and only sparingly soluble in the surrounding brine, and these droplets rise through the column absorbing heat through direct contact. Preheating, boiling, and superheating of the isobutane all take place in the same vessel.

If the downward velocity of the brine exceeds the rising droplet velocity, the IC_4 is swept out the bottom of the DCHX with the exiting brine. This carryunder condition is avoided through judicious selection of the vessel diameter. Based on available correlations of holdup (defined as the column fraction occupied by IC_4) and carryunder, an inside column diameter of 40 inches was selected. This diameter is expected to yield an actual holdup equal to 90% of the holdup that occurs just prior to carryunder conditions.

The IC_4 power turbine configuration is a radial inflow design operating at 25,000 rpm. The impeller is 7.75 inches in diameter and the predicted efficiency is 0.83 at the design conditions. The turbine is provided with variable area nozzles. At a constant inlet pressure, flow rates of 60% to 120% of design can be accommodated with small changes in turbine efficiency. The turbine wheel is mounted directly on the high speed shaft of the gearbox, thereby eliminating any additional bearings and couplings.

The vapor mixture (IC_4, steam, and CO_2) leaving the DCHX, and thence the turbine, is returned to liquid by means of an evaporative condenser. An evaporative condenser is similar to a cooling tower with the cooling tower core replaced by the condensing coil. Working fluid vapor is condensed to liquid inside the condensing coil, the outside of which is continually wetted by a recirculating water system. Air is simultaneously blown upward over the coil causing a small portion of the recirculated water to evaporate. This evaporation removes heat from the coil, thereby cooling and condensing the working fluid vapor inside the coil. The evaporative condenser has lower parasitic power requirements and lower capital costs than the cooling tower approach.

The IC_4 recovery system is designed to remove 95% of the dissolved isobutane from the brine stream exiting the DCHX and return it to the hotwell. A two-stage flash operation is employed to separate the IC_4 from the brine stream. The flashed vapors are compressed and then cooled to recondense the IC_4.

TEST RESULTS

An electric submersible downhole pump was used to supply brine to the 500 kW plant. The pump was installed and started November 17, 1979. Except for a few intermittent power outages, the pump operated continuously for 5 months and 20 days. The pump then failed for causes not determined at the time of this writing. The downhole temperature is estimated to be approximately 350°F.

Based on measured flow rates, inlet and outlet conditions and column temperatures, the DCHX performed better than expected. Overall heat balances between brine cooling and IC_4 heating were very good, being within 2-3% in most cases. The most significant aspect of the data is the indicated low pinch temperature achieved over the entire operating flow rates. While the expected pinch temperature at plant design was estimated to be 7°F, the pinch temperature calculated at the actual conditions ranged from 1.1°F at high brine flow rates (Figure 2) to 3.7°F at low brine flow rates. No attempt was made during the first tests to flood the column to determine its operating limits. The close pinch temperatures achieved indicate that very little back mixing exists and that the flow is very stable in the 40 inch diameter column.

The close approach temperature demonstrated by this DCHX design offers the potential for high utilization factors for the DCHX binary system. Since fouling cannot occur in the DCHX, this high performance potential should exist for extended periods. Continuing testing will establish the limits for this DCHX design.

The turbine-generator was initially started January 15, 1980, for a total run time of 13.5 hours. During the preliminary plant runs, the generator output power was not measured directly due to instrumentation problems. A coarse measurement of output was made by monitoring generator amperage. These values appeared reasonable during the first startup.

The evaporative condenser performance was evaluated based on the heat transfer and the measured condensing temperature. The heat transfer performance is a function of hardware design and also the non-condensibles existing in the vapor stream. Figure 3 shows the condenser performance plotted as the ΔT between condensing wet bulb temperature versus heat load. The wet and bulb temperatures ranged from 48° to 54°F during these tests. The data indicates that the condensers were able to dissipate their heat at lower condensing temperatures than expected, thus exceeding their design performance.

The components in the recovery system performed functionally to expectation. The recovery compressor maintained the recovery flash tank at the 5 psia design level even with higher than 50 ppm design value of CO_2 in the effluent brine. The acutal performance level achieved by the recovery system will be determined in the follow on test series presently underway.

A more detailed discussion of this entire test program is contained in the final report, Reference 3.

ACKNOWLEDGEMENTS

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1. Barber-Nichols Engr. Co., "Direct Contact Heat Exchanger, 10 kW Power Loop," Lawrence Berkeley Laboratory, LBL-7036, July, 1979.

2. Barber-Nichols Engr. Co., "Design Definition of a 500 kW Direct Contact Geothermal Pilot Plant," Lawrence Berkeley Laboratory, UCID 8009, March, 1978.

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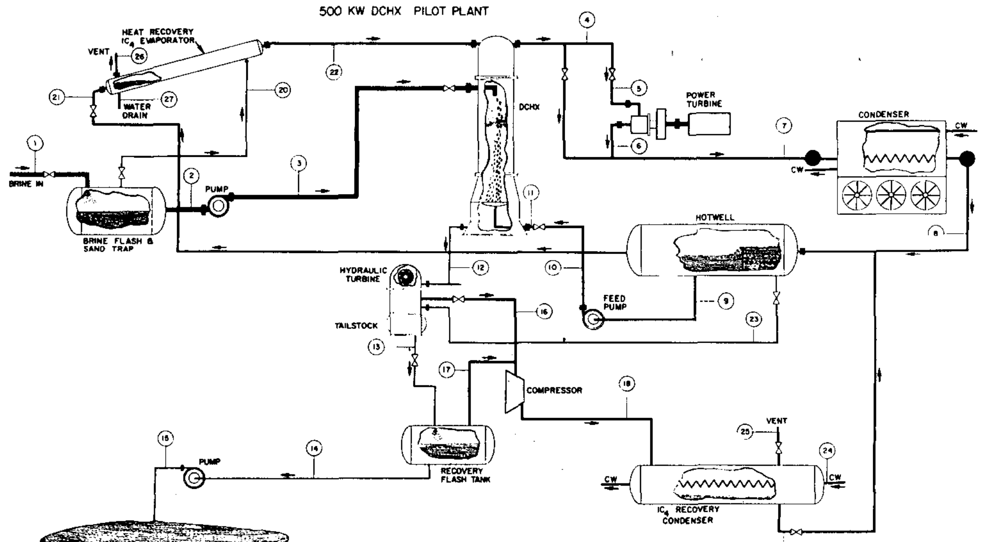
Fig. 1

PROCESS FLOW DIAGRAM

500 KW DCHX PILOT PLANT



MATERIAL BALANCE

PROCESS STREAM NUMBER

PARAMETER \ STREAM	1 GEOTHERMAL BRINE SUPPLY	2 GEOTHERMAL BRINE TO BOOST PUMP	3 GEOTHERMAL BRINE TO DCHX	4 ISOBUTANE VAPOR FROM DCHX	5 ISOBUTANE VAPOR TO TURBINE	6 ISOBUTANE VAPOR TO CONDENSER	7 CONDENSER INLET	8 ISOBUTANE CONDENSATE TO HOTWELL	9 ISOBUTANE LIQUID TO FEED PUMP	10 ISOBUTANE LIQUID FROM FEED PUMP	11 ISOBUTANE LIQUID TO DCHX	12 GEOTHERMAL BRINE FROM DCHX	13 GEOTHERMAL BRINE FROM HYD. TURBINE	14 RETURN BRINE
FLOW RATE (lb/hr x 10^3)	97.8	97.2	97.2	99.4	99.4	99.4	99.4	99.4	98.0	98.0	95.4	95.8	97.2	97.2
TEMPERATURE (°F)	340	335	335	255	253.4	140.6	140.6	94.0	94.0	95.0	95.0	148.8	144.8	144.8
PRESSURE (PSIA)	175	118	485.0	452.7	442.7	72.0	71.6	70.0	70.0	485	467	457	17.0	5.0
ENTHALPY (BTU/LBM)	311.4	306.1	306.6	-581.0	-581.0	-607.7	-607.7	-776.1	-788.9	787.2	787.2	114.1	112.98	112.98
DENSITY (LBM/FT³)	56.0	56.1	56.2	6.46	6.32	0.692	.688	34.0	33.8	33.8	33.8	61.4	61.3	61.3

PARAMETER \ STREAM	15 RETURN BRINE	16 VENT FROM TAILSTOCK	17 VENT FROM RECOVERY FLASH TANK	18 FLOW TO RECOVERY CONDENSER	19 CONDENSATE FROM IC_4 RECOVERY CONDENSER	20 STEAM & CO_2 TO EVAPORATOR	21 IC_4 TO EVAPORATOR	22 IC_4 FROM EVAPORATOR	23 WATER CONDENSATE FROM HOTWELL	24 COOLING WATER TO IC_4 RECOVERY CONDENSER	25 IC_4 RECOVERY CONDENSER VENT	26 IC_4 EVAPORATOR VENT	27 IC_4 EVAPORATOR DRAIN
FLOW RATE (lb/hr x 10^3)	97.2	.011	.018	.029	.023	.0629	2.6	2.6	1.4	16.0	.006	.140	.489
TEMPERATURE (°F)	144.8	144.8	144.8	250	76	335	95	260	94	74	76	270	225
PRESSURE (PSIA)	20.0	17.0	5	90	90	95	485	460	17	—	90	95	95
ENTHALPY (BTU/LBM)	112.98	—	—	—	—	417.3	-787.2	-610.8	62.0	42.0	—	—	—
DENSITY (LBM/FT³)	61.3	—	—	—	—	.224	33.8	7.0	62.1	62.3	—	—	—

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FIGURE 2

500 KW PILOT PLANT
DIRECT CONTACT HEAT EXCHANGER
HEATING CURVE (HIGH FLOW CASE)
JAN. 18, 1980 4:29 P.M.

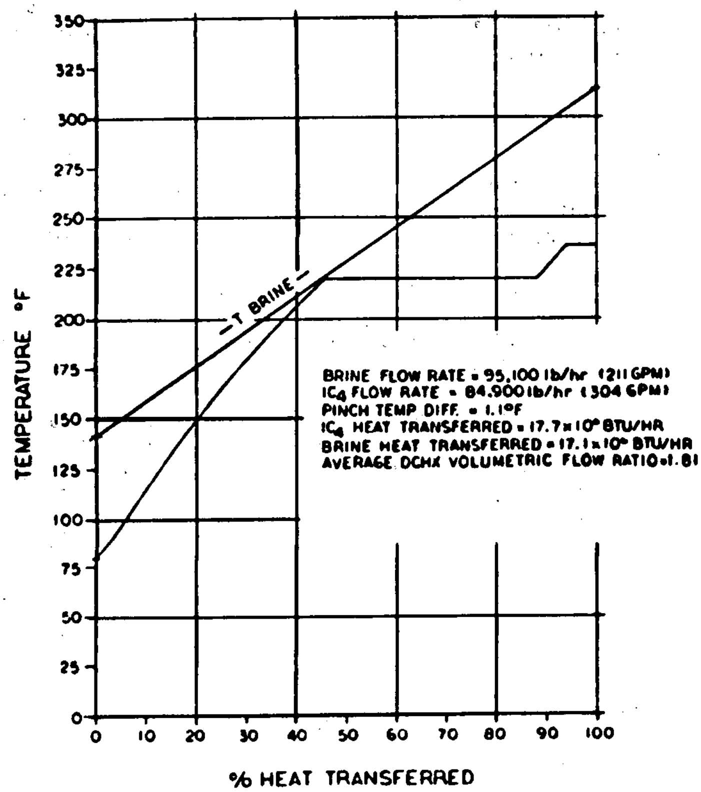

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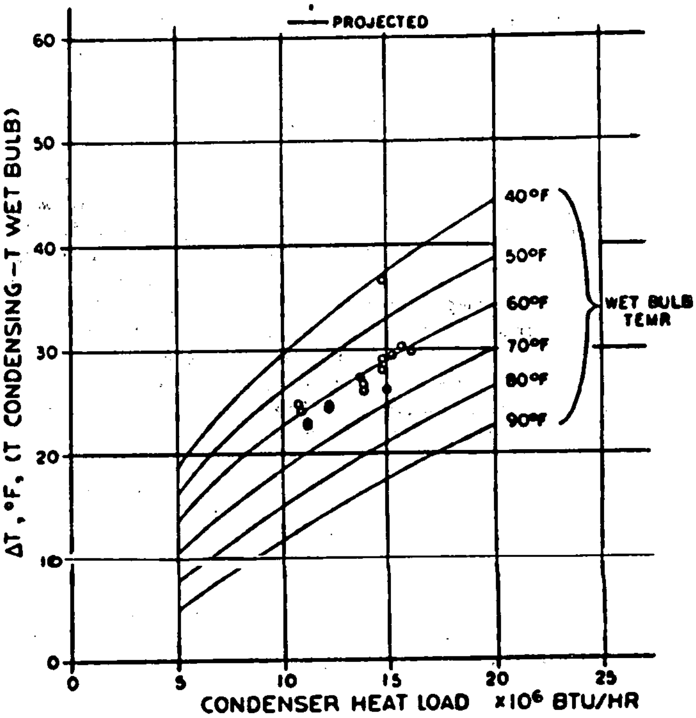
FIGURE 3

PROJECTED & ACTUAL
CONDENSER HEAT
TRANSFER PERFORMANCE

DATA WET BULB TEMPERATURE RANGE 48°F-54°F



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TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720