2800 Airport Blvd., Santa Monica, CA 90405
213-391-0691

Biphase Energy Systems

A Research-Cottrell
Transamerica Delaval
Joint Venture

MASTER

FIELD-TEST RESULTS FOR A TWO-PHASE NOZZLE OPERATING ON A SALTON SEA GEOTHERMAL RESOURCE

DOE/ET/27124--T2

DE82 008222

November 20 • December 19, 1980

AC03-79ET27124

DISCLAIMER

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

DOE OFFICE OF PATENT
COUNSEL/LIVERMORE

APR 26 1982

RECEIVED

Prepared for
UNION OIL COMPANY

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It January 1981
has been reproduced from the best available
copy to permit the broadest possible avail-
ability.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Jeff Record
Jeff Record
Engineer

Donald J. Cerini
Donald J. Cerini
Project Manager

William E. Amend
William E. Amend
Technical Director

DISCLAIMER

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

DISCLAIMER

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

INTRODUCTION

An important part of the Biphase Rotary Separator Turbine (RST) is the two-phase nozzle. For the geothermal application, the input to the nozzle is the two-phase (brine/steam) mixture from the well. The mixture is expanded nearly isentropically through the nozzle. As the mixture goes through the nozzle, it undergoes an enthalpy change. The purpose of the nozzle is to convert as much of the potential enthalpy change as possible into kinetic energy of the brine. The nozzle efficiency is defined as the ratio of kinetic energy of the brine to the isentropic enthalpy change across the nozzle. Knowledge of nozzle efficiency, for given resource conditions and a given nozzle, is vital to the analysis of the Biphase RST.

Biphase has signed contracts with both the Department of Energy (DOE) and the Electric Power Research Institute (EPRI). Both agreements require that Biphase demonstrate the ability to measure nozzle efficiency, as a function of various inlet parameters.

A serious problem with attempts to expand the use of hot geothermal brine to produce power has been severe scaling on the power-production equipment. The Biphase system will minimize this scaling problem, because of the small brine-residence time of the Biphase RST. Still, the magnitude of the scaling problem that Biphase faces is relatively unknown. Biphase has demonstrated the ability to control carbonate scale, but other types scale (sulfides and silicates) may present a problem. Of particular interest are the scaling characteristics of the two-phase nozzle. The large pressure drop (~300 psi) over a short distance (~24 inches) are favorable conditions for scaling to occur. Demonstrating the ability to control scaling in the two-phase nozzle is an important step towards demonstrating the ability to control scale in the whole Biphase system.

The Biphase-EPRI contract states that Biphase must obtain experimental scaling-rate data. If a scaling problem occurs (which was expected), Biphase will examine methods of controlling the scaling, using chemical injection.

It is these contractual obligations, along with Union Oil Company cooperation, that brought Biphase to the Union Oil geothermal site at the Salton Sea. Typical results, as well as any reference to the Union Oil resource or any Union Oil equipment that Biphase would like to publish, are presented in the following report.

TEST SYSTEM

Figure 1 is a flow diagram for the test system. The dashed line separates the parts of the system controlled by Union Oil from the part of the system controlled by Biphase. Union supplied the brine for the tests, as well as disposed of the brine after the test.

The Union separator separates the well flow into its two components (brine and steam). The flow rate into the separator was constant, independent of the Biphase tests. Thus, a Union operator was required during Biphase testing, to keep the total flow rate out of the separator constant, despite Biphase's fluctuating demands. The Union brine and steam valves shown were operated by Union personnel. This assured that a Union operator would be on hand during Biphase testing. A headset was strung to the Union operator, to provide a means of communication.

The instrumentation in the Biphase-controlled part of the system is summarized in Table 1.

Not shown in Figure 1 is the load cell, which transmitted the force exerted on the nozzle by the mixture exiting the nozzle.

Photographs of the system and some of the system components follow. Figure 2 shows the nozzle-test stand, the receiving separator and the coupling between the two. The test stand is supported by a scissors-lift in order to elevate the test stand to the height of the receiving separator inlet. The inlet plumbing is also shown.

Figure 1. Schematic of Test System

Table 1. Biphas Instrumentation

	Device	Measured Quantity
ΔP_1	Differential-Pressure Transmitter	Pressure-Drop across steam Orifice
ΔP_2	Differential-Pressure Transmitter	Pressure-Drop across Liquid Orifice
P_1	Pressure Transducer 0-450 psig	Pressure at Inlet to Biphas Test Stand
P_2	Pressure Transducer 0-450 psig	Mixer-Inlet Pressure
P_3	Pressure Transducer 0-450 psig	Nozzle-Inlet Pressure
P_4	Pressure Transducer 0-150 psig	Nozzle-Exit Pressure
P_5	Pressure Transducer 0-150 psig	Receiving-Separator Pressure
P_7	Pressure Transducer 0-450 psig	Brine Pressure at Brine Orifice
T_1	Iron-Constantan Thermocouple	Temperature at Inlet to Biphas Test Stand
T_2	Iron-Constantan Thermocouple	Mixer-Inlet Temperature
T_3	Iron-Constantan Thermocouple	Nozzle-Inlet Temperature
T_5	Iron-Constantan Thermocouple	Receiving-Separator Temperature
T_6	Iron-Constantan Thermocouple	Steam Temperature before Throttle Valve
T_7	Iron-Constantan Thermocouple	Brine Temperature at Brine Orifice

Figure 2. Test Stand and Receiving Separator

Figure 3 is another view of the test stand. This view shows the location of the Biphase test trailer, with the instrumentation lines between the test stand and the trailer also shown.

Figure 4 shows the locations of the liquid-level controller and of the backpressure-control valve (both supplied by Union). The liquid-level controller controlled the liquid level inside the receiving separator. This was accomplished by opening or closing the valve on the liquid line leaving the separator.

The backpressure-control valve controlled the pressure in the receiving separator. Pressure was changed by opening or closing the valve on the steam line leaving the separator. Figure 4 shows the liquid-level and backpressure controllers, as well as the valve on the liquid line.

Figure 5 shows the configuration of the brine and steam throttle valves. Flow direction is indicated on the figure. Note that an additional brine valve was added, in parallel with the brine valve shown. This was done because the brine flow rate was being limited by the size of the brine valve shown.

Figures 6 and 7 show the liquid and steam orifice sections, respectively. Also shown are the differential-pressure transmitters. Note that the orifice section on the steam line is in a vertical position. This was done to insure that only steam would pass through the orifice section.

DATA-ACQUISITION SYSTEM

All system data inputs (temperature, pressure, etc.) were received in the test trailer in the form of voltage signals. These signals were related to the flow quantity by some predetermined calibration equation. The voltage signals were input to the data-acquisition system. The system recorded and converted the inputs into the desired readings (pressure, temperature, etc.) and printed and/or analyzed the data.

Figure 3. Test Stand, Receiving Separator, and Test Trailer

Figure 4. Liquid-Level and Backpressure Controllers

Figure 5. Steam and Brine Throttle Valves

Figure 6. Liquid Orifice Section

Figure 7. Steam Orifice Section

The components of the data system are listed in Table 2.

The data-acquisition system has the following capabilities:

1. Printing (on calculator tape) and/or displaying input from one channel (pressure at one station, etc.).
 2. Scanning all stations, and printing results (temperatures in $^{\circ}\text{F}$, and voltage inputs from all other inputs) on calculator tape.
 3. Scanning all stations and recording voltage inputs on magnetic tape.
 4. Reading data from the magnetic tape, reducing the data (calculating nozzle-exit velocity and nozzle efficiency), and printing the calculated results on the printer.
- Note that the component interactions while performing functions 3 and 4 are shown in Figure 8.

This data-acquisition system had many advantages over recording by hand. First, the inputs were all scanned simultaneously, rather than one at a time. The in-field data reduction was helpful to the Biphasic operator, making it easier to scan a diverse set of conditions. Also, possible human error was eliminated from the recording process.

All data inputs were paralleled into the control panel for manual data monitoring. These inputs were:

1. Voltage inputs from thermocouples
2. Pressures (pressure transducers mounted in back of panel)
3. Voltage outputs from pressure transducers
4. Voltage input from load cell
5. Voltage input from differential-pressure transmitter.

The back of the control panel is shown in Figure 9.

Figure 10 shows the front view of the control panel. Also shown is the printer, scanner, and voltmeter.

Table 2. Data-Acquisition System Components

Purpose	Component
Controller	HP-9825A Desktop Computer
Printer	HP-2631A Printer
Signal Scanner	HP-3495A Multiplexer Scanner
Signal Measurement	HP-3455A Voltmeter

Figure 8. Data-Acquisition Component Interaction

Figure 9. Rear View of Control Panel

Figure 10. Control Panel — Front View

OPERATING PROCEDURE AND DATA ACQUISITION

The start-up procedure is described by the checklist on the following page. Following the checklist is the procedure for taking a data point and the shut-down procedure.

- ☐ Verify test plan with Union Oil Supervisor.
- ☐ String headset lines. One to operator in trailer, one to to Biphas valve operator, one to Union valve operator.
- ☐ Check valves 3, 4, and 5 are closed.
- ☐ Set valve 6 for desired liquid level.
- ☐ Set valve 7 for desired separator pressure.
- ☐ Verify valves 6 and 7 are in correct mode for automatic operation.
- ☐ Cycle valves 6 and 7 (closed to open to closed) by manually sending artificially-high signals (moving the needle past the set-point).
- ☐ Check valves on pressure-transducer manifold. System valves should be open, calibration valves should be closed.
- ☐ Get Union operator on line.
- ☐ Get Union operator's permission to open valve 8. Open valve.
- ☐ Have Union operator open main valves (1 and 2).
- ☐ Bring differential-pressure transmitters on line.

- ☐ Crack open steam-throttle valve to $\Delta P \approx 10$ inches. Allow steam to pressurize separator. Keep close watch on separator pressure, as valve has shown a tendency to stick closed during start-up. As a rule, the valve will actually begin to operate automatically at a pressure 30 to 50 psi above the set-point. By setting the separator pressure below the desired point, the valve will actuate before the shutdown pressure in the separator (burst disk setting is 134 psig). Note that the separator pressure must be increased slowly, to avoid cracking windows on access/view ports.
- ☐ Verify automatic operation of valve 7 (backpressure controller).
- ☐ Slowly open valve 4, to bring liquid on line.

Note that Union operator must be notified each time valve 3, 4, or 5 is adjusted.

PROCEDURE FOR TAKING DATA

Following start-up, 15-20 minutes were allowed to pass before any data was taken. This was done to allow the system to approach an equilibrium state.

After adjusting brine and steam flows for a desired data point, we would wait approximately five minutes for conditions to steady out before recording the point. Before taking a point, the operator would visually verify that conditions were steady, by inspecting the pressure gauges and temperature indicator. Particularly close attention was paid T_5 (separator temperature), as it appeared to be the least-steady input.

After taking the point, we would wait approximately five minutes, then take the point again. By comparing the reduced-data outputs on the printer, we could verify whether or not conditions were actually steady. If conditions were steady, we could move on to the next point. If not, we would continue to scan the point at five-minute intervals until satisfied that a steady-state condition had been reached.

SHUTDOWN PROCEDURE

Shutdown procedure is as follows:

1. Notify Union operator of intention to shut down.
2. Shut both Biphase brine valves. Allow steam to flow through system for two-three minutes in order to flush the brine from the system.
3. Shut Biphase steam valve. Have Union operator shut off both main valves.
4. If induced thrust vs. backpressure data is desired, do not adjust backpressure controller. Instead, allow back pressure to drop solely due to the leakage of the system. As back pressure drops, take desired data points.
5. Watch thrust reading to be certain that it drops to a reasonable level following the run. The observed thrust reading, once all flow has been shut down and backpressure had dropped to atmospheric, is a result of thermal effects. This value is normally about 24 lbf following each run.
6. If pressure-transducer calibration data is desired, isolate transducers from test system (by closing system valves) and open valves to manifold. Pressurize manifold to desired level, and scan pressure stations. Repeat as often as desired.

Be certain to isolate 150-psi transducers from manifold before raising pressure above 150 psig.

DISCUSSION OF NOZZLE EFFICIENCY

As mentioned earlier, the purpose of the two-phase nozzle is to convert an enthalpy change (from the pressure drop across the nozzle) into additional kinetic energy in the liquid. The kinetic energy of the liquid is obtained (approximately) by determining the nozzle-exit velocity. Nozzle-exit velocity is determined by measuring the force exerted on the nozzle by the exiting flow. The equations governing these relations are:

$$V = \frac{F \cdot g_c}{\dot{m}} \quad (1)$$

where V = nozzle exit velocity,
 F = force on nozzle due to exiting fluid,
 $\dot{m}$ = total mass flow,
 g_c = gravitational constant

and

$$\eta = \frac{\frac{1}{2}V^2}{(\Delta h)_s} \quad (2)$$

where η = efficiency (dimensionless) and
 $(\Delta h)_s$ = isentropic enthalpy change across the nozzle.

Note that F is defined as the force exerted on the nozzle by the fluid. We have observed an additional force, that is due to the operating backpressure. This force was mapped by determining induced force as a function of backpressure with no flow through the system.. This induced force was subtracted from the measured force, yielding the force on the nozzle due only to the flow.

Biphase has generated theoretical data, relating predicted velocity vs. nozzle-inlet pressure (Figure 11 is an example). Note that this data was generated purely for the design case (i.e., each point

Figure 11. Theoretical Curves - Velocity vs. Nozzle-Inlet Pressure

on the figure represents the nozzle-exit velocity for the optimum nozzle design at the given back pressure). Thus, the test data obtained will allow us to do two things:

1. Compare near-design operation with the theoretical calculations.
2. Compare off-design operation with the theoretical calculations, in order to get an idea of the efficiency penalty for off-design operation.

EFFECT OF NON-CONDENSABLES

For geothermal brine containing large quantities of non-condensable gases (as a rule, primarily CO_2), the Biphase system offers a unique advantage. The added quantity of gas (the non-condensables) will further accelerate the brine as it passes through the nozzle, to velocities higher than those seen with small non-condensable concentrations. Thus, the non-condensable content of the steam was of interest to Biphase during these tests.

RESULTS OF NON-CONDENSABLE EVALUATION

A sampling port was installed in the steam line. The sample was run through an ice bath, to condense the steam. The remaining non-condensables were then run through a dry test meter, with the following results:

12/17/80	Volume of Non-Condensables Through Test Meter (ft^3)	Volume H_2O Condensed (cm^3)	Gas Conditions (Test Meter)	
			T($^{\circ}\text{F}$)	P
Sample 1	0.4	850	65	1 atm
Sample 2	0.4	820	65	1 atm
Average	0.4	835	65	1 atm
12/18 - 12/19/80	0.4	819	60	atm
	0.412	860	67	atm
	0.453	918	62.5	atm
	Average	866	63.2	atm

From these results, it is possible to calculate the total non-condensable gas flow rate. This was done as follows:

$$\begin{aligned}\text{Assume: volume of non-condensables} &= 0.4 \text{ ft}^3 \\ \text{condensed H}_2\text{O} &= 835 \text{ cm}^3\end{aligned}$$

Using the ideal gas law, $PV = nRT$, where

$$\begin{aligned}n &= \text{number of moles,} \\ T &\text{ is in } ^\circ\text{K} \\ R &= 1.987 \text{ cal/deg-mole} \\ V &= \text{volume of gas} \\ P &= \text{pressure.}\end{aligned}$$

$$\text{First evaluate PV: } P \approx 1 \text{ atm} = 14.7 \text{ lbf/in}^2 = 2117 \text{ lbf/ft}^2$$

$$\implies PV = (2117 \text{ lbf/ft}^2)(0.4 \text{ ft}^3) = 847 \text{ lbf-ft}$$

$$\text{But } 1 \text{ cal} = 3.09 \text{ ft-lbf} \implies PV = (847 \text{ lbf-ft}) \frac{1 \text{ cal}}{3.09 \text{ ft-lbf}} = 274 \text{ cal.}$$

$$\text{Now, evaluate RT, and solve for } n = \frac{PV}{RT}$$

$$T = 65^\circ\text{F} = 18.3^\circ\text{C} = 290.5^\circ\text{K}$$

$$\text{so } RT = (1.987 \text{ cal/deg-mole})(290.5^\circ\text{K}) = 577 \text{ cal/mole}$$

$$\implies n = \frac{274 \text{ cal}}{577 \text{ cal/mole}} = 0.475 \text{ moles of non-condensables.}$$

Assuming that the non-condensables have the same molecular weight as CO_2 (analysis of the non-condensables indicated the percentage of CO_2 in the non-condensables to be in excess of 97 percent), the mass of non-condensables in the sample taken would be

$$(0.475 \text{ moles})(44 \text{ gr/mole}) = 20.9 \text{ gr}$$

the density of pure water $\approx 1 \text{ gr/cm}^3$, so the percentage by weight of non-condensables in the steam is equal to

$$\frac{20.9}{20.9 + 835} = 0.024 \text{ (2.4\%)}$$

Assuming a value of 10 percent for the wellhead steam quality, we get a total non-condensable flow rate of

$$(0.10)(0.024) = 0.0024 \quad (0.24\% \text{ of total mass flow})$$

Preliminary theoretical analysis by Biphase indicated a velocity boost between 20 and 40 ft/sec for a system with 2 percent of the total mass flow as non-condensables. The observed non-condensable flow rate of 0.24 percent of the total mass flow implies a velocity boost due to the non-condensables of less than 5 ft/sec. This small effect was neglected in the analysis.

THERMODYNAMIC EFFECT OF DISSOLVED SOLIDS

The high dissolved-solids concentration at the Salton Sea resource has a large impact on the nozzle-efficiency calculations. This is due to the fact that the enthalpy change across the nozzle is based on a pure water/steam mixture. The dissolved solids in the brine tend to reduce the magnitude of the enthalpy change across the nozzle.

The qualitative effect of the dissolved solids was difficult to pinpoint. To Biphase's knowledge, no experimental work has been done concerning the thermodynamic qualities of Salton Sea-type brine. However, some work has been done using water/NaCl solutions of varying salinity. This work was the basis for Biphase analysis. The work was done by Silvester and Pitzer⁽¹⁾. The work used is shown in Figure 12. Figure 12 represents the available work, per kg of solution, in an expansion to $T = 50^{\circ}\text{C}$. Figure 12 was used as in the following example:

Given an expansion from 250°C to 175°C . The steam tables define an isentropic enthalpy change for pure water. This is denoted by $(\Delta H)_{\text{water}}$.

(1) Silvester, L.F. and K.S. Pitzer. "Thermodynamics of Geothermal Brines. Thermodynamic Properties of Vapour Saturated NaCl (aq.) solutions from 0-300°C," LBL 4456, 1976.

Figure 12. Available Work as a Function of Temperature - Water and NaCl Solution (Silvester and Pitzer)

From Figure 12, we ratio the work available from the brine to the work available from pure water. Thus, for an expansion from 250 to 175°C,

$$\frac{(\Delta H)_{\text{brine}}}{(\Delta H)_{\text{water}}} = \frac{160 - 65}{200 - 80} = 0.792$$

We used this value to obtain $(\Delta H)_{\text{brine}}$, as

$$(\Delta H)_{\text{brine}} = 0.792 (\Delta H)_{\text{water}}$$

Efficiency is now defined as

$$\eta = \frac{\frac{1}{2}V^2}{(\Delta H)_{\text{brine}}}$$

Brine samples taken by Biphase justify the use of a curve for a Niland-like resource. Dissolved-solids content of Niland brine = 250,000 ppm⁽²⁾. Ten brine samples were analyzed for total dissolved solids, with values ranging from 264,000 to 330,000 ppm, with a mean value of 291,900 ppm.

TEST RESULTS

Table 3 is a typical page of reduced data. The headings are defined as:

- Scan: Scan number (to identify data scan)
- LF: liquid flow
- SF: steam flow
- X1: steam quality, inlet to test stand
- X2: steam quality, mixer inlet
- X3: Steam quality, nozzle inlet
- Neff: nozzle efficiency
- Vel: Nozzle-exit velocity (ft/sec)
- dH₁: enthalpy change across nozzle
- T1: temperature at entrance to test stand (°F).

(2) DOE publication SAN-1124-2, "Advanced Design and Economic Considerations for Commercial Geothermal Power Plants at Heber and Niland, California." Work performed by Bechtel Corporation, October 1977.

Table 3. Test Results

Scan	LF	SF	X1	X2	X3	NEff	Vel	dHi	T1	T2	T3	T5	T6	T7	Thru	P1	P2	P3	P4	P5	P6	PR1	PR2	PR3	del 1	del 2	Corr
65	14.4	0.4	0.058	0.063	0.073	0.683	500	7.3	412	409	401	323	447	468	313	232	231	219	91	97	427	1.23	1.18	1.14	3	16	116
66	14.7	0.4	0.058	0.063	0.072	0.649	496	7.6	412	408	401	321	446	468	316	232	231	219	91	97	427	1.22	1.18	1.13	3	16	116
67	14.3	0.9	0.085	0.090	0.106	0.690	623	11.2	428	423	410	321	433	467	365	278	276	262	89	98	427	1.21	1.16	1.06	16	16	117
68	14.1	0.9	0.086	0.092	0.106	0.753	650	11.2	428	423	412	321	436	468	372	277	276	262	89	98	427	1.21	1.16	1.07	15	15	117
69	14.3	0.9	0.085	0.091	0.105	0.767	648	10.9	428	423	412	323	435	468	377	277	276	262	89	98	427	1.21	1.16	1.08	15	16	117
70	13.5	1.7	0.134	0.140	0.152	0.687	753	16.5	439	434	424	320	438	467	426	314	310	294	90	98	425	1.20	1.15	1.09	52	14	118
71	13.4	1.7	0.136	0.142	0.156	0.665	739	16.4	439	434	422	321	443	467	418	313	311	295	90	98	425	1.20	1.15	1.07	52	14	118
72	9.8	1.9	0.188	0.195	0.205	0.658	758	17.4	424	418	409	321	443	467	346	266	263	250	89	98	424	1.21	1.15	1.09	62	7	117
73	9.8	1.9	0.187	0.194	0.204	0.619	750	18.2	424	418	409	317	442	467	343	267	264	251	89	98	425	1.21	1.15	1.09	61	7	117
74	9.8	1.9	0.186	0.192	0.204	0.627	735	17.2	424	419	408	321	440	467	337	268	264	251	89	98	424	1.21	1.15	1.08	62	7	117
75	10.6	1.2	0.127	0.134	0.143	0.754	653	11.3	413	407	400	324	436	467	308	235	233	221	89	98	428	1.22	1.15	1.12	24	9	117
76	10.3	1.1	0.129	0.136	0.144	0.757	659	11.4	413	407	400	323	435	467	304	235	233	221	89	98	426	1.22	1.16	1.12	24	8	117
77	10.6	0.7	0.093	0.100	0.102	0.572	476	7.9	400	394	392	322	447	468	237	203	200	190	88	97	426	1.23	1.16	1.19	7	9	116
78	10.3	0.7	0.094	0.100	0.105	0.715	544	8.3	400	395	391	320	447	467	255	202	200	190	88	97	426	1.23	1.17	1.17	7	8	116
79	10.6	0.7	0.094	0.099	0.104	0.570	484	8.2	400	396	391	320	447	467	239	202	201	191	88	97	426	1.22	1.18	1.17	8	9	116
80	10.5	0.4	0.077	0.083	0.086	0.676	463	6.3	391	386	384	320	446	467	226	180	180	171	88	97	427	1.24	1.17	1.20	3	8	116
81	10.5	0.4	0.076	0.081	0.084	0.584	424	6.1	391	387	384	320	446	467	214	181	180	171	88	97	426	1.23	1.18	1.20	3	8	116
82	6.2	0.4	0.111	0.117	0.110	1.102	425	3.3	362	357	362	329	445	466	157	127	127	121	88	97	426	1.24	1.15	1.31	3	3	116

T2: temperature at mixer inlet
 T3: temperature at nozzle inlet
 T5: temperature in receiving separator
 T6: temperature in steam feed line
 T7: temperature in brine feed line
 Thru: measured thrust
 P1: pressure at entrance to test stand, psia
 P2: pressure at mixer inlet
 P3: pressure at nozzle inlet
 P4: pressure at nozzle exit
 P5: pressure in receiving separator
 P6: pressure in steam feed line
 PR1: $\frac{\text{saturation pressure corresponding to } T1}{P1}$
 PR2: $\frac{\text{saturation pressure corresponding to } T2}{P2}$
 PR3: $\frac{\text{saturation pressure corresponding to } T3}{P3}$
 del 1: pressure drop, steam orifice (inches H₂O)
 del 2: pressure drop, brine orifice
 Corr: thrust correction due to back pressure.

Note that the values shown for dH1 incorporate a correction for the dissolved solids in the brine. The faint numbers that were handwritten above dH1 represent the values assuming a water/steam mixture.

Also note that T7 shows a temperature that is higher than the resource temperature. Final temperature results await calibration of all thermocouples with a thermocouple oven.

Figure 13 shows the results from an early run, with back pressure = 100 psia. Note the close agreement between measured and predicted velocities.

Figure 14 is a plot of nozzle efficiency vs. nozzle-inlet pressure. The effect of the dissolved solids correction is evident in this figure.

Figure 13. Nozzle-Exit Velocity vs Nozzle-Inlet Pressure

Figure 14. Nozzle Efficiency

This is the format that the presentation of all nozzle-test results will follow. It is possible that graphs of velocity and/or efficiency vs. percent of design flow and steam quality may also be included, if deemed useful. These graphs would contain no new information.

During the nozzle tests, Biphase tested two different nozzles. The first nozzle tested was a high-pressure steel nozzle. It was tested at 60, 80, and 100 psia back pressure, over a matrix of different inlet conditions. A low-pressure, aluminum nozzle was also tested. It was tested with back pressures of 40 and 60 psia, again over a matrix of different inlet conditions.

Figure 15 shows the steel nozzle following a series of tests. Information on the rate of scale formation follows in the summary of the scale tests. Note that no corrosion problems were encountered with the steel nozzle.

Figure 16 shows a closer view of the steel nozzle, and the aluminum support ring that supported the cantilevered end of the nozzle, inside the test stand. Note the chemical reactions that have taken place with the aluminum, resulting in a discolored, scaled surface.

Figure 17 is a picture of the low-pressure, aluminum nozzle after a series of tests. Note the corrosion of the inside surface of the nozzle. Figures 16 and 17 show clearly that aluminum is not a suitable material for use in contact with high-salinity brine.

BRIEF SUMMARY OF SCALE TESTS

Biphase Energy Systems conducted three tests to evaluate means for controlling chemical scaling in the Biphase nozzle at the Union Oil Geothermal site at the Salton Sea (see Figure 18). The tests were 24 hours in duration and consisted of the measurement of scale growth over the test period for constant mass flow and test conditions. Samples for chemical analysis were taken of the brine, of the non-condensable gases given off by the brine, and of the chemical scale deposited in the Biphase nozzle. The pH of the influent

Figure 15. High-Pressure Steel Nozzle

Figure 16. Close-Up of Aluminum Support Ring

Figure 17. Low-Pressure Aluminum Nozzle

Figure 18. Salton Sea Nozzle Tests Chemical Additive System

and effluent brine was also determined. Scale thickness was determined for three locations in the nozzle (entrance, throat, exit) and scale samples for analysis were obtained from two locations (entrance and exit).

The chemical additives used for control of the chemical scaling were:

<u>Test No.</u>	<u>Additive</u>	<u>Concentration</u>
1	none	--
2	HCl	100 ppm
3	HCl	35 ppm
	Dequest 2060	3 ppm
	Corcat P-18	10 ppm

The additive concentrations in test 3 were $\sim 1/3$ of those intended. A problem in the additive injection system caused the lower concentrations. For all three tests the scale build-up at the throat was not measurable (see Figure 19). Approximately one mil of scale accumulated at the nozzle entrance during tests 1 and 2, but scale build-up was not measurable at that position for test 3. At the nozzle exit the thickness of the scale build-up was 35, 6, and 15 mils, respectively, for tests 1, 2, and 3. The profile of the scale thickness at the nozzle exit was determined for test 3 and showed a decrease in thickness from 15 to 5 mils within ~ 2 inches of the nozzle exit. These measurements confirmed the existence of what appeared to be the localized build-up of a ridge of scale near the nozzle exit. The latter appeared to have a peak $\sim 1/4$ inch in from the nozzle exit plane. The localized build-up of scale at the nozzle exit is believed to be associated with wall-flow separation and the resulting recirculation zone.

The silica content of the scale deposited in the nozzle changed from ~ 15 percent at the entrance to ~ 30 percent at the nozzle exit. Although chemical analyses are not yet complete, sulfides appear to be the dominant chemical scale species.

Figure 19. Summary of Scale Measurements for 24-Hr Scale Tests

The addition of 100 ppm HCl caused a reduction of effluent brine pH of 0.25. It was anticipated that this quantity of acid might prevent ionization of the H_2S and the resulting formation of sulfide scale. This result seems to be borne out from the results of tests 1 and 2. To further reduce the quantity of scale that would form, the intent of test 3 was to add Dequest 2060 and Corcat P-18 for carbonate and silica-scale control while simultaneously maintaining a pH drop of ~ 0.25 . Unfortunately, equipment malfunction prevented achieving this latter objective.

CONCLUSIONS

Nozzle Calibration Tests

1. The existing Biphase nozzle-test system (test stand and instrumentation) is satisfactory for nozzle calibration.
2. The Elliott nozzle-design program accurately predicts nozzle-exit velocities.
3. The resource used for testing did not have a high-enough level of non-condensable gases for any observations about the effect of non-condensables on nozzle operation.
4. Aluminum is an unsatisfactory material for nozzle fabrication, if the nozzle is to be used at a resource with high dissolved-solid content in the brine.

Scale-Control Tests

1. HCl by itself is an effective inhibitor of scale formation in the Biphase nozzle.
2. Results concerning the effectiveness of other additives used with HCl proved inconclusive.
3. A study permitting optimization of additive type and concentration, and providing for longer test times, is required to obtain quantitative results.