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FIELD TESTS OF THE BIPHASE GEOTHERMAL ROTARY-SEPARATOR TURBINE

Lance Hays and Donald J. Cerini
Biphase Energy Systems
2800 Airport Avenue
Santa Monica, CA 90405

ABSTRACT

An experimental Biphase Rotary-Separator Turbine (RST) was designed for moderate wellhead brine conditions. The 30-inch RST was fabricated, mounted in a trailer together with its controls and instrumentation, and tested under laboratory and field conditions. Electric-power production, clean-steam production, and brine repressurization for injection were measured at three different locations with various brine temperatures and compositions. The measured power output at design conditions was equivalent to the production of 25 percent more electricity per unit of brine than would be produced by an optimized single-stage flash power system operation at the same resource conditions. A full-size nozzle test rig was also field-tested to evaluate the critical performance parameter of nozzle efficiency operating on wellhead, high-salinity flows. Nozzle tests simplified the method of resource evaluation.

Significant flexibility in handling the range of resource temperatures leads to a 54-inch wellhead-size RST suitable for use on a variety of geothermal resources or on a resource that changes with time

INTRODUCTION

The rotary-separator turbine (RST) is a geothermal power-conversion system that extracts work from the thermal energy of geothermal brine. The system is capable of receiving two-phase flow directly from a geothermal well, separating the liquid and vapor phases after expanding them together in a nozzle, and supplying three forms of output energy: (1) electricity produced by a liquid turbine/generator driven by the accelerated liquid, (2) steam at pressure capable of producing electricity if expanded further in a steam turbine/generator, and (3) liquid (brine) at pressure suitable for reinjection back into the geothermal reservoir. The RST increases the efficiency of power generation from a geothermal resource by extracting power from the kinetic energy imparted to the liquid phase.

The Electric Power Research Institute (EPRI) awarded Biphase Energy Systems a contract to apply the Biphase RST concept to geothermal-power systems. The EPRI/Biphase project includes evaluation and development of the geothermal application through turbine design, fabrication, and field testing. This paper describes the testing of the 30-inch experimental unit, compares the RST system to single-stage direct flash based on performance measured in the tests, and discusses field-test simplification using a test rig for a full-size nozzle.

FIELD-TEST PROGRAM

The experimental RST was fabricated, mounted in a trailer together with its controls and instrumentation, and tested under laboratory and field conditions. Test objectives were satisfactorily met; these included:

1. Demonstrate mechanical turbine output power, clean steam separation and delivery, and delivery of pressurized return brine.

2. Demonstrate equipment reliability in the field operating environment.

3. Quantify performance trends; provide reliable design mathematical model; demonstrate wide flexibility in fluid conditions.

4. Compare Biphase wellhead system performance with alternate approaches to geothermal power.

The RST, Figure 1, has three rotating elements: the primary separator, the U-tube liquid turbine, and the liquid-transfer rotor. Geothermal brine enters the system through nozzles, and clean steam and repressurized brine leave the system; the brine exits via a stationary diffuser. A complete wellhead system would include an RST and a steam turbine, with the RST producing steam of the quality required by the steam turbine. The shaft power produced by the liquid U-tube turbine in the RST is the margin of performance superiority over a single-stage flash-steam system using only a steam turbine.

Initial test operation of the RST took place at the Biphase laboratories. Components were tested and developed separately. Then the test trailer was transported to East Mesa, California for a three-week period of operation. The trailer was

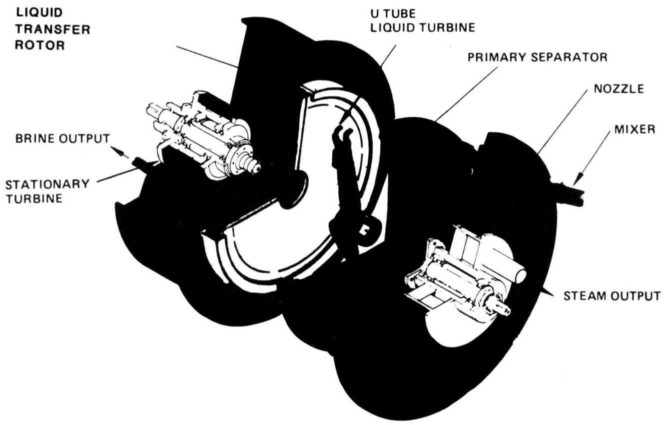

Figure 1. Rotary-separator turbine.

returned to the laboratory for performance tune-up involving the rotary-separator windage, then sent to Raft River, Idaho, for tests, and finally to Roosevelt Hot Springs, Utah.

Design conditions for the prototype were selected as shown in Table 1. RST inlet pressures of 80 psia and temperatures of 312°F are generally compatible with resource downhole pressures of 150 psia and temperatures of 350°F. Analysis and experiment have led to the expectation of satisfactory performance over a wide range of inlet condition; the three field test sites supplied brine temperatures ranging from 265°F at Raft River to 352°F at Roosevelt Hot Springs. The RST was operated near design conditions at Roosevelt and at East Mesa, and with a wide variety of off-design conditions indicated in Table 1. In addition to temperature variations, the three field sites supplied brine of various composition of dissolved solids and gases.

Item	Design Point	Laboratory	East Mesa	Raft River	Roosevelt
Fluid Inlet Temperature, (°F)	312		285-329	265-279	203-352
Nozzle Inlet Pressure (psia)	80	23-80	35-141	62-112	27-84
Exhaust Pressure (psia)	14.7	14.7	14.7	13.8 & 7.3	13.1
Total Flowrate (lb/sec)	4.7		1.6-9.3	1.9-5.6	0.5-4.1
Nozzle Inlet Steam Quality	0.05		0-0.05	0	0.05-0.10
Power (kW)	27.7		1.5-29.6	9.0-9.3	1.2-28
Steam Output Quality		0.9990-0.9995	0.9996	0.98-0.999	0.985-0.999
Brine Output Pressure (psia)	56		28-105	31-52	16.72
Hours Operation		114	112	30	60

Table 1. Design and range of operating conditions.

FIELD OPERATIONS

Prototype test operations at East Mesa utilized Well No. 6-2. Early difficulty with carbonate-scale formation in the RST nozzles was cured by addition of 2 to 10-ppm quantities of an organic phosphate. The test program was completed with no further scale problems on any of the test equipment. Results showed good performance of the nozzles, U-tube liquid turbine and diffuser, and reduced performance of the rotary separator due to high windage. High windage was traced to liquid droplets in the housing. When the equipment was returned to the Biphase laboratory, the nozzles, U-tube turbine, and separator geometry were tuned-up to eliminate the stray liquid. Windage was reduced by a factor of four. For the remainder of the program the component parts were unchanged, and performed as described by the mathematical model.

Tests at the DOE Geothermal Test Facility at Raft River, Idaho, were made with brine conditions significantly below design. An initial hook-up placed the test trailer approximately one mile from the wellhead. Wellhead brine temperature of 285°F decreased to 255°F at the trailer input, a temperature too low for meaningful tests. The trailer was then moved to the wellhead where tests were conducted. A series of tests was made employing a steam condenser to reduce back pressure to about one-half atmosphere. Brine enthalpy extraction under these conditions was more than doubled. In these subatmospheric tests the RST produced about 80 percent of the power that a single-stage steam turbine would have produced from the same brine flow. This means that an RST unit could be used without a steam turbine and still get most of the power that a direct-flash system could get from a low temperature hydrothermal resource.

The RST test trailer was moved directly from Raft River to Roosevelt Hot Springs, Utah. Brine conditions were in the range of RST design, so component performance was measured in the design ranges. Power output was measured at the design value of 20 kWe.

RESULTS

Significant results of the field tests included demonstration of hardware durability with various brine compounds, demonstration of significant flexibility in handling off-design conditions, and correspondence of test to a performance model. The model is now used with confidence for scale-up and optimization. Other results include measurement of power output, steam quality, diffuser performance, and resource-utilization advantage.

Power Output of the RST, measured under a variety of inlet pressures and inlet-steam qualities, is presented in Figure 2, with experimental points related to performance-model predictions. Design-point machine efficiency of 36 percent was measured at Roosevelt Hot Springs.

Steam Quality is important to a wellhead system where the steam from the RST is delivered to a steam turbine. Output steam quality was measured with a throttling calorimeter and also by a chloride analysis. The two methods agreed within one percent. The steam separation mechanism depends upon high rotor speed, so that the brine and steam are separated in a high-gravity field. At design rotor speeds, steam quality of 0.9996 was

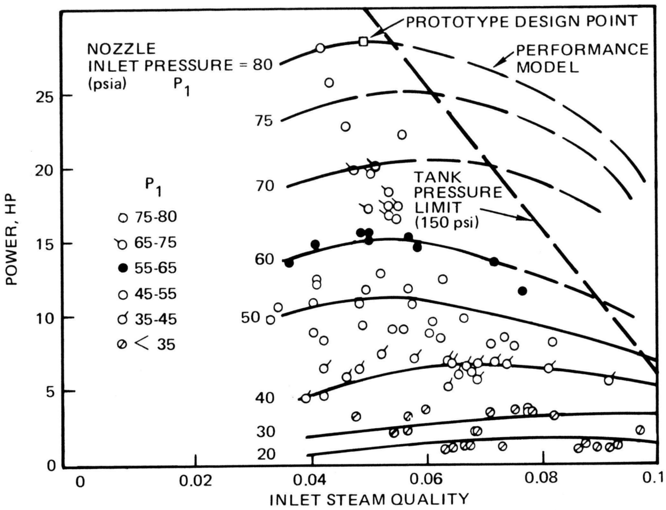

Figure 2. Measured output power as a function of inlet steam quality and nozzle inlet pressure.

measured. Figure 3 illustrates quality measurements at off-design conditions, and includes some measurements below 0.99 with rotor speeds well below design.

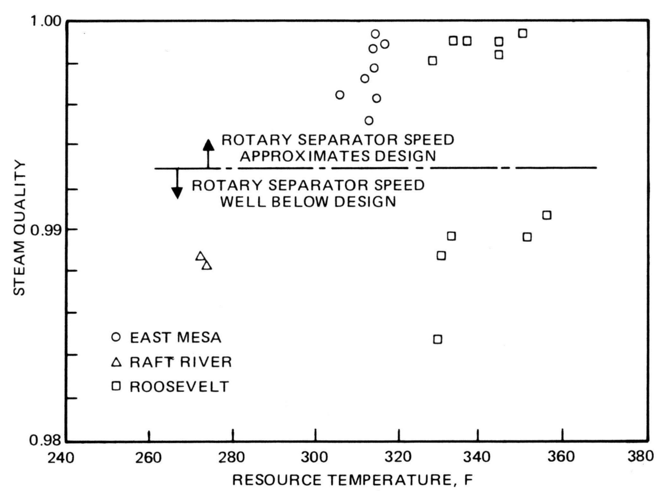

Figure 3. Experimentally-determined steam quality leaving RST, based on TDS analysis.

Stationary Diffuser performance is important for adjusting brine-delivery pressure as needed for reinjection. Brine repressurization is accomplished by retaining a portion of the liquid kinetic energy on the transfer rotor, and then converting this kinetic energy to pressure in a stationary diffuser. The energy partition is accomplished by adjustment of the turbine-to-separator speed ratio; as shown in Figure 4, pressures equal to or exceeding brine-entry pressures are obtained by operating the liquid turbine in the range 0.54 to 0.6 of separator speed.

Resource Utilization Advantage has been calculated using experimentally RST performance and inlet/outlet conditions, together with calculated steam turbine, condenser, and accessory power conditions.

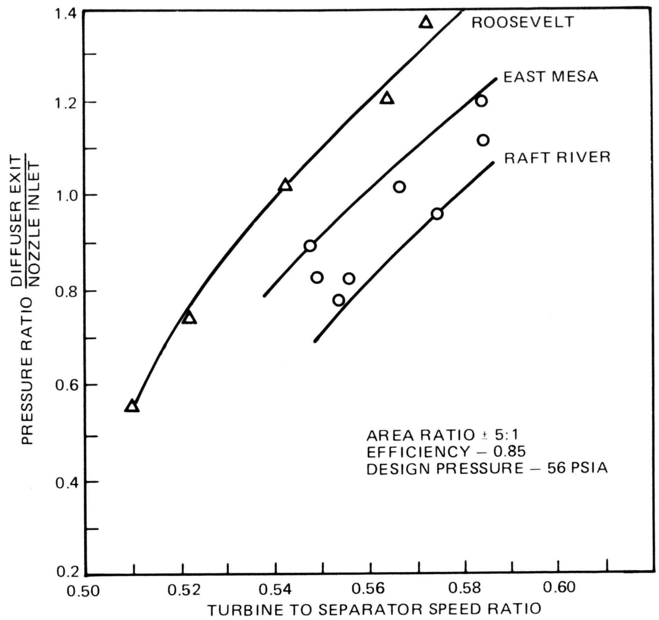

Figure 4. Experimental verification of stationary liquid-diffuser performance

The RST/steam-turbine power output is compared by the utilization ratio to an optimized single-stage flash system. The ratio, determined by the RST performance model shown in Figure 5, was confirmed by the experimental data.

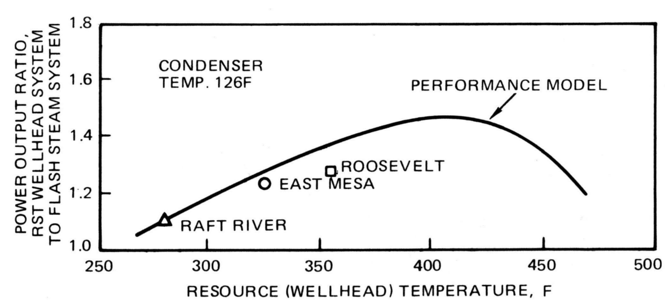

Figure 5. Comparison of experimental determination with theory, resource utilization advantage for Biphase single-stage RST/steam-turbine system to optimized single-stage flash system.

NOZZLE-CALIBRATION TESTS

The single most critical component-performance efficiency is that of the nozzle. For instance, the decline in power-output ratio (RST system compared to single-stage flash system) at lower temperature shown in Figure 5 is due primarily to the lower nozzle efficiencies at the lower temperatures. To verify nozzle-efficiency predictions, a calibration-test rig was assembled for field testing of nozzles that would be full-size for a wellhead unit. This calibration-test rig was operated at a Union Oil wellhead in the Salton Sea geothermal area. The test was designed to confirm predictions by the RST calculation model and to obtain off-design performance data. The results of the nozzle field tests are shown in Figure 6.

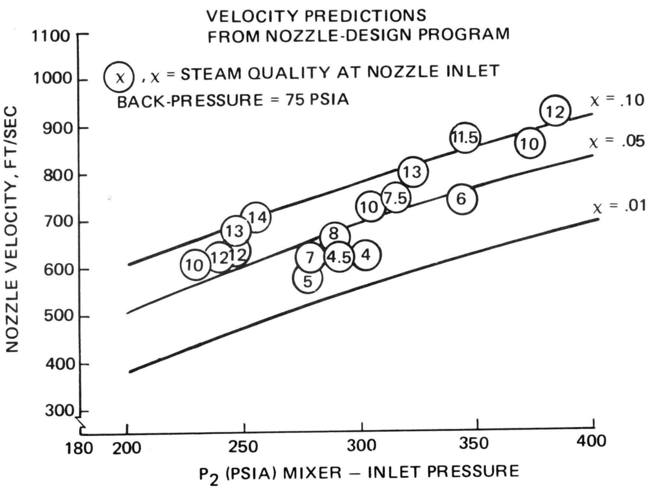

Figure 6. Experimental nozzle exit velocity.

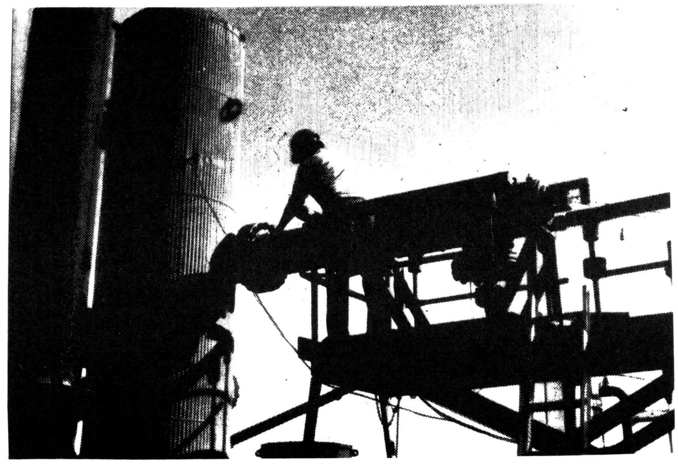

Figure 7. Nozzle test rig.

The test nozzle was full-sized relative to a wellhead RST. Nozzle velocity is determined from force measurements, and these data may be compared to theoretical results obtained from the mathematical model, Figure 6. The close agreement between observed and predicted performance at near-design conditions is very encouraging, because the four-nozzle design of the RST will make most conceivable operating conditions achievable using one or more nozzles flowing at or near design conditions. Figure 7 illustrates the nozzle rig.

SUMMARY

Field tests accomplished in the test trailer, Figure 8, and the nozzle test rig demonstrated consistency with system-performance predictions. Biphase Energy Systems and EPRI have accordingly continued in the design, production, and test of a production-type 54-inch wellhead-size Rotary Separator Turbine.

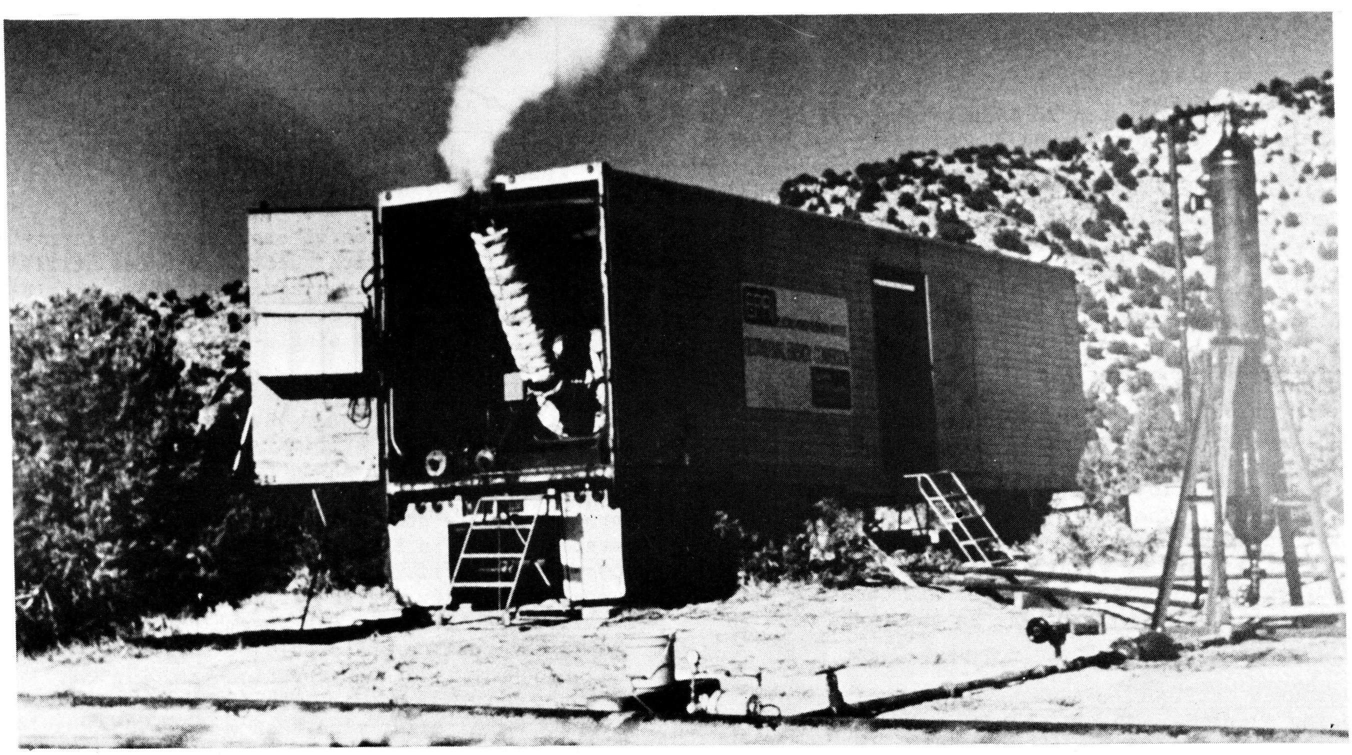

Figure 8. Geothermal test trailer.