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GEOTHERMAL PUMP TEST FACILITY

Final Report, July 1977—July 1978

By
Ralph W. Blakemore

September 1978

Work Performed Under Contract No. EY-76-C-04-3715

Barber-Nichols Engineering Company
Arvada, Colorado

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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ABSTRACT

The design configuration and fabrication description of a transportable geothermal pump test facility is discussed in this report.

The test facility, consisting of a test rig and data acquisition system trailer, provides the user with the unique opportunity to develop and calibrate geothermal pumps with less liability and risk, and at lower cost than would be incurred by actually installing the pump in a geothermal well. Pump tests may be performed using either domestic water, heated by pumping energy, or by using actual geothermal brines supplied directly to the test rig which would be located adjacent to the well.

The geothermal pump test facility is completely self supporting and requires only an electrical supply source to become fully operational.

Information and discussion presented in this report provides substantive background, design and operational capabilities, and pertinent fabrication details.

1.0 INTRODUCTION

Based on Barber-Nichols' experience with the design and development of a downwell geothermal pump and an evaluation of the cost and problems associated with final development of a geothermal pump in an actual well, it became evident that a special test rig that could duplicate true, in-the-well conditions was needed. Test rigs being used by pump manufacturers were limited in that they could not be used for the simulation of geothermal brine environments and the determination of their effects on geothermal pump performance and component life.

In-the-well testing is very expensive and somewhat risky with respect to the well, even for the case in which no major development problems are encountered. If development problems are encountered with a pump during the test program, costs would be increased significantly due to the expense of pulling the pump from the well and re-installing it after repairs or modifications were made. There are also other risk factors involved, including the possibility of losing a pump in the well or destroying the productivity of the well. Damage to the wells could result in a suit by the well owners against the pump manufacturer or agency trying to run such in-the-well tests. The geothermal pump test facility can be moved to a well site so that the actual brine can be used during final development and endurance testing without risk to the well. Also, pumps can be tested with different brine chemical compositions by locating the rig at different well sites. The test facility is designed on a universal basis, allowing all potential geothermal pump manufacturers to test and develop their pumps.

2.0 GEOTHERMAL PUMP TEST FACILITY OPERATIONAL CAPABILITIES AND FABRICATION DESCRIPTION

The objective behind the design of the geothermal pump test facility (GPTF) was to provide a test rig for geothermal pumps that would simulate the operating environment in a geothermal well. To achieve the well simulation requirements, the test facility can be transported to a well site where it can utilize the actual geothermal well water with all its normal constituents. With an approach of this type, the only aspect of the well conditions that is not simulated is the reduced content of the sands which are normally pulled in from the water-bearing strata. Alternatively the pump test facility can also be located and used at the pump manufacturer's plant for in house testing prior to operation on geothermal water.

The pump test loop is designed to accept submersible and vertical shaft driven deep well pumps that have been designed for use in 13.375 inch or smaller well casings. Submersible type pumps and vertical shaft/bowl assemblies may be up to 11 ft. long in the standard test loop although the addition of "spools" to the pump test loop would allow pump assemblies of up to 35 ft. long to be installed in the pump test loop.

The remaining test maximum parameters are listed below:

Fluid specific gravity range	.6 to 1.1
Maximum pump flow rate	1000 gpm
Maximum pump inlet pressure	500 psi
Maximum pump outlet pressure	1200 psi
Maximum fluid temperature	500°F
Maximum pump horsepower	750 hp

The GPTF was fabricated in accordance with the foregoing design considerations and is configured as shown in Figure 1. Referring to the schematic diagram shown in Figure 2, the pump test flow loop (1) is closed so that the large flow rates can be handled without direct support of the well or the problems of disposing of the geothermal brine. The loop contains a pump test section that simulates nominal 13.375 inch well casings. The pump section mounts vertically on the testing frame with the pump discharge being taken off downstream of the pump and routed around and down through another vertical section back across to the inlet end of the well casing test section. The return portion of the loop is constructed of nominal 6 inch pipe that allows flow rates of 1000 gpm with very moderate pressure drop. The vertical 6 inch section returning the flow back to the inlet of the pump has an ASME flow measuring orifice (2) installed in it. Downstream of the orifice is a throttling valve (3) that is used to set the flow or operating point of the pump to establish the flow head characteristics. Downstream of this throttling valve or on the suction side of the pump are lines which

Figure 1. Geothermal Pump Test Facility

Figure 2. GPTF Flow Loop Schematic

allow the loop to be filled with well water, or drained and flushed. Pumping energy that is dissipated across the orifice and throttling valve is turned into heat and is utilized to bring the operating temperature to the level required to simulate the desired well conditions. To control this temperature level, advantage is taken of the ΔP across the throttling valve to provide a bypass flow through a counter-flow heat exchanger (4) and back to the loop. The counter-flow heat exchanger, in turn, is connected to a fan coil unit (5) through a water or water/glycol solution. The ΔP across the throttling valve can also be utilized to provide flow through a sample flow pipe section (6). This section contains locations for test coupon probes and a small sample cylinder.

Operating pressure within the loop can be controlled by either of two methods. In the case where the loop is filled and then shut off or isolated, a nitrogen-filled accumulator (7) will be used to maintain the correct suction pressure level to the pump. The nitrogen accumulator is fed from a nitrogen source through a regulator that would maintain the proper pressure level. For the second method of operation it is possible to supply the loop with a steady exchange flow of fresh brine. This type of operation may be required to establish the effects of the brine on the materials used in the construction of the pump. By providing a steady through flow of fresh brine in the loop, the effects of deterioration or chemical change in the recirculated brine are reduced. In this mode of operation, a pump (8) supplies a constant brine flow to the loop and pressure is controlled by means of a back pressure regulator valve in the vent line from the loop. A pneumatic system (9) is used to supply the air required for the pneumatic powered control valves.

Charging of the system is accomplished with the same pump (8) used to provide a through flow of brine in the loop. Bleed lines (10) are installed at the highest point in the loop to allow the removal of gas. To eliminate the buildup of salts in the rig or on the pump hardware, a wash pump (11) circuit has been provided. The main loop may either be gravity drained or pumped dry with the wash pump, and then filled with clean water contained in the 500 gallon tank near the crane. The contaminated wash water can be disposed of or returned to the wash tank depending on the level of contamination.

The test rig assembly consists of a box structure frame with crane and hydraulic circuit, a piping system, a pneumatic system, and an electrical and controls system. The entire test rig assembly may be raised or lowered to facilitate loading and unloading from a truck-trailer. Raising the frame off of the truck-trailer is accomplished by withdrawing the outrigger beams from the frame rectangular tubes and attaching the outrigger pedestal assemblies to the outrigger beams. "Q-D" fittings and flexible hydraulic lines are then attached from the frame hydraulic lines to the leg cylinders. Temporary wiring from an electrical power source to the crane hydraulics motor starter allows the crane hydraulic system and controls to be used to raise the frame off of the truck-trailer. The trailer is then driven out from under the test rig frame and the frame lowered to its rest position. The opposite procedure is employed for loading the frame into the truck-trailer.

2.1 TEST RIG PIPING

The pump test rig piping is divided into four subsystems: pump test loop, brine cooling, pipe washing system, and brine make up. All piping including instrument tubing that conveys brine is at least 1/2 inch nominal size to minimize plugging. All piping for water, and/or brine must be capable of being drained and purged with air to prevent corrosion damage when the test rig is not in use.

2.1.1 Pump Test Loop

The test pump is connected to the loop by means of a 14 inch nominal 600 psi ANSI raised face flange. The entire test loop has been designed for 1200 psig at 500°F for ease of pressure testing, even though the portion of the loop between the pump throttle valve and the pump inlet will not be expected to see such high pressures in operation. Spiral wound asbestos/304 stainless steel gaskets are specified throughout because of the high temperatures and pressures. The test loop also contains a nitrogen over brine accumulator and nitrogen supply system to maintain pump suction pressure. The nitrogen pressure regulator is non-relieving.

2.1.2 Brine Cooling

The brine cooling system dissipates the energy added to the brine by the pump. The cooling system is capable of rejecting 1.91×10^6 Btu/hour from 300°F brine to 110°F ambient air at sea level. The heat is rejected from the brine to 220 gpm of 50/50 water/glycol which is pumped in a closed loop through an air cooled heat exchanger. The brine temperature in the loop is controlled by throttling the flow of hot brine through the coolers by a pneumatic powered temperature control valve. The pressure drop across the pump throttle valve forces hot brine through the brine coolers. The brine piping in the cooling loop must be capable of withstanding the same temperature and pressure as the pump test loop.

The water/glycol secondary coolant permits better control of the brine temperature than rejecting heat directly from the brine to the cooling air. Block valves are incorporated into the water/glycol system to permit servicing or replacement of components without completely draining the water/glycol.

2.1.3 Pipe Washing System

Because of the corrosive nature of some geothermal brines, provision has been made to wash the brine piping with clean water which is stored in a 500 gallon tank. The water may be directed to the test loop through the brine heat exchangers and back to the wash tank or to waste disposal by using a 3-way valve. The wash pump suction valve selects the clean water from the tank or water from the loop. Also provided are valves and connectors for use with a hose for flushing the charge pump. The maximum allowable water temperature in the wash loop is approximately 210°F.

2.1.4 Brine Make Up

Two duplex type charge pumps are supplied to insure that the brine in the test loop is "fresh". The pumps are plumbed in parallel and only one is used to provide a constant through flow of 4 gpm. The second pump serves as a "backup" and is used in the event of a failure of the primary pump. This allows servicing of the failed pump while geothermal pump testing continues. Excess brine in the loop is released through a pressure relieving valve. Coolant for the water cooled stuffing boxes on the charge pump is provided by the water/glycol pump. Charge pump suction conditions are limited to 200 psig and 360°F.

2.2 TEST RIG INSTRUMENTATION

In addition to the previously discussed items, the test loop contains instrumentation for measuring the test pump performance and for monitoring the pump test system. This instrumentation is independent of the data acquisition system. Numerous pressures are monitored and the four most important (test pump suction, test pump discharge, test loop relief valve inlet, and charge pump discharge) are located on an instrument panel mounted on the main frame. In addition to these gages, the panel also has a differential pressure recorder to record flow measuring orifice delta pressure and pyrometers to indicate test loop temperature and make up brine temperature. Other system status pressures and temperatures are measured by pressure gages and thermometers mounted in area the information is obtained from.

2.3 PNEUMATIC SYSTEM

The pneumatic system provides the air required by the electro-pneumatic control valves used to control loop flow, temperature and pressure. The three control valves require 35 psig air at .6 scfm each for actuator power. At full stroking rate valve air consumption goes from .6 scfm to 7.0 scfm.

The pneumatic system to supply the control valve air consists of a compressor, ASME storage tank, regulator, filter-water separator and lines supplying the valves. The compressor is a two horsepower unit capable of 6.4 cfm at 100 psig. The storage reservoir is a 30 gallon ASME tank equipped with relief valve and pressure switch for the compressor. A filter with a water separator is in the line to the valves with a regulator to supply clean air at 35 psig.

2.4 ELECTRICAL AND CONTROL SYSTEM

The electrical and control system is made up of four subsystems. There is a main power subsystem, a lighting and convenience power outlets subsystem, a valve controller subsystem, and an alternate valve controller subsystem. The main power subsystem is composed of the motor starters and logic required to control all of the pumps and fans required to operate the test loop. The lighting and convenience power is independent of the main power

section and provides lighting and convenience outlet components required to operate and maintain the system and pump testing. The test loop has three closed loop valve controllers for maintaining proper pump operating conditions. The normal location of the controllers is in a cabinet located in the data acquisition system trailer. For the situation where it is desired to run the test loop without the data system an alternate cabinet is provided on the main frame.

The main power system is configured to use 480 V, 3 ϕ service. A single disconnect serves all of the system. The pumps and fans for the brine cooling loop are all controlled from a single cabinet that incorporates relay logic tied to system status switches to assure proper test loop operation. Indicator lights are provided to allow operator convenience in monitoring component power status and test loop parameter status.

A separate disconnect for 110 V, 1 ϕ service is provided to handle convenience power and lighting for the test loop. This provides 2 flood lights, an instrument and power panel light and convenience outlets at three locations for power tools. A convenience outlet is also provided for the flow recorder.

The geothermal pump test loop contains three valve controllers to provide control for these major loop parameters: 1) pump suction pressure, 2) pump inlet temperature, and 3) pump flow rate.

The control process is accomplished by three closed loop controllers in conjunction with three valve positioners. The controllers accept signals from pump inlet pressure, orifice temperature and orifice ΔP transducers described above and compare then to reference conditions set by the user to control the pump suction pressure, inlet temperature, and flow rate.

Pump suction pressure is maintained by controlling a back pressure valve which dumps brine from the main loop. The main loop is charged with fresh brine by the brine charge pump. Pump inlet temperature is maintained by a control valve which allows some of the brine to pass through a glycol cooling loop before it re-enters the main loop. Pump flow rate is maintained by controlling a throttle valve downstream of the flow orifice. This throttle valve maintains a preset ΔP across the orifice.

The closed loop controllers are Fisher Model TL-101 3 mode process controllers. These controllers have a manual dial for setting the desired value of the loop parameter. Parameter values are measured by three of the transducers in the loop data acquisition system and are fed to the controllers. The controllers then feed a position command signal to electro-pneumatic valve positioners which position the control valves until the proper parameter values are achieved. The valve controllers can be installed in either the valve controller cabinet in the trailer or the one on the rig. Normal placement is in the trailer and requires that the instrumentation system be hooked up and operational. Operation of the controllers in the rig cabinet requires the use of a special jumper cable to the loop instrumentation terminal box.

3.0 DATA ACQUISITION AND REDUCTION SYSTEM

The data system as fabricated is designed to provide 4 basic services.

- 1) To provide data collection for both the test pump and test pump support system.
- 2) To provide data reduction for both the test pump and support system.
- 3) To monitor the pump test loops and support system for purposes of providing a warning signal if one or more of the monitored parameters is "outside" of the specified operating range.
- 4) To provide a permanent and formal record of test pump characteristics and performance versus time.

The calculator-based system fabricated will scan the 4-20 ma test rig transducers at a rate of 100 channels per second. At this rate the system will collect all data for the 33 channels specified below in .60 second (.30 second for 30 transducers and 3 accelerometers, .1 second each for 3 frequency inputs, which may exist), if accelerometer inputs are only monitored for RMS determination.

Pump Test Loop Instrumentation

<u>Device</u>	<u>Quantity</u>	<u>Range</u>
Pressure Transducer	3	0-1200 psi $\pm$ 1%
Δ P Transducer	1	0-500 in. H ₂ O $\pm$ 1%
Temperature Transducer	5	0-500°F $\pm$ 1%
Vibration Accelerometer	3	0-5 g's $\pm$.5%
Δ P Transducer	1	0-800 psid $\pm$ 1%

Pump Support System Instrumentation

<u>Device</u>	<u>Quantity</u>	<u>Range</u>
Pressure Transducer	6	0-2000 psi $\pm$ 1%
Δ P Transducers	1	0-100 psid $\pm$ 1%
Temperature Transducers	6	0-500°F $\pm$ 1%
Wattmeter	1	0-1 kw $\pm$ 1%
Current Transducers	3	0-500 A $\pm$ 1%
Voltage Transducers	3	0-3 kv $\pm$ 1%

If a vibration analysis is desired, .5 second sample time per accelerometer must be allowed to obtain sufficient data. This increases the total system data collection time to 2.07 seconds.

3.1 SYSTEM CONFIGURATION

Figure 3 is a diagram of the system showing the system components and their relationship. The central controller for the system is the Hewlett-Packard 9825 calculator. It performs the functions of initializing the settings of the instrumentation, scanning the sensors, reading, recording and printing the data, and doing the standard and optional data reduction calculations which describe and evaluate system performance.

The instrument interface bus connects five primary devices to the calculator. These are the Hewlett-Packard 9871 printer, the Hewlett-Packard 3437 system voltmeter (SVM), the Hewlett-Packard 59309 clock, the Hewlett-Packard 5300 counter, and the CDS 53A-001 ASCII Party Line System. These components are configured as shown in Figure 4 and installed in the trailer shown in Figure 1. The CDS 53A-001 system shown in Figure 3 in dashed lines performs the scanning of the analog channels and selects the SVM or the HP 5300 counter as the analog-to-digital conversion device. The combination of scanner cards shown will allow two-wire analog input channel to be switched to either the HP 3437 or 5300, as well as providing for up to ten channels of filtered two-wire analog input. The 53A system includes four scanner relay cards configured to give 57 channels of analog input and a relay card. The function of the relay card in the overall system will be to provide for ten DPST or SPDT contact closures to control valves, lights, etc.

The HP 9825 with option 002 has a read/write memory of 24,000 bytes - large enough for all anticipated pump performance programs. The high speed tape cartridge utilized in data collection reduced data storage can record up to 250,000 bytes. This means for the 40 channel system provided and four bytes per word, 1562 complete data sets can be recorded. If data sets were recorded four times per hour on the average, the tape would store 390.5 hours worth of pump performance data. This is equivalent to 16.3 days of 24 hour per day operation, or 48.8 days of eight hours per day operation.

4.0 PRESENT GEOTHERMAL PUMP TEST FACILITY STATUS

To date the Geothermal Pump Test Facility fabrication is complete and has undergone preliminary shakedown tests. These tests consisted of an 1800 psi at 80°F pressure test for piping and plumbing qualification, short term operation of all pumps, fans, and electric motors, cycling of pneumatic control valves and operation of the crane and lift leg hydraulic system. The data acquisition system has also been tested by simulating 4-20 ma test rig transducer signals. The later test insured proper component interface and system response to external inputs.

A simulated pump test initialization has been performed to gain experience in operation of the GPTF as a total system. Each subsystem was energized in a specified sequence to the point where a hypothetical geothermal pump would have been started and the data acquisition system data sample interval set.

All qualification tests performed to date have been successful to the point where the GPTF is ready for use in an actual pump test program.

DATA COLLECTION AND REDUCTION SYSTEM DIAGRAM

Figure 4. Data Acquisition and Reduction System Components