TITLE: HOT DRY ROCK ENERGY EXTRACTION OPERATIONS

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INTRODUCTION

The Hot Dry Rock Geothermal Energy Project of the Los Alamos Scientific Laboratory (LASL), under contract to the Department of Energy, aims to develop a concept and technology to enable extraction of thermal energy from basement rock where there is no natural water in the high-temperature formation. The establishment of a two-hole and connecting-fracture system on the southwest flank of the Valles Caldera in north-central New Mexico is reported elsewhere.1-3

This paper will report on the piping and equipment to complete the energy extraction system, the initial operation, and some brief and early interpretations of such operations. This loop has completed 1250 h of operation and is running as this report is written.

The goals of the Phase I operation are to study system characteristics, behavior, and changes related to time. The salient items are: water losses, thermal output, impedance to flow, geochemistry, seismicity, and fracture system configuration.

ENERGY EXTRACTION SYSTEM

The selection of equipment and design and procurement of piping components began during drilling of the second borehole. Figure 1 shows a simplified schematic of the energy extraction system, showing flow from borehole GT-2, through a strainer, through parallel heat exchangers, to the main circulating pumps and into the underground system via borehole EE-1 and through the fracture zone. Other features are the point of introducing fill and make-up water, a bypass or vent to atmosphere, and a bypass line between wellheads, and important data sensing locations.

The heat exchangers were purchased first as long lead time would probably be required. The water-to-air units are arranged for vertical forced draft across aluminum-finned carbon-steel tubes. The straight tubes with plugged headers may be mechanically or chemically cleaned in the event of scaling. Scaling is more probable than corrosion due to the silica and calcium encountered in the granitic formation. Design conditions are: 17,235 kPa (2500 psi), 250°C (475°F), and 8.3 \(\ell/s\) (290 gpm). Each bay contains 2 axial flow fans driven by 22.5-kW (30-hp) motors.

The circulating pumps were specified after drilling the two boreholes, but while the redrilling was in progress. They are canned, seven-stage vertical turbines with mechanical seals. Two pumps are installed in series. The pumps are each driven by 150-kW (200-hp) motors; the combination will deliver 19 \(\ell/s\) (300 gpm), from 1725 kPa (250 psi) inlet to 10,000 kPa (1450 psi) discharge pressure. Four pumps were purchased—the second pair will be installed in parallel to provide standby or additional flow.

Piping was designed for 17,235 kPa (2500 psi) and up to 250°C (475°F). Water is supplied from an on-site well, utilizing a 1500 m\(^3\) (400,000 gal) storage pond. During the later part of March, melting snow augmented the supply of stored water.

Instrumentation will provide 80 channels of information for data acquisition and control signals. The incoming signals will be conditioned and scanned as programmed by an on-line programmable calculator with memory of 15,000 words. All raw data is recorded on cassette magnetic tapes with periodic printout for selected information. Primary and operational data is numerically displayed from the time scans (15-s intervals). Twenty channels are reserved for signals from the console to operate the system pumps, fans, and valves. The data system is protected by an uninterruptible battery power backup system.

OPERATIONS

A preliminary experimental run of the loop was made in late September 1977 with partial instrumentation and pumping provided by service company truck-mounted piston pumps. After flushing residual water from the borehole system, the loop was circulated for about 60 h. Flow stabilized at about 9.6 \(\ell/s\) (150 gpm) injection rate with gradually increasing outflow reaching a maximum of 7 \(\ell/s\) (110 gpm). The impedance was 1300 kPa-s/\(\ell/s\) (12 psi/gpm). Maximum thermal power and outlet temperature were 3.2 MW(t) and 132°C respectively. Injection pressure was nominally 7000 kPa (1000 psi) initially and increasing to 9260 kPa (1325 psi) for the last 46 h. The experiment was considered successful and the information was used to plan for the first full
phase operation reported below. Injection pressure is limited to be somewhat less than that required to extend the fracture system, and the flow is initially selected to maintain that pressure.

The Phase I operation was begun on January 27, 1978 under adverse winter-weather conditions of freezing and snowing. Heat exchangers, thought to have been thoroughly drained and vented after the September experiment had retained enough water to freeze and rupture several tubes during the idle period. This was discovered during the instrument calibration run (first step of Phase I operation); three of the heat exchanger bundles had ruptured tubes. We moved directly from the abbreviated calibration run into loop operation through the remaining good heat exchanger to avoid possible further damage during a shutdown. Repairs were begun immediately on the damaged units, which fortunately were not required for the limited initial flows.

To date the loop has been run 52 days with several minor interruptions of short duration and 3 longer ones of up to 14 h. A total of 4900 m$^3$ (1,294,450 gal) has been pumped into the system as fill and make-up water, while 50,150 m$^3$ (13,250,000 gal) has been circulated. Energy has been extracted at rates up to 5 MW(t). Flow has increased to over 16.4 L/s (260 gpm) before being throttled down to maintain better pressures have been well below the 9100 kPa (1300 psi) set as a limit.

The longer stoppages were (1) there appeared to be a sudden reduction of the downhole flow impedance; (2) a short power interruption caused a shutdown and make-up pump prime was lost; (3) a long power outage. The first resulted in a series of problems in adjusting flows to control temperatures in the system and to maintain flow through all pipes to prevent freezing. A sudden change in the massive downhole system had not been anticipated and, of course, occurred at 1:30 am. The second incident also occurred at night—a phase failure confused the on-duty crew since all motors did not stop and by the time the proper diagnosis was made there was trouble with the make-up system. The third outage was caused by heavy snow and wind on the power line requiring several hours for the utility company to find the fault on a section of line in a steep timber area with deep snow. Standby power from a diesel-powered generator kept vital systems functioning and the downhole system was vented to maintain flow and prevent freezing.

Mechanical operation of the system, as indicated, must contend with the weather, as well as system components and behavior. The system has undergone piping revisions, to other than the main loop, under these freezing conditions and use of the tremendous downhole water volume are utilized to maintain flow in all pipes under shutdown conditions. It is no surprise that power outages are a probability in this mountainous rural area. Shaft seals on the main pumps did not seal well on installation and soon had to be replaced. They failed completely after 275 h and were finally changed by factory representatives and have given entirely satisfactory performance. One fan was shutdown due to vibration caused by a loose clamp allowing the pitch angle of one blade to change. System flow has been limited by a valve selected from flows of the preliminary run. These flows were easily exceeded as the impedance decreased.

The data acquisition system has also performed very well. Some adjustments have been necessary for differential pressure transducers on venturi flow meters as flow increased beyond selected ranges. Alarm signals have been reprogrammed as system limits were extended. The power backup system has worked each time it was required. The seismic recording system unfortunately is located where standby power is not available—the data is missing from that file. The seismic system has been in operation during development of the site and all fracturing experiments prior to circulation, and was not relocated for this operation.

Geochemistry is being studied by periodic sampling and analysis of circulating water. Samples are collected at both high and low temperature points. Make-up water is also monitored.

**DATA SUMMARY**

The data collected is studied each day and summarized weekly. Graphical presentation shows the variation of some important parameters against operating time.

Figure 2 shows the declining water make-up requirement, with a theoretical curve superimposed. The water loss model used here is for a linear-with-pressure homogeneous one-dimensional reservoir. Other models are also being developed and studied. The peaks and plunges are directly related to system shutdowns and are more severe early in the operation and for longer shutdown periods.

Figure 3 shows the downhole temperature (i.e., water temperature), again compared to a model. The variation of the measured data not only reflects starts and stops but variations in flow and apparent reservoir changes. It is anticipated that in a large reservoir with higher initial temperature that an upturn of temperature, following an initial drawdown, will indicate reservoir extension due to thermal stress cracking.

Figure 4 shows the declining specific impedance. Note the decrease did not begin until about the tenth day. The sudden drop on day 22 caused system operating problems mentioned earlier. There is indication that the impedance is dependent on continued flow. Strategic bypasses and use of the tremendous downhole water volume are utilized to maintain flow in all pipes under shutdown conditions. It is no surprise that power outages are a probability in this mountainous rural area. Shaft seals on the main pumps did not seal well on installation and soon had to be replaced. They failed completely after 275 h and were finally changed by factory representatives and have given entirely satisfactory performance. One fan was shutdown due to vibration caused by a loose clamp allowing the pitch angle of one blade to change. System flow has been limited by a valve selected from flows of the preliminary run. These flows were easily exceeded as the impedance decreased.

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REFERENCES


5. H. D. Murphy, Los Alamos Scientific Laboratory, personal communication, March 1978.


Fig. 1.
Schematic diagram of circulating energy extraction system.

Fig. 2.
Water loss data for Phase 1.
Fig. 3.
Fluid temperature at 8500-ft depth during Phase I energy extraction.

Fig. 4.
Impedance history for Phase I energy extraction.