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SOME RESULTS OF A LONG-TERM FLOW TEST OF A HOT DRY ROCK RESERVOIR

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ABSTRACT

Results from a 286-day flow test of a new hot dry rock reservoir created at Fenton Hill in the Jemez Mountains in northwest New Mexico are presented. The reservoir was created by fracturing an interval of granitic rock at a depth of 2.93 km (9620 ft). The system was formed from a recemented wellbore pair used to create the first hot dry rock reservoir. The undisturbed rock temperature at the bottom of the new reservoir was 197°C.

With a nominal outlet flow of 5.7 x 10^{-3} m3/s (95 gpm), the reservoir showed a thermal drawdown of about 8°C. A preliminary estimate of the heat transfer area is 45 000 m^3 (480 000 ft^2). The water loss rate to the formation was 4.6 x 10^{-4} m3/s (7 gpm). The flow impedance was 1.6 GPa s/M^3 (15 psi/gpm).

The results of the flow test show that in comparison with the earlier smaller hot dry rock system at the same site, the large increase in heat transfer area was accompanied by only a small increase in the water loss and with the impedance staying essentially constant.

INTRODUCTION

The basic idea in extracting energy from hot dry rock (HDR) is to form a manmade geothermal reservoir by drilling into low-permeability basement rock to a depth where the temperature is high enough to be useful and form a reservoir by hydraulic fracturing. A circulation loop is formed by drilling a second hole to intersect the hydraulically fractured region. Thermal power would be extracted from this system by injecting cold water down the first hole, forcing the water to sweep by the rock surface into the fracture system, and then returning the hot water to the surface where the thermal energy would be converted to electrical energy or used for other purposes. Pressure in the system would be maintained so that only liquid water would exist. The first hot dry rock reservoir was evaluated by a 75-day period of closed loop operation from January 28 to April 13, 1978. The rapid thermal drawdown of the produced water from 175°C to 85°C indicated that the effective heat transfer was small—about 8000 m^2 (86 000 ft). The water loss diminished throughout the experiment and eventually this loss was less the one percent of the injected flowrate. The impedance observed during this flow test was initially 1.7 GPa/m^3 (15 psi/gpm) and decreased by a factor of five as thermal contraction and continued pressurization resulted in the opening of natural joints that provide additional communication with the producing wells. Details of this experiment are found in Ref. 1.

The evaluation of the newest reservoir took place in a 286-day run between March 10 and December 8, 1980. The longer time was necessary to determine the heat transfer area from thermal drawdown data.

In the following sections the heat-transfer area, water loss data, and impedance for the two reservoirs are compared in an effort to show how these parameters are affected by reservoir size.

RESERVOIR GEOMETRY

The reservoir geometry can be inferred from several different experiments and a variety of data. The most common data used are obtained from tracer, spinner, and temperature logs and heat extraction experiments. These experiments, together with the assumption that the minimum earth stress at reservoir depth is in the horizontal direction, have led to the inferred fracture geometry shown in Fig. 1.

As can be seen from Fig. 1, the model is characterized by a number of vertically oriented fractures. Figure 1 is a simplified drawing in that there are more complicated fractures present in the reservoir than is shown. The heat transfer model presented here actually has upper and lower reservoirs. The upper reservoir consists of three vertical fractures and the lower reservoir consists of two vertical fractures.

WATER LOSSES

The water loss of a hot dry rock system is important because this water must be provided from some outside source. This information can be vital for environmental as well as economic reasons. The water loss is a strong function of system pressures and flow rate. Wellhead pressures were typically 9 GPa (1300 psi) for the injection well (EE-1) and 1.4 GPa (200 psi) for the production well (GT-2). Injection and production flowrates were 6.6×10^{-3} m3/s (110 gpm) and 5.7×10^{-3}m3/s (95 gpm) respectively. Accurate determination of the water loss rate was difficult because of an annulus leak that developed in the injection well after 160 days of flow.

Smoothed fits of the integrated water loss data are presented in Fig. 2. Also shown in Fig. 2 are results from the flow test of the smaller reservoir. The results presented are for only the first 30 days of each experiment because of operation conditions that made comparison at later times difficult. Because the pressures were about ten percent higher in the latest flow test than the earlier one, Fig. 2 also shows results scaled on pressure so a better comparison of the two systems may be made. The increase in water loss after pressure scaling is 30 percent for the new system.

FLOW IMPEDANCE

The flow impedance, defined as the difference of the inlet and outlet pressures divided by the outlet flowrate, is an important parameter used in determining pumping requirements.

Measurements of impedance for the main flow period (March 10 to December 8, 1980) are shown in Fig. 3, both uncorrected and with buoyancy corrections. The corrected impedance accounts for the fact that the water in the injection well was colder than in the production well so an additional pressure difference existed because of density variations. The calculated pressure correction as a result of these density variations was estimated with a transient wellbore heat transmission computer code. Generally, uncorrected impedances are 20 percent lower than corrected values.

The impedance change for the first reservoir is shown in Fig. 4. The great disparity between the impedance behavior in the present experiment and that observed in the earlier system is probably due to the fact that the earlier smaller system experienced a thermal drawdown of 100°C, whereas an 8°C drawdown was observed in the present system.

HEAT TRANSFER

The heat-transfer system in the reservoir is complicated and is governed by flow in several large fractures. In the past, analyses of the heat transfer system were made assuming a system of independent fractures. In the earlier system, this proved satisfactory and good fits were obtained. In the present experiment, drawdown and recovery as well as flow measurements suggest that the reservoir can be modeled best as a system of parallel, thermally interacting fractures. A two-dimensional heat-transfer model with lumped parameters was used to model the system. A finite element computer code was used in the modeling. Details may be found in Ref. 2.

The model grid shown in Fig. 5a consists of a multiple-fracture system embedded in a two-dimensional rock matrix. Three-dimensional heat-conduction effects are ignored. A specific flow rate (Q/A) is programmed into each branch of the fracture. Because the flow rate (Q) is known, this is a specification of the area (A) of each branch. At the midpoint of the reservoir a small transverse region connects the upper and lower systems. The lower system has two fractures; the upper system has three. Each problem in the parameter study runs from several months before the flow test through the end of the test. The initial temperature field was determined by the depletion of the reservoir in earlier flow tests. Because the vertical gradients in each fracture of the upper reservoir were unknown, no attempt was made to include them. The transverse temperature profile (x-direction in Fig. 5) was Gaussian with a minimum width determined by the recovery time since earlier system flow test and a maximum width determined by the total energy removed in the earlier flow test. The temperatures in the lower fractures were intially set to the measured original geothermal gradient temperature. A typical transverse profile is shown in Fig. 5b. A typical vertical profile is shown in Fig. 5c.

Figure 6 shows the best fits to the temperature data obtained. In Fig. 6, temperatures in the three fracture zones intersecting the production well are given. The best estimate of the total heat-exchange area at the end of the flow test is 45 000 m^2 (480 000 ft^2) with 30 000 m^2 (320 000 ft^2) residing in the portion of the reservoir cooled by previous flow experiments.

It is interesting to note that a single fracture model was also fit to the data of this flow test yielding a fracture area of 50 000 m^2 (530 000 ft^2). The agreement of the results of the two models indicates that little interaction has occured among the fractures in the time span of the experiment.

DISCUSSION AND CONCLUSIONS

The 286-day flow test of the newest hot dry rock reservoir at the Fenton Hill site provided important information on the effect of reservoir size on several key reservoir parameters. The nominal water loss rate, impedance, and heat transfer area are shown compared to those of the smaller earlier system in Table 1.

	Old Reservoir	New Reservoir
Heat transfer area	8000 m2	45 000 m^2
Integrated water loss*	3900 m^3	4900 m^3
Impedance	1.6–0.32 GPa s/m^3	1.6 GPa s/m^3

* at 24 days

Table 1. Comparison of reservoir parameters for old and new reservoirs.

To summarize, the heat transfer area of the new system was 5.5 times that of the earlier system, the water loss was 30 percent higher, and the impedance was nearly the same initially though the earlier system impedance decreased dramatically after substantial thermal depletion. These results made hot dry rock systems of a commercial size look very promising. For more details of this test the reader is referred to Ref. 3.

REFERENCES

Tester, J. W., and Albright, J. N., eds., 1979, Hot dry rock energy extraction field test: 75 days of operation of a prototype reservoir at Fenton Hill; Los Alamos National Laboratory report LA-7771-MS.

Lawton, R. G., 1974, The AYER heat conduction computer program; Los Alamos National Laboratory report LA-5613-MS.

Zyvoloski, G. A., ed., in preparation, Evaluation of the second hot dry rock geothermal energy reservoir: results of phase I, run segments; Los Alamos National Laboratory report.

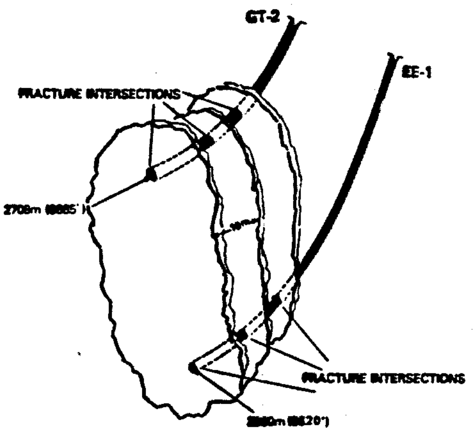

Figure 1. Inferred fracture geometry in reservoir.

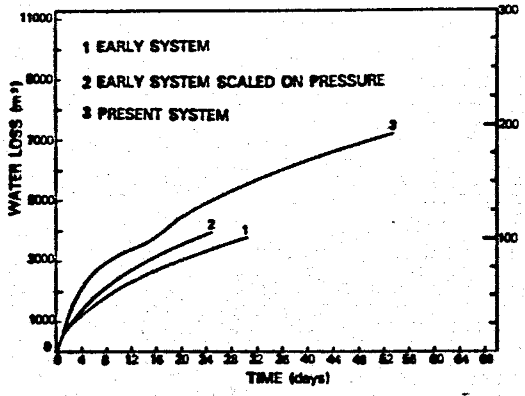

Figure 2. Water loss data for early and late hot dry rock reservoirs.

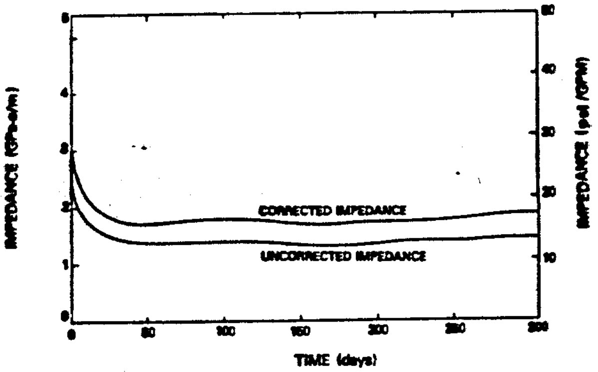

Figure 3. Impedance for flow test of latest reservoir.

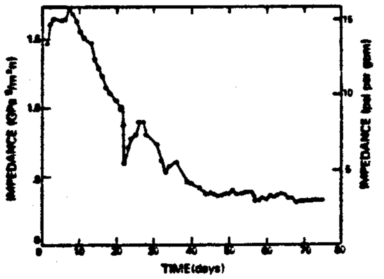

Figure 4. Impedance for flow test of early reservoir.

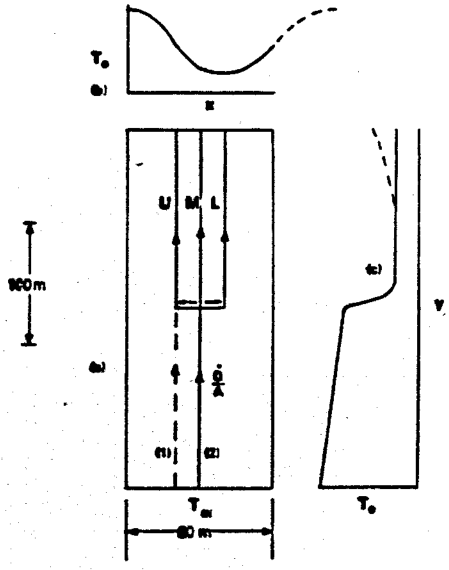

Figure 5. Model domain for heat transfer calculations.

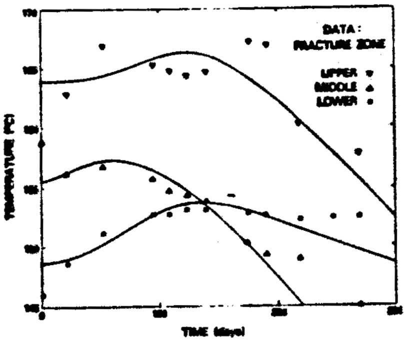

Figure 6. Comparison of field data with model calculations.