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RESERVOIR MODELING OF THE PHASE II
HOT DRY ROCK SYSTEM

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ABSTRACT

The Phase II system has been created with a series of hydraulic fracturing experiments at the Fenton Hill Hot Dry Rock site. Experiment 2032, the largest of the fracturing operations, involved injecting 5.6 million gallons (21,200 m^3) of water into wellbore EE-2 over the period Dec. 6-9, 1983. The experiment has been modeled using geothermal simulator FEHM developed at Los Alamos National Laboratory. The modeling effort has produced strong evidence of a large highly fractured reservoir. Two long term heat extraction schemes for the reservoir are studied with the model.

INTRODUCTION

The creation of a geothermal reservoir by hydraulic fracturing is a major component in energy extraction by the Hot Dry Rock (HDR) method. The primary purpose of experiment 2032 of this operation was to make an hydraulic connection to wellbore EE-3 360 meters above EE-2. While this purpose was not realized an enormous reservoir was created. It is this reservoir which is modeled.

THE MODEL

The governing equations and numerical procedures used in the code FEHM have been described by Zyvoloski (1983) and will not be discussed in detail here. Briefly the code solves the equations which describe the flow of heat and mass in fractured or porous media by the finite element method. To model the system the reservoir was divided into a number of fractures with the total flow divided equally between them. Figure 1 shows this idealization of the reservoir. Figure 2 shows the finite element mesh used to simulate the flow in each fracture. Not shown in the figure are nodes orthogonal to the fracture - 1200 nodes in all were used.

The data available from the experiment, which is to be simulated by the mode is of four types: pressure, flow rate, return temperature and seismic data. The downhole pressure data is perhaps most important and is shown in Figure 3. The return flow after the stopping of pumping amounted to 54% of the injected volume. The return temperature was estimated from geochemistry, which indicated a rapid return to initial thermal conditions (216°C). The seismic results placed constraints on the diffusion of the pressure pulse through the reservoir.

To model the effect of the pressure opening of rock joints, a pressure dependent fracture aperture law was used:

$$V_f = 0.003(P_f/75)^4$$

where V_f is a fracture aperture (m) and P_f (MPa) is the pressure in a fracture. At the initial fracture pressure of 32.7 MPa (hydrostatic) the aperture width is 0.1 mm; but at 75 MPa, the aperture width is 3 mm. Fracture permeabilities were calculated from the formula:

$$k_f = (V_f)^2/12$$

The physical properties used in the computer runs are given in Table 1. The results of the FEHM simulation using the quartic pressure law are given in Figure 4. It is clear from the figure that the aperture law cannot realistically model the sudden opening of the *in situ* rock joints. Numerical experiments with aperture laws using higher exponents on pressure produced better fits at substantially higher computer costs. It was also observed that the higher exponent aperture laws required more fractures to model the pressure response. The quartic law was used as a compromise between computing cost and reality while observing that the results will be conservative with respect to the number of fractures. The fracture opening at maximum pressure (3mm) was adjusted to a value inferred from tracer analysis studies on earlier reservoirs. Figure 5 shows the flow rates during the pump. It can be seen that the return flow of 50% was achieved with the computer model.

The results of the extensive seismic surveillance during the pump were also used in modeling. The observation that there were no seismic events greater than 1 km from the injection point meant that a significant pressure pulse could not have propagated that far. Also, the minimum dimension, 200 m, of the seismic "cloud" observed was used as the dimension orthogonal to the fractures (to be equally divided between the fractures resulting in 30 m spacing.)

So far no use of temperature data was used in the modeling process. The temperature near the injection point is given in Figure 6. Geochemistry placed the return temperature very near the average temperature of the injection point of 216°C. As can be seen from Figure 6, the model fits this data also.

SUMMARY OF MODELING RESULTS

The model which best fits the data contains the following elements:

1. An aperture law of the form $V_f = .003(P_f/75)^4$
2. A permeability law of the form $K = V_f^2/12$
3. Seven fractures
4. A fracture spacing of 30 m

APPLICATION OF THE MODELING RESULTS OF EXPERIMENT 2032 TO LONG TERM HEAT EXTRACTION

Two heat extraction schemes were investigated based on the reservoir modeled in Experiment 2032. The first method is the flow-through system. In this system the fluid is pumped down in the injection well and produced from the extraction well. The well spacing is shown in Figure 2. The reservoir parameters are given in Table I with the exception of the flow rate which was 20 BPM (.05 m^3/s). The temperature drawdown is given in Figure 7. Of note is the steady but slow drawdown from 216°C to about 195°C in twenty years. Over this period the reservoir should produce about 35 MWt using an injection temperature of 20°C.

The second method of energy extraction is the huff-puff technique. In this method water is pumped down a borehole for some length of time (typically several days) and then allowed to vent back out the same well. This method has the obvious advantage of using only one well, but suffers some thermodynamic inefficiencies.

Figure 8 gives results of the simulation of a three-day (3 days pumping, three days venting) huff-puff cycle. The output given is the average outlet temperature. It should be noted that not only does the temperature drawdown quicker in the huff-puff system than in the flow-through system, but also produces power only one half the time. Thus a two well system would produce 25 MWt from this reservoir. Varying the cycle time from 1 to 3 days produced essentially the same results. The calculations presented here do not take into account thermal contraction effects. This may well enlarge the capabilities of the huff-puff scheme. The pressure cycling may also open new flow paths to enhance the heat transfer between the rock and water.

CONCLUSION

(1) The Experiment 2032 (5.6 million gallon pump) can be described with a multiple fracture pressure-dependent aperature law based computer code.

(2) Long term thermal drawdown calculations reveal a reservoir capable of producing 35 MWt for 20 years with the flow through heat extraction scheme or 25 MWt for 20 years with the huff-puff method.

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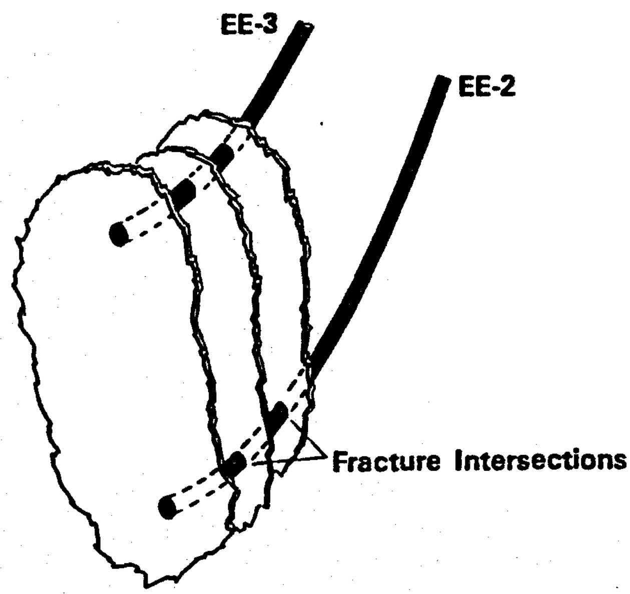

FIGURE 1
Idealized reservoir created during the MHF.

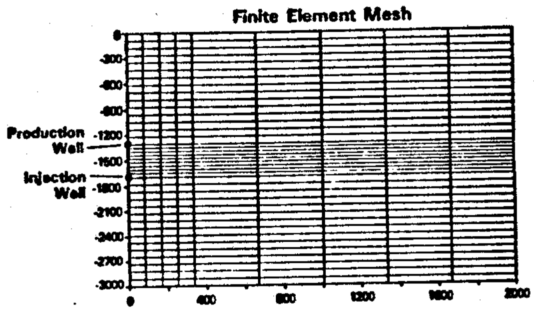

FIGURE 2
Finite element mesh used in simulation of Experiment 2032.

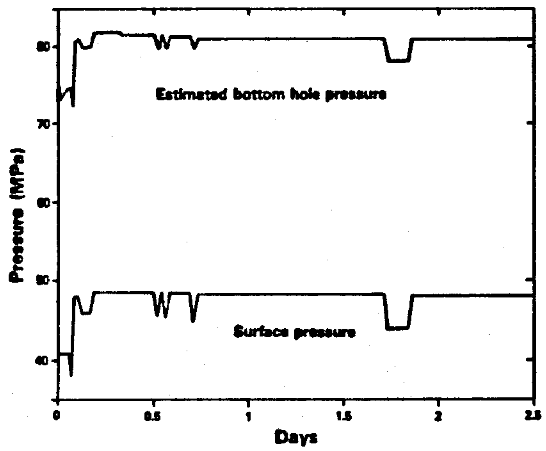

FIGURE 3
Bottom hole pressures during Experiment 2032.

TABLE 1
Parameters for Dual Porosity Simulation

Parameter	Symbol	Value
Permeability: Rock	k_R	10^{-17} m^2
Fracture	k_F	See text page 1
Thermal Conductivity	$K\phi$	2.7 W/(m°C)
Porosity: Rock	ϕR	0.005
Fracture	ϕF	1.0
Rock Density	r	$2700/kg/m^3$
Rock Specific Heat	C_r	1000 J/kg°C
Reservoir Horizongal Length	--	40000 m
Reservoir Vertical Length	--	40000 m
Initial Pressure	$p^0{}_{ij}$	32.7 MPA
Initial Temperature	$T^0{}_{ij}$	216°C
Discharge Production (Production Controlled by Pressure)	q_m^o	See Fig. 6
Injection Flowrate	q_m^i	See Fig. 6
Fracture Spacing	d	30 m
Initial Fracture Aperture	V_j	0.1 mm

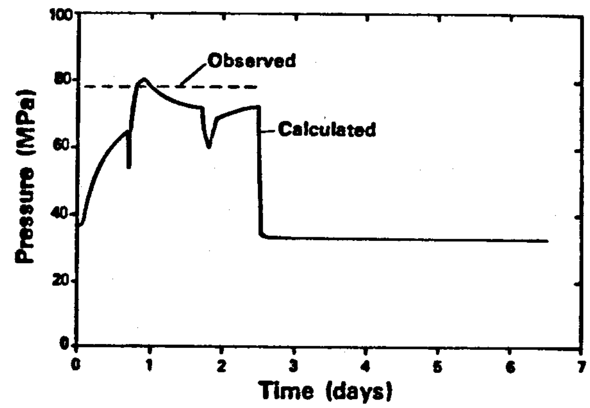

FIGURE 4
Computer generated pressure response (7 fracture system).

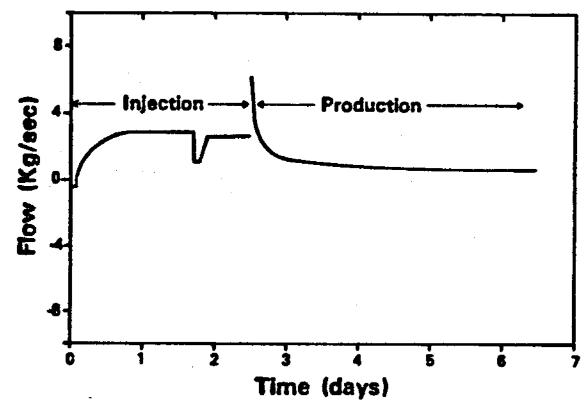

FIGURE 5
Flowrate during Experiment 2032.

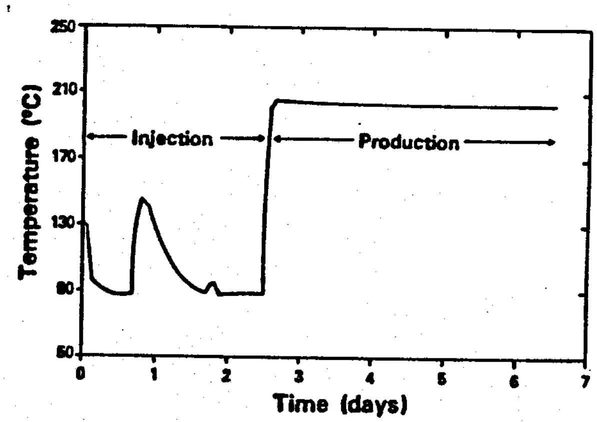

FIGURE 6
Near wellbore temperature (7 fracture system).

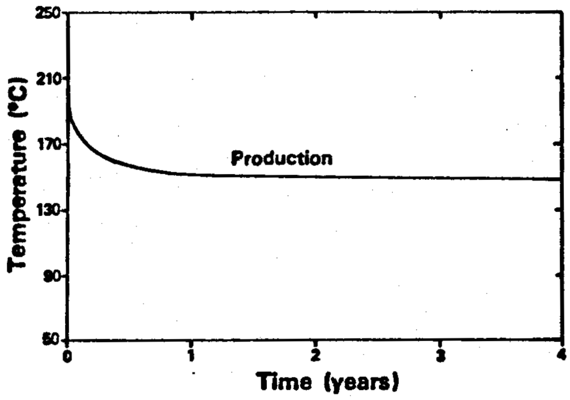

FIGURE 7
Thermal drawndown for the flow through system.

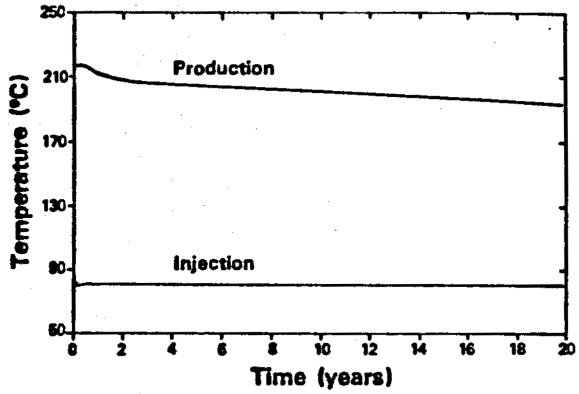

FIGURE 8
Thermal drawndown for the huff-puff system.