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HOT DRY ROCK GEOTHERMAL RESERVOIR ENGINEERING

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History

The Los Alamos Hot Dry Rock Geothermal Energy project is located on the Jemez plateau, in northern New Mexico, about two miles (3.2 km) west of the ring fault which bounds the Valles Caldera. Two wells, GT-2 and EE-1, were originally drilled to a depth of 9600 ft (2.93 km) and 10,000 ft (3.05 km), respectively, and, after some difficulties, including re-drilling of the bottom portion of GT-2, a good fracture connection was made between EE-1 and GT-2B, as the modified GT-2 was called. Water entered this fracture from EE-1 at a depth of 9020 ft (2.75 km) and emerged from several exits in GT-2B. The main exit was located at 8760 ft (2.67 km).

This circulation system was studied extensively for the purpose of establishing a number of fracture properties. Techniques were developed to determine orientation, geometry, heat exchange area, volume, flow impedance and impedance distribution.

A much larger fracture system was then created from a depth of 9620 ft (2.93 km) in EE-1. Similar studies are underway or have been completed on this system. Figure 1 shows schematically the system as it appears today. The techniques used and results obtained in the study of the new and old fracture systems are discussed below.

Fracture Creation

All fractures created in EE-1 and GT-2 by hydraulically pressurizing the wellbore appear to have been weakly cemented natural fractures, as no breakdown-pressure peak has been seen. The fractures may not be oriented at right angles to the least principal horizontal earth stress. They appear to stay partially open after their formation, possibly because of a shear component in the earth stress acting on the fracture, with a resulting displacement of the faces relative to one another.

When the gradient in earth stress is considered, normal hydraulic fracture equations usually do not apply. Quasi 3-D machine calculations by A. Vollan and T. Wacker of Dornier System GmbH, West Germany[1] show that with a fracturing fluid such as water, fractures will generally assume an elongated pear shape, eventually running away in the upward direction.

Pumping at high flow rates reduces this effect, maximizes shear displacement of the fracture faces, and opens up the maximum number of joints of various orientations.

Fracture Orientation

Seismic signals accompanying fracture growth delineate regions of high pressure. The signals are observed with a downhole seismometer having three sets of four seismometers oriented at right angles. Signal direction can be determined, with 180° ambiguity, from the first P-wave cycle, while distance is deduced from the time difference between P- and S-wave arrivals. A pressure sensor at a different point in the wellbore can remove the directional ambiguity.

Geometry

Information about joint systems can be derived in a single well by borehole televiewer and dipmeter logs. Correlation of logs in nearby wellbores is also informative. Spinner and temperature logs taken under flowing conditions identify the major entrance and exit points. The top of the fracture can be located by passing sound waves between wellbores, if the fracture lies between them. Since temperature recovery in radial geometry is faster than in plane geometry, the bottom of the fracture can be located after a few weeks of no flow, if it is close enough to one wellbore.

Heat Exchange Area

Figure 2 shows the fit obtained between calculations and observations of temperature drawdown in the old fracture system during the 75-day test. The new fracture is now undergoing a flow test. The heat exchange area is one of the most reliable numbers obtained during a flow test.

Volume

Fracture volume is obtained by injecting a slug of concentrated dye into the reservoir. Figure 3 shows results for both the old and new fractures. The new volume is ∿32,000 gallons (122 m^3), if the volume at the peak of the returning dye concentration is used. This is about ten times the volume of the old fracture.

Flow Impedance and Distribution

Flow impedance is defined as the difference in pressure between the exit and entrance points of a flowing well-pair, divided by the flow rate. The overall impedance requires a correction for the difference in pressure of water in the hot and cold legs of the reservoir. An entrance and exit impedance may be derived from the prompt change in pressure when the wells are shut in.

References

1. MAGES, Report submitted to the Executive Committee for the Program of Research and Development on Man-Made Geothermal Energy Systems under the auspices of the International Energy Agency, 1979.

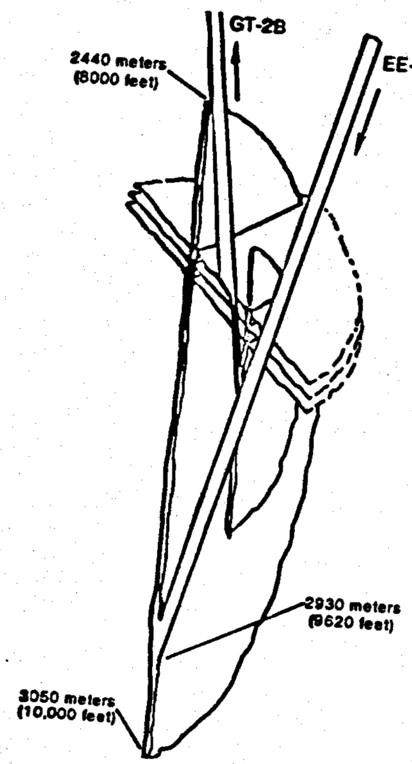

Fig. 1. Present configuration of reservoir (schematic).

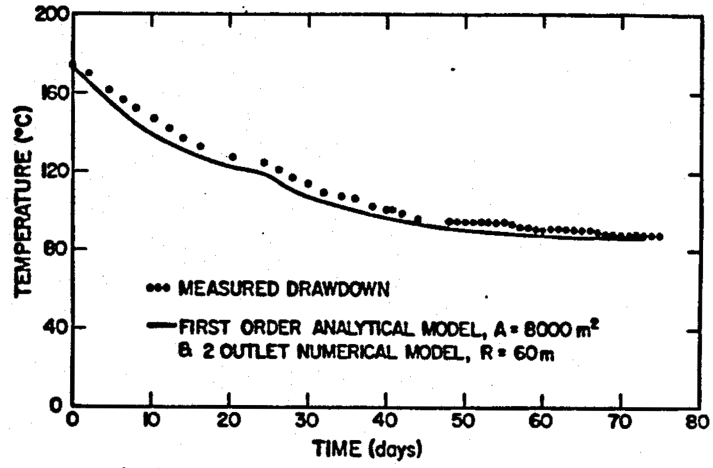

Fig. 2. Calculated and observed temperature drawdown curves.

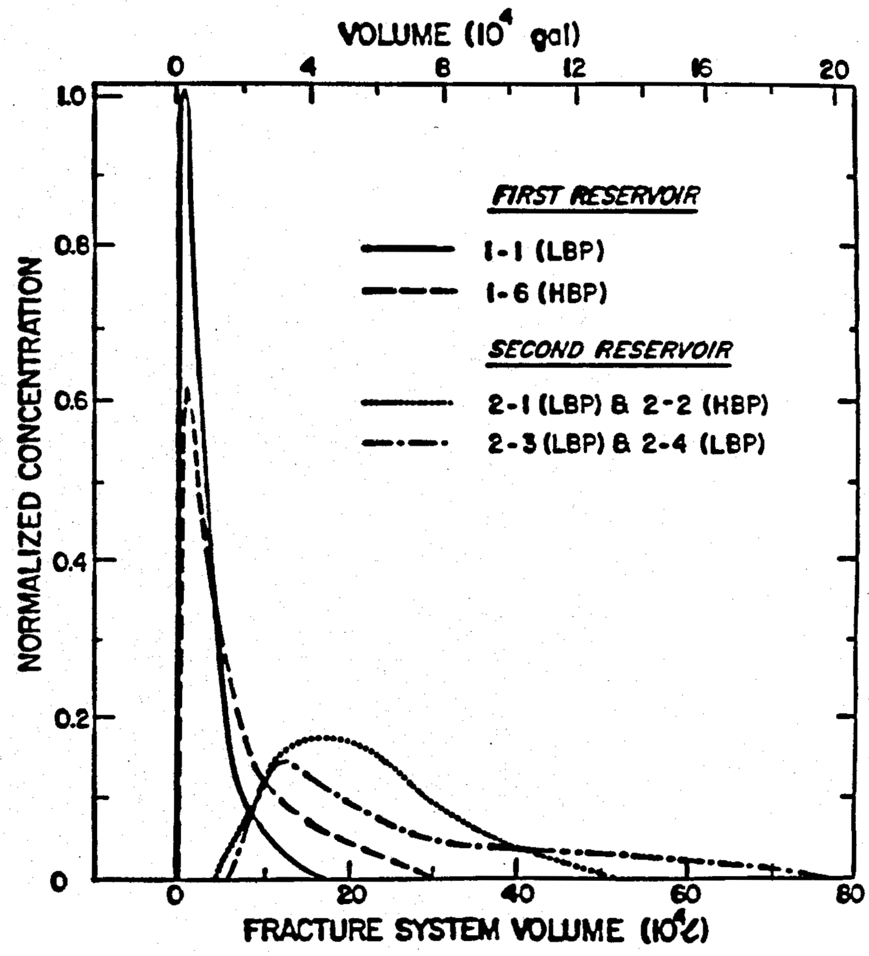

Fig. 3. Dye tracer recovery curves.