RESERVOIR FACTORS DETERMINING THE FRACTION OF STORED ENERGY RECOVERABLE FROM HYDROTHERMAL CONVECTION SYSTEMS

Manuel Nathenson
U.S. Geological Survey
Menlo Park, California 94025

The recoverability factors used to estimate resources of hydrothermal convection systems in Nathenson and Muffler (1975) are based 'on extracting the stored heat from a volume of porous and permeable rock, neglecting recharge of heat by either conduction or movement of water (Nathenson, 1975). The potential for heat recharge by conduction is neglected because it is very small compared to expected rates of production from any volume of rock greater than a few cubic kilometers. Likewise, for most of the hot-water systems of the United States, the natural discharge of thermal waters is low compared to reasonable production rates, and, accordingly, the potential for heat recharge by upflow of hot water to most reservoirs is probably low and can be neglected. The validity of this assumption can be assessed only after extensive production histories have been obtained for a reservoir. In those systems in which heat recharge by upflow of hot water is shown to be important, recoverability factors will have to be raised accordingly. Although the recharge potential of heat is neglected, the potential and, in fact, the need for cold water recharge are not.

Two possible methods for extracting energy from a liquid-filled volume of porous and permeable rocks are analyzed. The first method assumes that the porous, permeable volume is virtually closed to inflow of water and is produced by boiling to steam by using the energy in the rock. The second method assumes that natural and artificial recharge of cold water is used to recover much of the heat from the reservoir by means of a sweep process.

The fraction of stored energy recovered in the process of boiling the water in a porous volume of rock depends on the amount and pressure of the produced steam, which in turn are determined by the porosity and the initial temperature of the system. The pressure of the produced steam must be high enough to drive the steam through the porous medium and up the well at a significant rate; a reasonable assumption is that the pressure of the steam must be at least 8 bars. At a given reservoir temperature, this restriction constrains the range of porosity for which boiling is a viable recovery scheme. At 200°C, the upper limit for the porosity is about 0.05, and the fraction of stored energy obtained is about 0.2. At 250°C, the upper limit for the porosity is about 0.12, and the fraction of stored energy obtained is about 0.4. At porosities below this limit the fraction of stored energy obtained decreases with decreasing porosity in a nearly linear fashion. This production scheme is severely limited if there is significant recharge of water to the reservoir; recovery by boiling is then possible only if steam in the dried zone and water in the recharge zone are produced simultaneously in order to keep the zone of boiling moving into new regions of the reservoir. In summary, the restricted range of porosity, temperature, and recharge over which the boiling method will work limits its application to rather special circumstances, in particular to vapor-dominated systems (see below).

The second production scheme involves the use of natural and/or artificial recharge of cold water to drive hot water in a reservoir to the producing wells. As the water sweeps through the hot rock, its temperature is raised by removing energy from the rock. The influence of heat conduction on this process takes place on two length scales. On the microscale of pores filled with water in a rock matrix, conduction makes the temperature of the rock and the pores come to equilibrium in a matter of a few minutes. On the scale of a volume of rock several hundred meters on a side having one zone of cold water and rock and a second zone of hot water and rock, conduction with no fluid movement spreads out an initially sharp change in temperature to a smooth transition of only 60 m thickness in a period of a decade. As cold water sweeps into a hot reservoir, conduction may be analyzed to a first approximation by superposition onto the movement of the temperature front, resulting in the premature breakthrough of cooler water into the hot zone. Another factor in the sweep process is the rotation of an initially vertical interface between cold water and hot water in a porous medium, owing to the difference in hydrostatic pressure on the two sides of the interface. Although this rotation is retarded by the energy stored in the rock, it also tends to cause premature breakthrough of cold water into the hot zone. These processes can be combined qualitatively to yield an estimate of energy that can be recovered from a reservoir of porous, permeable rock in a hot-water system.

Vapor-dominated reservoirs are assumed to contain steam as the pressure-controlling phase, with liquid water immobilized in the pores by surface forces (Truesdell and White, 1973). Production results primarily from the boiling of this pore water to steam, although in later stages there may be some boiling from an inferred deep water table. Because the liquid fraction in a vapor-dominated reservoir is small, the pressure and temperature of steam produced in the boiling process are generally close enough to the initial values for the system that ample pressure remains to drive the steam to and up the well. The fraction of stored energy that may be recovered, calculated by considering an energy balance for the boiling process, is critically dependent on the average liquid saturation.

REFERENCES

Nathenson, Manuel, "Physical factors determining the fraction of stored energy recoverable from hydrothermal convection systems and conduction dominated areas," U.S. Geol. Survey open-file report 75-525, 38 pp., 1975.

Nathenson, Manuel and L. J. P. Muffler, "Geothermal resources in hydrothermal convection systems and conduction-dominated areas," in (D. E. White and D. L. Williams, eds.) Assessment of the Geothermal Resources of of the United States--1975, U.S. Geol. Survey Cir. 726, pp. 104-121 1975.

Truesdell, A. H., and D. E. White, "Production of superheated steam from vapor-dominated geothermal reservoirs," Geothermics, V. 2, pp. 145- 64.