GEOTHERMAL ENERGY FROM DRY HOLES

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ABSTRACT

It may reasonably be clained that geothermal energy production would be environmentally more acceptable than most other forms of energy production. From this aspect a closed-loop system seems to be especially advantageous. Hungarian Plain is full of unsuccessible drillholes for petroleum fluids. These dry holes can be utilized as underground geothermal heat exchangers. The weakness of this proposed production technology is the moderate outflowing water temperature. The numerical simulation shows that this temperature is rather low, so this technology has only restricted importance.

INTRODUCTION

The present practice of the geothermal energy production in Hungary is the production of hot water based on the elastic expansion of the aquifer. Most geothermal wells are drilled and completed to produce water from the so-called Upper Pannonian sedimentary aquifer (ERDÉLYI, 1979). This mineralized water represents a major problem for geothermal energy utilizers. Disposal of the water after utilization is problematic: the mineral salt contained in it, the cooled water temperature and the siguificant discharge do not permit it to be eliminated in surface systems. A possible solution to reinject the water into the aquifer where it originated, which likewise allows the reservoire pressure to be maintained, limits subsidence and assures the continuous supply of water. Furthermore, water reinjected at a lower temperature than the aquifer allows the energy contained in the reservoir rock to be recovered by cooling the aquifer. Nonetheless the thermal front can sometimes rapidly reach the production wells, rising the danger of considerable lowering the yield of the production. Another adverse phenomenon can be the increasing reinjection pressure because of the decreasing permeability of the aquifer round the reinjection well.

To avoid these problems an amazing idea occurs time to time. ARMSTEAD (1983) suggested to circulate water in a closed casing well. The water flows downward through the annular space between the casing and the tubing, and upward through the production tube, while it warms up.

It seems to be a pure heat mining method without thermal water production. It would be environmentally more acceptable then any other form of geothermal energy production. Such experimental production unit has been installed in Hungary near Szolnok, in 1989. The results, as expected, were rather modest because of the small heat transfer area of the system (BOBOK et al 1993). In the following we shall introduce a mathematical model of such a system, to predict its thermal behavior in order to avoid further unefficient and expensive experiments and to show the range of the dry hole utilization.

THE MATHEMATICAL MODEL

The simplified model of a closed geothermal well is shown in Fig. 1. The casing is closed at the bottom without any perforations. The water flows downward through the annulus between the coaxial casing and tubing. Since the adjacent rock is warmer than the circulating water, the water temperature increases in the direction of the flow. An axisymmetric thermal inhomogeneity is developed around the well together with a radial heat conduction toward the well. This is the heat supply of the system. The warmed up water flows upward through the tubing while its temperature slightly decreases, depending mainly on the heat conduction coefficient of the tubing. The system is analogous to a countercurrent heat exchanger. The main difference is the increasing adjacent rock temperature distribution with the depth. Thus the familiar methods for design of heat exchangers are not sufficient for this case.

Let's consider the schematic drawing of the system in Fig 2. The geometrical parameters are defined as shown in the figure. It is convenient to separate the system into two sub-systems. One of them is the flowing fluid, in which the convective heat transfer is dominant. The other is the adjacent rock mass around the well, with a radial conductive heat flux. Thus the internal energy balance can be written for the two subsystems in a simplified form. Cylindrical co-ordinates are chosen. The radial coordinate r is measured from the axis of the coaxial cylinders, while z lies along the axis directed downward. The steady, axisymmetric turbulent flow is taken to be uniform at a cross-section, the velocity v and temperature T are cross-sectional average values. The indices T and A refer to the tubing and the annulus. Thus the balance equation of the internal energy for the flow across the tubing is:

$$R_{1i}^2 \pi \rho c v_T = 2R_{1i} \pi U_{1i} (T_T - T_A) dz \tag{1}$$

in which ρ is the density, c is the heat capacity of the fluid, U_{1i} is the overall heat transfer coefficient referring the inner radius of the tubing. For the annular flow we get:

$$\left(R_{2i}^2 - R_{10}^2\right) \pi \rho c v_A dT_A = 2R_{2i} \pi U_{2i} (T_B - T_A) dz + 2R_{1i} \pi U_{1i} (T_T - T_A) dz \tag{2}$$

where T_B is the temperature at the borehole radius R_B, U_{2i} is the overall heat transfer coefficient referring to the radius R_{2i}.

The unsteady axisymmetric heat flux around the well can be expressed as

$$\dot{Q} = 2\pi k_R \frac{T_\infty - T_B}{f(t)} \tag{3}$$

in which $\dot{Q}$ is the heat flux over the unit length cylinder, k_R the heat conductivity of the rock. The undisturbed natural rock temperature is T_∞, its distribution linear with depth

$$T_\infty = T_s + \gamma z \tag{4}$$

where T_s the annual mean temperature at the surface γ is the geothermal gradient. The parameter f(t) is the transient heat conduction time function (RAMEY, 1962).

SOLUTION

Combining the equations (1) and (2) we obtain

$$\left(R_{2i}^2 - R_{10}^2\right) \pi \rho c v_A dT_A - R_{1i}^2 \pi \rho c v_T dT_T = 2R_{2i} \pi U_{2i} \pi U_{2i} (T_B - T_A) dz \qquad 5)$$

It is obvious, that

$$R_{1i}^2 \pi \rho v_T = \left(R_{2i}^2 - R_{1i}^2\right) \pi \rho v_A = \dot{m} \tag{6}$$

from the continuity equation, where m is the mass flow rate. Thus the energy balance is obtained in the simple form:

$$\dot{m}cd(T_A - T_T) = 2R_{2i}\pi U_{2i}(T_B - T_A)dz \tag{7}$$

The heat fluxes at the cylindrical surface of the borehole are equal both in the fluid and the rock side:

$$2\pi k_R \frac{T_\infty - T_B}{f(t)} = 2R_{2i}\pi U_{2i}(T_B - T_A) \tag{8}$$

Combining the equations (8) and (9) we get

$$\frac{d(T_A - T_T)}{dz} = \frac{2R_{2i}U_{2i}k_R(T_\infty - T_A)}{\dot{m}c[k_R + R_{2i}U_{2i}f(t)]} \tag{9}$$

Since the variables on the right-hand side are constants for a given well, at a constant mass flow rate the so-called depth coefficient can be introduced:

$$A = \frac{\dot{m}c(k_R + R_{2i}U_{2i}f)}{2R_{2i}U_{2i}k_R} \tag{10}$$

Thus we get a simple differential equation

$$A\frac{d(T_T - T_A)}{dz} = T_B - T_A \tag{11}$$

The other energy equation for the flow through the tubing can be written as

$$\frac{\dot{m}c}{2R_{1i}\pi U_{1i}}\frac{dT_T}{dz} = T_T - T_A \tag{12}$$

Since the coefficients of the left-hand side of the equation are independent of the depth, they can be replaced by a constant

$$B = \frac{\dot{m}c}{2\pi R_{1i}U_{1i}} \tag{13}$$

thus we obtain the differential equation

$$B\frac{dT_T}{dz} = T_T - T_A \tag{14}$$

Combining the equations (11) and (14), a second-order linear inhomogeneous differential equation is obtained:

$$AB\frac{d^2T_A}{dz^2}+B\frac{dT_A}{dz}-T_A+T_s+\gamma(z-B)=0 \tag{15}$$

In a similar way we can obtain for the flow through the tubing

$$AB\frac{d^2T_T}{dz^2}+B\frac{dT_T}{dz}-T_T+T_s-\gamma z=0 \tag{16}$$

These equations can be solved easily in the form:

$$T_T=T_s+\gamma(z+B)+K_1e^{x_1z}+K_2e^{x_2z} \tag{17}$$

and

$$T_A=T_s+\gamma z-T_i+C_1e^{x_1z}+C_2e^{x_2z} \tag{18}$$

The characteristic equations for (15) and (16) are the same, their roots are

$$x_1=-\frac{1}{2A}\left(1-\sqrt{1+\frac{4A}{B}}\right) \tag{19}$$

and

$$x_2=-\frac{1}{2A}\left(1+\sqrt{1+\frac{4A}{B}}\right) \tag{20}$$

The constants of integration in (17) and (18) can be determined satisfying the following boundary conditions.

1. At $z = 0$, $T_A = T_i$, where T_i is the temperature of the injected cold water.
2. At $z = H$, $T_A = T_T$, the bottomhole temperatures in the annulus and in the tubing is the same.
3. At $z = H$, $\frac{dT_T}{dz}=0$, the bottomhole derivative of the tubing temperature is zero. It is the consequence of the Eq. (14).
4. The energy increase of the circulating fluid is equal to the integral of the heat flux across the borehole wall between the bottom and the surface:

$$\dot{m}c(T_{out}-T_i)=\int_0^H q(z)dz \tag{21}$$

where T_{out} is the outflowing water temperature at the wellhead.

The obtained equations from the boundary conditions are:

$$T_i-T_s=C_1+C_2, \tag{22}$$

$$K_1 e^{x_1 H} + K_2 e^{x_2 H} + \gamma B = C_1 e^{x_1 H} + C_2 e^{x_2 H} \tag{23}$$

$$K_1 x_1 e^{x_1 H} + K_2 x_2 e^{x_2 H} = -\gamma \tag{24}$$

$$A\left(T_i - T_s + \gamma B + K_1 + K_2\right) = -\frac{C_1}{x_1}\left(e^{x_1 H} - 1\right) - \frac{C_2}{x_2}\left(e^{x_2 H} - 1\right) \tag{25}$$

After solving the equation system the temperature distributions (17) and (18) is determined.

RESULTS

Thus the temperature distributions of the annulus and the tubing along the depth are determined. As illustration three calculated temperature distributions for a closed well are presented. The depth is 1900 m, the casing is 7” (177,8 mm) and the tubing is 3 ½” (88,9 mm). The undisturbed bottomhole tempetature is 96 ^oC, the annual mean temperature at the surface is 10,5 ^oC. Three different mass flow rate is taken, 1 kg/s, 5 kg/s and 20 kg/s. The tubing material is steel (k = 50 W/m^oC) and polypropylene (k = 0,2 W/m^oC) in every case. The bottomhole temperature is depending strongly on the mass flow rate. If the tubing is steel, the outflowing water temperature is very low, especially at high flow rates. Results are some better applying polypropylene tubing with low conductivity. It can be seen that the bottomhole temperature is rather moderate, thus the outflowing water temperature too. The higher geothermal gradient at a given region can obtain higher bottomhole and outflowing temperatures. It seems only small-scale utilizations can be based on this clean technology.

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