Geosciences and Engineering, Vol. 1, No. 2 (2012), pp. 321–327.

HEAT LOSSES IN A GEOTHERMAL RESERVOIR

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Abstract
The petroleum industry has always participated in the utilization of favourable geothermal conditions in the country. Most of the Hungarian geothermal wells were drilled by the MOL Ltd. as CH prospect holes. Accordingly the field of geothermics belonged to the petroleum engineering, although marginally. It was therefore a surprise to hear of the decision of MOL Ltd. to build a geothermal power plant of about 2–5 MW. The site selected for the geothermal project is near the western border of a Hungarian oilfield, close to the Slovenian border. The location of the planned geothermal power plant was chosen after an analysis of suitable wells owned by the MOL Rt. The decision was made on the basis of different reservoir data. The existence of a reservoir of the necessary size, temperature, permeability, productivity and water chemistry data was proved. The wells provide enough information to understand the character of the reservoir and will be the production wells used by the planned power plant. Before the drilling operations and the discharge tests, the temperature of the outflowing water can be prognosticated. This is made possible by applying recently elaborated simulation methods (Bobok–Tóth, 2003; Tóth, 2004).

1. The selected site and wells

The site of the planned geothermal power plant was chosen after an analysis of the suitable wells of the MOL Rt. The wells Ortaháza Ny-3 and Ortaháza Ny-5 are suitable to investigate the behavior of the reservoir and will be the producing wells of the planned power plant. The Ortaháza Ny-3 well has a depth of 3200 m and a 7” string (178 mm) to 2028 m. It is completed as an open hole from the 7” casing shoe to the bottom. The well completion is shown in *Figure 1*. There are two perforated sections at 1930–1934 m, and 2589–2595 m. The Triassic formation is reached at 2851 m. The Ortaháza Ny-5 well was drilled to 2930 m. It has a 7” (178 mm) string to 2892 m. Below the casing an open hole section can be found. The Triassic formation starts at 2917 m. At this depth the undisturbed reservoir temperature is 141 ^{o}C. During the well test 128 ^{o}C was measured at the depth of 2879 m, but this value is necessarily lower than the previous because the circulated drilling mud cooled down the surrounding rock. The flow rate was 96 m^3/day (1,11 l/s) through a choke of 20 mm diameter. The well is temporarily closed by a cement plug at the interval of 1869–1919 m, under the plug the wellbore is filled by drilling mud.

According to the preliminary ideas both wells will be drilled further 300 m. Thus Triassic formation will be drilled through its full thickness to get inflow surface as much as possible. Thus the flow rate of the well can increase. The well Or-Ny-5 will be the production, Or-Ny-3 the reinjection well. A submersible pump will be run in the 9 5/6” casing of the production well, after cutting the upper section of the 7” casing. Thus the designed flow rate of 50 l/s can be attained. First a one-day discharge test is carried out. If this short-term test is successful a six-month long-term discharge test comes after it. Within the well test the wellhead pressure, the flow rate, the outflowing water temperature the dynamic fluid level and the chemical components will be measured. At the reinjection well injection tests will be made.

Before the drilling operations and the discharge tests the temperature of the outflowing water can be prognosticated. It is possible to use by applying recently elaborated simulation methods (Bobok–Tóth, 2003; Tóth, 2004). This calculation is introduced in the following.

2. Calculation of the temperature distribution

The first solution of this problem was developed by Boldizsár (1958). This version is a simplified solution of the original Boldizsár's work. The Bessel functions of the exact solution are replaced by a transient heat conduction function. A cylindrical coordinate system is chosen in accordance the geometry of the well. The z-axis of it is the symmetry axis of the well and is directed downward. The origin is at the surface as it is shown in *Figure 1*.

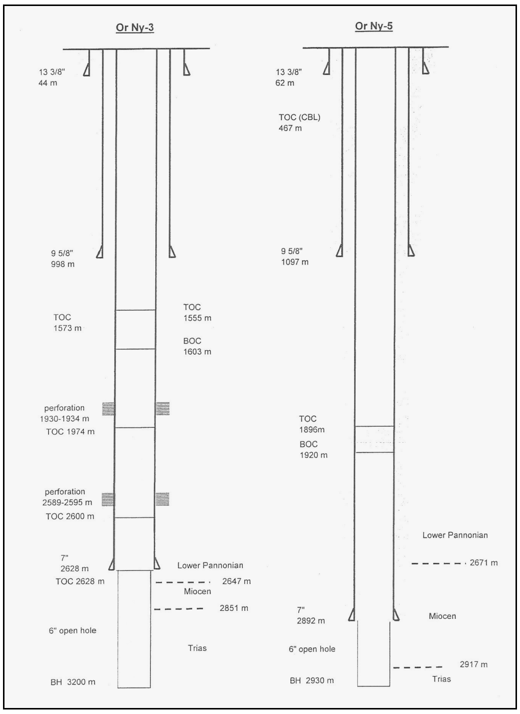

Figure 1: Schematic drawings of the wells

The balance equation of the internal energy is written for a control surface Bobok–Tóth, (2003). Let it be a cylinder coaxial with the well. Consider an infinitesimal length of it, bounded by horizontal planes in an arbitrary depth, a distance dz from each other. Its radius is R_∞, the distance of the location of the undisturbed geothermal temperature from the borehole axis.

The control surface is shown in *Figure 2.* Two sub-systems can be distinguished within it. One is the upflowing hot water in the tubing; the other is the well and the surrounding rock around it. Between the upflowing water and the tubing wall a surface heat transfer is the dominant phenomenon, across the tubing interval surface of the radius of R_{1B}. Across the elements of the well structure and the surrounding rock a radially outward heat conduction is developed.

The overall heat resistance of the wellbore consists of the following elements. Across the tubing wall between the outer radius R_{1K} and the inner radius R_{1B} radial heat conduction occurs. The annular space between the tubing and casing is filled mostly by muddy water. Sometimes it is filled by foamy cement or other heat insulating material. In the first case natural convection, in the latter radial conduction is the way of the heat transfer. Across the casing wall and the cement sheet radial conduction can be found.

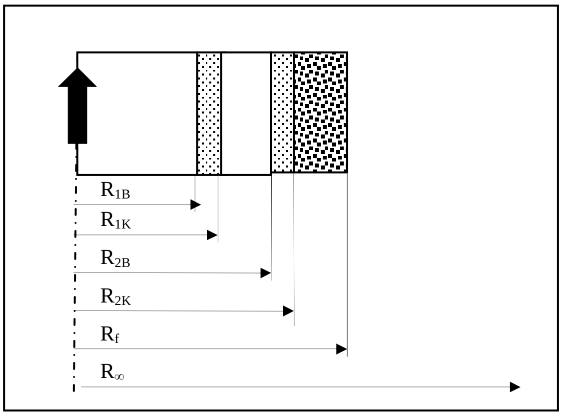

Figure 2: Control surface element

Some approximate assumptions are made before the solution of the energy equation. The upward flow in the tubing is considered to be a steady, fully turbulent flow. The flowing fluid is incompressible. It is well known that the greater Reynolds-number the more uniform the velocity profile. In the fully rough turbulent region the velocity profile can be replaced by the cross-sectional average velocity. Because of the turbulent mixing the radial temperature distribution can be also considered uniform. The temperature drop in the thermal boundary layer close to the wall can be replaced by a finite temperature jump. The vertical heat conduction in the water is neglected. The temperature distribution of the surrounding rock around the well is considered axi-symmetric. The model is adequate as long as the heat transfer around the well is conductive.

The balance equation of the internal energy is written first for the upflowing water (Bobok–Tóth, 2003). The decrease of energy content of the water is equal to the transferred heat across the wellbore. The overall heat flux is calculated by an overall heat transfer coefficient U_{1B}. Thus

$$\dot{m}cdT = 2\pi R_{1B} U_{1B} \left(T - T_F\right) dz \tag{1}$$

The radial heat flux across the wellbore is equal to the heat flux in the surrounding rock

$$2\pi R_{1B} U_{1B} \left(T - T_F\right) = 2\pi k_k \frac{T_F - T_p}{\ln \frac{R_\infty}{R_F}} \tag{2}$$

The quantity $1n \frac{R_\infty}{R_F}$ is the increasing function of the time. R_∞ is the radius of the contour of the heated region around the well, where the undisturbed geothermal temperature is

$$T_\infty = T_0 + \gamma z \tag{3}$$

T_0 is the annual mean value of the surface temperature.

The geothermal gradient is γ = 0,0406 $^oC/m$. Since the surrounding rock around the wellbore is heated by the upflowing hot water the value of $1n \frac{R_\infty}{R_F}$ increases monotonically with time. The radius of the contour of the heated region decreases along the depth, because the bottomhole temperature of the water and the rock is equal (Tóth, 2005). In the model its integral mean is taken, as the function of the Fourier-number and the overall heat transfer coefficient.

$$\ln \frac{R_\infty}{R_F} = f\left(Fo, U_{1B}\right) \tag{4}$$

This so-called transient heat conduction function is a dimensionless quantity. The Fourier-number is the similarity invariant of the transient heat conduction:

$$Fo = \frac{k_\infty}{\rho_k c_k} \frac{t}{R_F^2} \tag{5}$$

Equations (1) and (2) lead to a differential equation to determine the temperature distribution along the depth in the well:

$$\frac{dT}{dz} = \frac{2\pi R_{1B} U_{1B} k_k \left(T - T_0 - \gamma z\right)}{\dot{m}c\left(k_k + fR_{1B} U_{1B}\right)} \tag{6}$$

Those parameters independent of depth are embedded into one quantity

$$A = \frac{\dot{m}c\left(k_k + f \cdot R_{1B} U_{1B}\right)}{2\pi R_{1B} U_{1B} \cdot k_k} \tag{7}$$

In this case Eq.(6) can be written in the simple form

$$A \frac{dT}{dz} = T - T_0 - \gamma z \tag{8}$$

Its general solution is

$$T = T_0 + \gamma(z + A) - \gamma A e^{\frac{z-H}{A}} \tag{9}$$

By integrating the differential equation (8) at one step between the surface and the bottom of the well we make an obvious approximation. As the well geometry and the surrounding rock quality changes with the depth it can be divided into many suitable chosen sections along the depth. Some differences occur in the boundary conditions only.

The coefficient A has different values within each interval. The lowest section is denoted by 1, the subsequent sections are 2, 3 … etc. The outflowing water temperature for the i-th interval is equal to the inflowing water temperature for the (i+1)-th interval. This boundary condition can be formulated easily.

For the first the lowest interval the temperature distribution can be obtained as

$$T^{(1)} = T_0 + \gamma(z + A_1) - \gamma A_1 e^{\frac{z-H}{A_1}} \tag{10}$$

where A_1 refers for the first interval.

The temperature distribution along the depth can be calculated for the second section as

$$T^{(2)} = T_0 + \gamma(z + A_2) + \left[T_{out}^{(1)} - T_0 - \gamma(H_2 + A_2)\right] e^{\frac{z-H_2}{A_2}} \tag{11}$$

For the third interval the temperature distribution is

$$T^{(3)} = T_0 + \gamma(z + A_3) + \left[T_{out}^{(2)} - T_0 - \gamma(H_3 + A_3)\right] e^{\frac{z-H_3}{A_3}} \tag{12}$$

Finally we get the temperature at the wellhead as

$$T_{out}^{(3)} = T_0 + \gamma A_3 + \left[T_{out}^{(2)} - T_0 - \gamma(H_3 + A_3)\right] e^{-\frac{H_3}{A_3}} \tag{13}$$

The three sections of the temperature distribution function obtain a continuous curve. Only the derivative has a jump at depths of H_1 and H_2.

3. Calculated result

Calculated results and the outflowing water temperatures are shown in *Figure 3*. It can be recognized that as the heated region around the borehole is developed with the time, the temperature at the wellhead increases and heat losses of the water decrease. The mass flow rate is the parameter of the curves. If the mass flow rate is smaller, the wellhead temperature decreases.

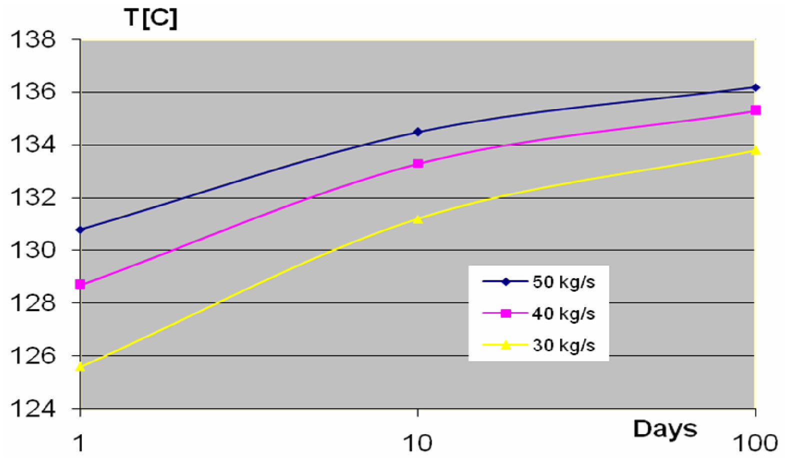

Figure 3: Wellhead temperatures vs. time

The strong influence of the mass flow rate on the temperature distribution can be recognized in both diagrams. The trend is the same in all cases. The results of the discharge test will probably modify this picture slightly.

4. Summary

A simulation procedure was introduced to determine the temperature distribution in hot water producing geothermal wells. Some factors influencing the temperature distribution have constant values such as bottomhole depth, the thermal conductivity of the rock, the completion of the well and the geothermal gradient. A different group of variables depends on the performance of the well, thus can be recognized analyzing the temperature distributions. The decreasing of the flow rate induced an important decrease of the temperature. In the initial days of the discharge test the water temperature increases until it reaches a stabilized steady value, this is the standard temperature for the operation of the power plant.

List of Symbols

T : bottomhole temperature [°C]
T_0 : surface temperature [^{o}C]
T_{out}: outflowing temperature [^{o}C]
T_∞ : undisturbed rock temperature [^{o}C]
f : transient heat conductivity function [–]
m : flow rate [kg/s]
c : specific heat capacity [J/kgK]
R : diameter [m]
U : overall heat transfer coefficient [W/m^{2}K]
K : heat conductivity [W/mK]

"Acknowledgement: This work was carried out as part of the TÁMOP-4.2.1.B-10/2/KONV-2010-0001 project in the framework of the New Hungarian Development Plan. The realization of this project is supported by the European Union, co-financed by the European Social Fund."

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