

First geothermal pilot power plant in Hungary

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Prvá geotermálna skúšobná elektrárň v Maďarsku

The Hungarian 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 tender was published in 2004.

The site selected for the geothermal project is near the western border of an 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 bases of different reservoir data. The existence of a reservoir of the necessary size, temperature, permeability, productivity and the water chemistry data was proved. The wells provide an enough information to understand the character of the reservoir and will be the production wells used by the planned power plant.

*The depth of the wells is about 2930 - 3200 m. The Triassic formation is reached at around 2851 m. The production and the reinjection wells are planned. The primary objective of the evaluation is to further learn the nature of the geothermal system. First a one-day discharge test is carried out. If this short-term test is successful, a six-months long-term discharge test will follow. The first period of the test is a transient **phenomenon**. 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. The heat transfer around the bore-hole is influenced by the flow rate and the time. For the right appreciation of the measured data, it is very important to analyse the heat transfer processes around the bore-hole. The obtained data from the experiments must be also fitted into the framework of a mathematical model in order to form a coherent system.*

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).

Key words: Heat transfer, bore-hole, production and injection well, wellhead pressure, flow rate, outflowing water temperature, dynamic fluid level, geothermal power plant

The selected site and wells

The site of a 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 Fig.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 can be found. The Triassic formation starts at 2917 m. At this depth the undisturbed reservoir temperature is 141 °C. During the well test, 128 °C was measured at the depth of 2879 m, but this value is necessarily lower than the previous one because the circulated drilling mud cooled down the surrounding rock. The flow rate was 96 m³/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 the drilling mud.

According to the preliminary ideas both wells will be drilled further 300 m. Thus, the Triassic formation will be drilled through its full thickness to get an 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-months 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 elaborated simulation methods (Bobok, Tóth, 2003; Tóth, 2004). This calculation is introduced in the followings.

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Calculation of the temperature distribution

The first solution of this problem was developed by Boldizsár T. (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 with 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 Fig. 1.

The balance equation of the internal energy is written for a control surface Bobok E.-Tóth A. (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.

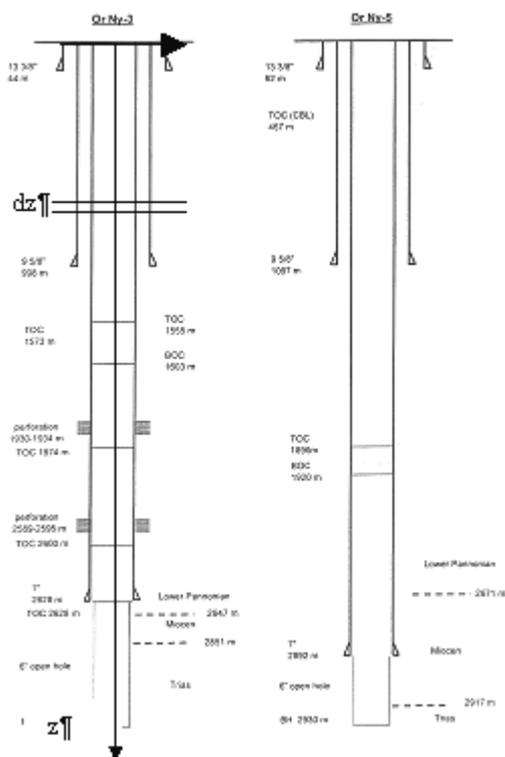


Fig. 1. Schematic drawings of the wells.

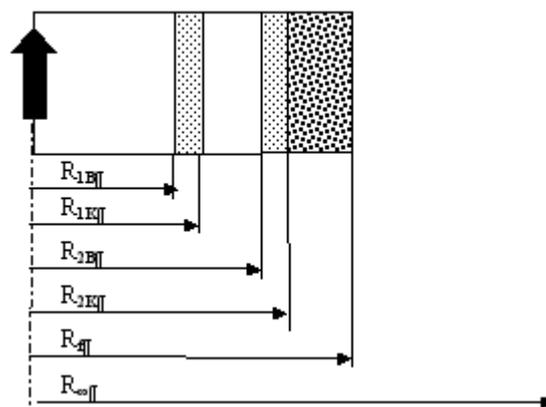


Fig. 2. Control surface element.

The control surface is shown in Fig.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, a natural convection in the latter radial conduction is the way of the heat transfer. Across the casing wall and the cement sheet, a radial conduction can be found.

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 axisymmetric. 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 the energy content of water is equal to the transferred heat across the wellbore. The overall heat flux is calculated by the overall heat transfer coefficient U_{1B} . Thus

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

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

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

The quantity $\ln \frac{R_\infty}{R_F}$ 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

$$T_\infty = T_0 + \gamma z \quad (3)$$

T_0 is the annual mean value of the surface temperature. The geothermal gradient is $\gamma = 0,0406$ °C/m. Since the surrounding rock around the wellbore is heated by the upflowing hot water, the value of $\ln \frac{R_\infty}{R_F}$ increases

monotonically with time. The radius of the contour of the heated region decreases along the depth, because the bottomhole temperature of 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:

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

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

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

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

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

The parameters which are independent of depth, are embedded into one quantity

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

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

$$A \frac{dT}{dz} = T - T_0 - \gamma z \quad (8)$$

Its general solution is

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

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 suitably 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 of the temperature distribution can be obtained as

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

where A_1 refers for the first interval.

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

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

For the third interval the temperature distribution is

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

Finally we get the temperature at the wellhead as

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

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 .

Calculated results

The calculated results are shown in Fig. 3, 4, 5 and 6. outflowing water temperatures are shown in Fig. 3. at the wellhead depending on the duration of production. It can be recognized that as the heated region around the borehole is developed with the time, the temperature at the wellhead increases and the heat losses of water decrease. The mass flow rate is parameter of the curves. If the mass flow rate is smaller, the wellhead temperature decreases.

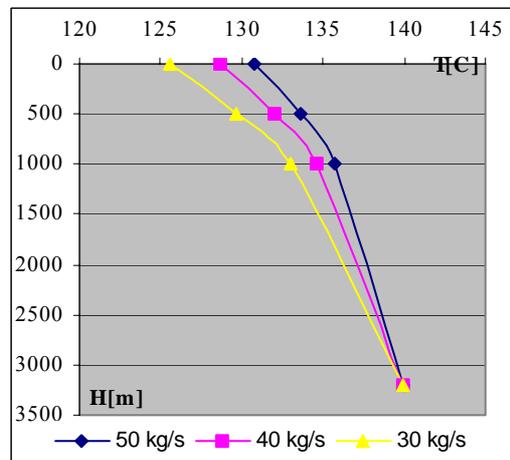
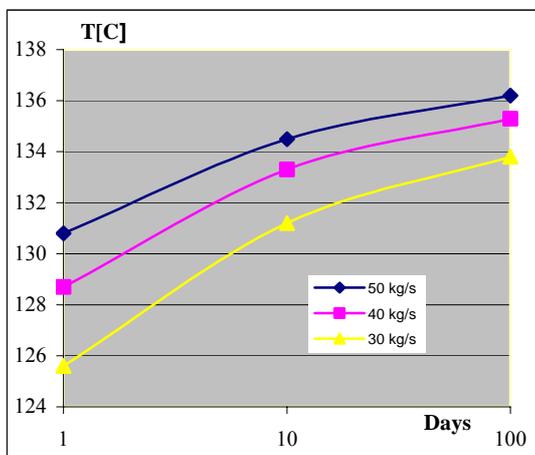


Fig. 3. Wellhead temperatures vs time.

Fig. 4. Temperatures after 1 day.

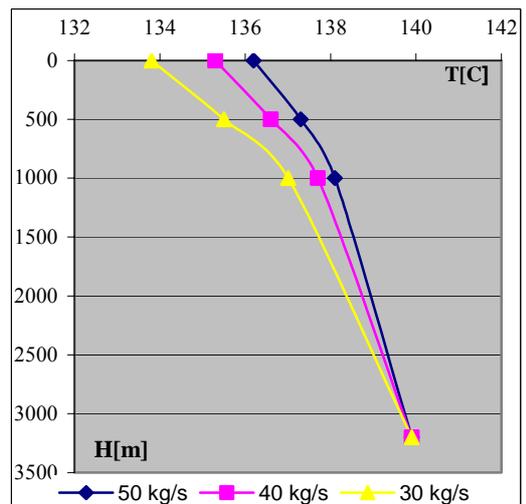
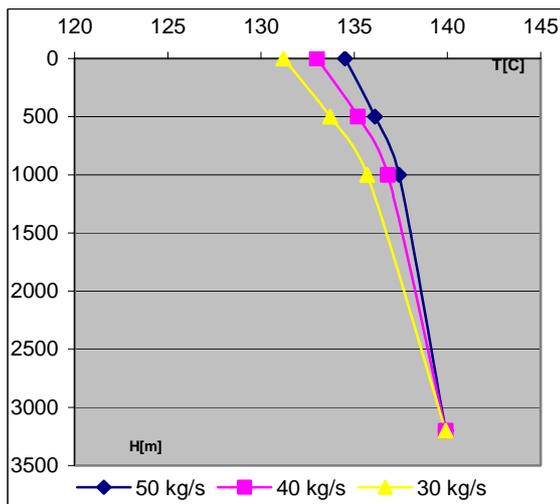


Fig. 5. Temperatures after 10 days.

Fig. 6. Temperatures after 100 days.

In Figs. 4, 5 and 6, the temperature distribution of the upflowing hot water is shown. In Fig. 4., the temperature is shown along the depth in the first day of the discharge test. The temperature distribution developed on the 10th day is shown in Fig.5. The stabilized temperature distribution on the 100th day is shown in Fig. 6.

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.

Summary

A simulation procedure was introduced to determine the temperature distribution of hot water producing geothermal wells. Some factors influencing the temperature distribution have a constant value such as the bottomhole depth, the thermal conductivity of the rock, the completion of the well and the geothermal gradient. A different group of variables depend on the performance of the well; it can be recognized by 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.

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