Flow Rate Estimate for Separate Layers in a Geothermal Well based on Well Log Temperature

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Abstract: The article gives the procedure of estimating flow rate in separate layers in a geothermal well based on well log temperature. For this purpose a theoretical mathematical model was developed with results examined in a suitable well by using a flow measurement device.

Key-Words: geothermal energy, heat transmission, flow rate estimate, well log temperature, mathematical model, geothermal well

1 Introduction

Heat is a form of energy, and geothermal energy is literally the heat contained within the Earth that generates geological phenomena on a planetary scale. Geothermal energy is often used nowadays, however, to indicate that part of the Earth's heat that can, or could, be recovered and exploited by humankind. The presence of volcanoes, hot springs and other thermal phenomena must have led our ancestors to surmise that parts of the interior of the Earth were hot. So far utilization of this energy has been limited to areas in which geological conditions permit a carrier (water in the liquid phase or steam) to "transfer" the heat from deep hot zones to or near the surface, thus giving rise to geothermal resources, but innovative techniques in the near future may offer new perspectives in this sector [1].

The conventional use of geothermal energy is usually divided into:

- high enthalpy resources (water with temperature above 150°C), used for electricity generation,
- low enthalpy resources (water with temperature under 150°C), usually used directly for heating.

According to data [2] the installed geothermal electricity generating capacities world-wide are increasing every year: In 1995 they were 6.833 MW_e, in 2000 7.974 MW_e and in 2005 8.912 MW_e [3].

The installed capacities of geothermal energy users from low enthalpy resources [4] amounted to 15.145 MW_t in year 2000 at the use of geothermal energy of 190.699 TJ/year. The total installed capacity, reported at the end of 2004 is 27.825 MW_t, almost a two-fold increase over the 2000 data, growing at a compound rate of 12,9 % annually [5].

2 Geothermal energy in Slovenia

Geologic and tectonic structure of Slovenia is complicated, its territory is comprised of five different geological structural units: the Pannonian Basin, Eastern Alps, Southern Alps, border region between Eastern and Southern Alps and Outer Dinarids. Due to the fact that Slovenia lies in an area where Alps, Dinarids and the Pannonian Basin join, folding and thrusting which accompanied the collision of African and European plate created deep ruptures (tectonic zones), which enabled a deeper circulation of water [6].

The depth of Earth's crust is essential for the transmission of water towards the surface. It is the thickest in the western part of Slovenia, around 50 km. The layer gets thinner towards the east, so that in the easternmost part it is only around 30 km.

Water suitable for heat gathering is situated in fissure aquifiers (mostly carbonate, in dolomite and limestone, partially also in sandstone) as well as in granular aquifiers (sand and gravel). Fissure aquifiers are represented by older layers, mostly

Mesozoic in age. In tertiary depressions where a full consolidation of sediments has not occurred yet and where the intergranular bonding has not been extracted yet, sand and gravel can be found in depths beyond 1.000 meters.

Slovenia already has 27 locations [7] at its disposal where geothermal water comes from wells, with total installed heat 42 MW_t (of which 53% are used). 750 TJ of heat comes from this source every year. It is being estimated that Slovenia has on its disposal 50.000 PJ of theoretical sources of heat found only in geothermal aquifiers, of which 12.000 PJ are usable.

Search for sources of thermal water in tertiary sediments of the Pannonian basin shows that any significant amounts of thermal water can only be found in Pliocene layers of Mura formation and that the thermal aquifier (which in the whole represents a low enthalpy geothermal system), that is nowhere thicker than 100 meters, supplies water for almost all balneologic- recreational centres in the area of north eastern Slovenia.

There is only one high enthalpy geothermal system known to lie in the area of Slovenia, layers of tertiary basis, which is in smaller depths in its northern part (up to 2000 meters), where the temperature of geothermal water comes up to 100°C. In the southern part, among towns Ptuj, Ormož, Ljutomer and Lendava, these layers can be found in greater depths (4000 to 5000 meters), where geothermal water probably reaches more that 200°C.

3 Well Lendava Le-2g

Well Le-2g lies in the north-eastern part of Slovenia, in municipality Lendava with Gauss Kruger coordinates X= 5 158 596, Y= 5 611 687, Z= 161,4. The well represents a low enthalpy geothermal resource with more producing intervals in depths from 810 to 1500 meters. It was finished in the period between 16.05.1994 and 14.06.1994. 7″ sloted liner in the well is divided to 9 perforated section between 813 and 1422 m.

The well produces geothermal water with artesian flow in the amount 11,6 litres/second at the temperature of approximately 64˚C at the wellhead.

From the tested compounds view the water sample contents a medium amount of mineral substances. The water from the well is a very low hardness thermal water of a sodium-hydrogen-carbonate character, with 1200 mg/liter of total dissolved solids (TDS). Report of water analysis shows, that the structure of geothermal water from well Le-2g is the following:

Na^+	310 mg/l or 95,03 meq/l
HCO_3^-	830 mg/l or 98,87 meq/l
pH	7,9
Corrosion index	+ 0,5
M alkalinity	13,6 mmol/l
Total hardness	10 CaOmg/l
Spec. el. conduct.	670 µS/cm

The field team of Geo-Log Ltd Hungary carried out hydrodynamic tests of the Le-2g thermal water well in summer 2005 as part of well inspection. Performed logs and tests were: Bottom check, Calliper log, Gamma Ray log, Full Wave Sonic log (Cement Bond evaluation, Screen position), Mud Resistivity check, Temperature, Differental Temperature log, Flow rate log, Capacity Test at well head and in 800 m depth, Recovery Test at the well head and in 800 m depth, Pressure Gradient determination (Bubble point determination), Gas and Water sampling at the well head and in 800 m depth.

4 Well log temperature

Even though measuring the temperature in a well is simple and precise, it is often neglected in practice as a suitable tool for qualitative and quantitative determination of production of separate intervals in a geothermal well.

Movement of water in a well is detectable by precise and repeated temperature measurement. Temperature patterns in a borehole may be interpreted to reveal very small water flows, and a complete temperature log may reveal many points of contact between the water in the hole and the water in fractures or porous zones of the surrounding rock [8].

For the interpretation of well log temperature it is necessary to know all the factors that affect the temperature in a well [9]. The factors include the temperature of separate layers, heat transmission between the well and separate layers, convection of heat due to flow of fluids and thermal changes of fluids in dynamic conditions [10] – Fig. 1.

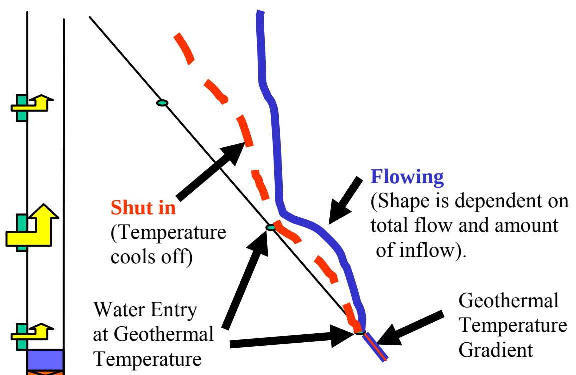

Fig. 1: Temperature profile in a geothermal well

Geothermal temperature gradient ($\Delta T/\Delta z$) in static conditions (no flow of fluid in the well) and in dynamic conditions (flow of fluid q_v=11,6 litres/second) needs to be determined in order to make a qualitative and quantitative interpretation of the flow of fluids from separate layers- Fig. 2.

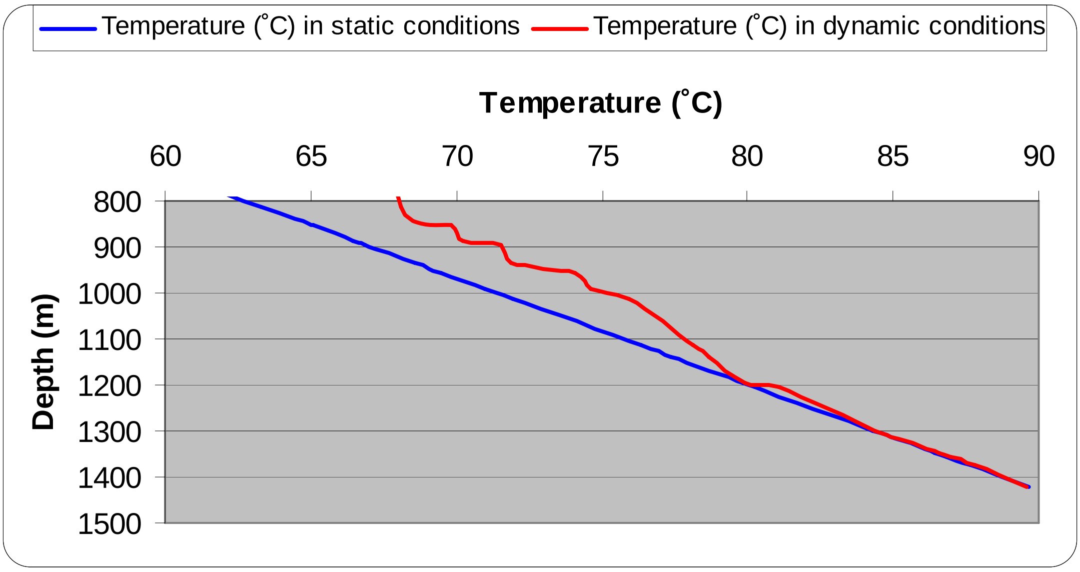

Fig. 2: The temperature gradient in well Le-2g in static and dynamic conditions (q_v=11,6 l/s)

5 Qualitative and quantitative interpretation of water inflows into the well

After measurements [11] of the temperature gradient in well Le-2g by a temperature probe at static and dynamic conditions the following productive intervals were examined, to detect and calculate the distribution of production:

- 813 m to 854 m,
- 885 m to 895 m,
- 934 m to 956 m,
- 991 m to 1011 m,
- 1115 m to 1138 m,
- 1195 m to 1205 m,
- 1298 m to 1310 m,
- 1348 m to 1358 m,
- 1376 m to 1422 m, which show productivity of layers on Fig. 3.

The distribution of production for separate sections was determined by the field team of Geo-Log Ltd. Hungary also.

6 Mathematic model

Hydrodynamic and thermodynamic processes going on during the pumping process in the well and surrounding stone are quite complex for an exact integration of a system of differential equations that describe the process. Therefore the analytical model is based on a simplified presumption which considers the stationary flow without environmental disturbances and temperature loss, so we can define volume flows of separate layers based on the measured temperatures of layers at static and dynamic conditions on various depths.

When recording the analytical model of the system in well we use the heat balance equation of separate measured layers (1):

$$\Phi = \sum_{i=1}^{N} c_{pi} \cdot q_{mi} \cdot t_i = \sum_{i=1}^{N} c_{pi} \cdot q_{vi} \cdot \rho_i \cdot t_i \qquad (1)$$

where: C_{pi} - specific heat (J/kgK)
q_{vi} - volume flow (m^3/s)
t_i - temperature (˚C)
ρ_i - density (kg/m^3)
Φ - heat flow (J/s=W)

Due to small changes in temperature of geothermal water along the well, density and specific heat are assumed to be constant.

The computer programme for calculation of productive intervals is based on presented mathematical model.

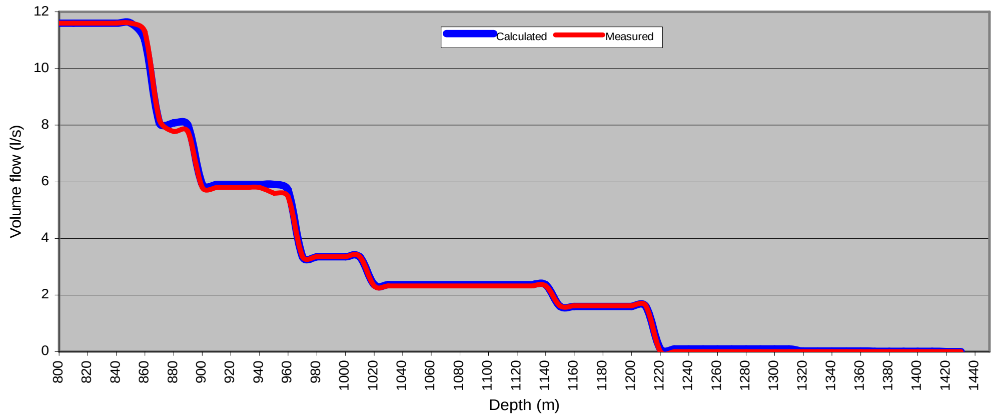

Fig. 3: Calculated and measured flow rate in dependence of the depth

7 Conclusion

Productivity of separate layers in a geothermal well can be qualitatively and quantitatively defined on the basis of well log temperature (measurement of temperature depending on the depth) in static and dynamic conditions.

Where fluid comes into the well, anomalies can be observed, which serve for a qualitative determination of productive layers.

The anomalies which occur due to the inflow of fluids into the well can be used for a quantitative estimation of productivity of separate layers. The developed mathematical model is based on temperature measurements at static and dynamic conditions on various depths and on heat balance of each separate layer.

Productivity of layers in well Le-2g defined on the basis of a mathematical model has been verified by a flow measurement device. The results of the measurements show agreement.

The advantage of temperature measurement in static and dynamic conditions and the mathematical model calculation is in the fact that the productivity of separate layers in a geothermal well can be established quickly and with low costs.

Continuous measurements of productivity and pressures of separate layers in a geothermal well are of vital importance for the analysis of the state of water under ground. In this way it can be determined which layers will be productive in long term, which again helps at defining the location and construction of reinjection well through which the water is returned under ground. Efficient long term use of geothermal water as a renewable resource can only be assured by returning water.

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