Proceedings European Geothermal Congress 2007
Unterhaching, Germany, 30 May-1 June 2007

Hungary's Pilot Geothermal Power Plant "Generates" Unnecessary Scrutiny Concerning the Thermal Lake of Hévíz

Aniko Toth PhD

University of Miskolc, Department of Petroleum Engineering 3515-Miskolc Hungary

toth.aniko@uni.miskolc.hu

Keywords: GEOTHERMAL PILOT POWER PLANT, THERMAL LAKE, ENVIRONMENTAL IMPACT, HEAT FLUX GAP

ABSTRACT

The implementation of Hungary's first geothermal power plant was decided two years ago. The chosen site is a small village called Iklódbördoce in southwestern Hungary. A deep karstic limestone aquifer will be tapped by a doublet. The depth of the aquifer is about 3200m and its temperature is 142 ^{o}C. The estimated volume of the combined fractures and voids is more than 8 million m^{3}. The pilot power plant based on this doublet may produce 2Mwe. The planned power plant caused serious concern for the inhabitants of Hévíz, where a popular health and tourism economy, developed around the famous thermal lake, was thought to be in jeopardy. The lake has a supply from the transdanubian karstic aquifer, thus the intervention to the deep karst inspired fear in spite of the 50km distance between the power plant and the lake. Investigation from many aspects verified that the deep reservoir of Iklódbördoce and the shallower aquifer supplying the Lake Hévíz does not negatively impact either underground flow system.

1. THE GEOTHERMAL PILOT POWER PLANT

Hungary's oil and natural gas reserves are not significant. Most of its hydrocarbon fields will deplete in the foreseeable future. On the other hand, Hungary has favorable natural conditions for geothermal energy production and utilization. The high terrestrial heat flow varies between the values of 0,08 W/m^{2} and 0,13 W/m^{2}. The geothermal gradient falls into the interval between 0,042 ^{o}C/m and 0,065 ^{o}C/m. There are vast sedimentary and fractured reservoirs suitable for thermal water production. The utilization of these low-enthalpy reservoirs has a long tradition in Hungary. Mainly agricultural, balneological and district heating applications are at present.

Geothermal electricity production is a new alternative in Hungary. The interest of petroleum industry has been aroused for this utilization. There are many exploratory drilling sites of suitable high bottomhole temperature for electricity production. There were many possible reservoirs and with proper well parameters. After thorough filtering of them, two exploratory wells were chosen near to a small oilfield Ortaháza. The preferred site is in Southwestern part of Hungary near to the Slovenian border as shown in (Fig.1). A deep Triassic fractured limestone aquifer is there at the depth of 3000 m. The two dry holes are the Ortaháza-West-5, and the Ortaháza-West 3. The Ortaháza-West-5 well was drilled to 2930 m. It has a 7" casing to 2892 m, which is cemented up to 467m. It is finished as an open hole, from the 7" casing shoe to the bottom. The Triassic carbonate rocks starts at 2917m depth. The reservoir temperature is 142^{o}C. The Ortaháza-West-3 well was drilled to 3200m. The well has a 7" casing to 2628m depth. The distance between the two wells is about 960m. The quality of the thermal water in the reservoir is quite favorable, its total dissolved salinity 5,8mg/l. The main production zone is the Triassic formation, but the wells are only drilled a few meters into that formation. Depending on the thickness of the Triassic formation and depth to possible permeable intervals in that formation the well will be deepened during a workover. This depth increase will be at least 200-300m.

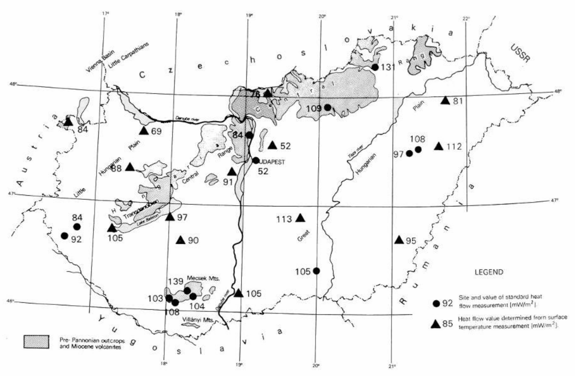

Figure 1: Heat flow data for Hungary (mW/m2)

Thus, the well pair can form a doublet. Ortaháza W-5 can be the production well and Ortaháza W-3 can be the injection well. The production well is fitted with a submersible pump lifting 50 kg/s of hot water. The temperature of the outflowing water at the wellhead is a calculated to be 136^{o}C by mathematical simulation, Toth (2006.). These data make it possible to attain a theoretical electric power of 2MW with a power plant based on these doublet parameters. If the long-term production tests are successful, two further wells would be drilled. In accordance to the Hungarian Environmental Act the utilized thermal water will be injected back to the same aquifer..

2. THE THERMAL LAKE OF HÉVÍZ

Hungary is an extremely rich thermal water country. Its thermal water reserves are significant even on a world scale. Most of thermal waters contain dissolved minerals. So this makes them suitable for bathing and drinking cures of a medical nature. There are more than a thousand wells in Hungary producing thermal water hotter than 35 ^{o}C. Natural springs are well known throughout the country Erdelyi (1980). Perhaps the most unique surface geothermal manifestation is the thermal lake of Hévíz. Hévíz is a small town in Western Hungary with about 6000 inhabitants. Lake Hévíz is Europe's largest thermal lake. It has an area of 47.500m^{2}. The supply of the lake is abundant more than 500 l/s. So the lake is completely replenished each day. The temperature of the lake is about 33-35°C in summer, and 26-29°C in winter. This balanced temperature is the result of a special phenomenon. A mist forms over the surface of the lake and acts as a cover, preventing heat loss from the lake surface.

The lake is fed by a thermal spring. The spring has a crater joined by a narrow channel to a cave. The depth of the cave is 40m. There are two separate springs in the cave: a warmer and a cooler one. The warmer one has a temperature of 40°C. Its flow rate is about 450 l/s. The cooler spring has a temperature 26,3°C. Its flow rate is 60 l/s. The two streams mix in the cave and the exit through the spring crater and into the lake (Fig.2.).

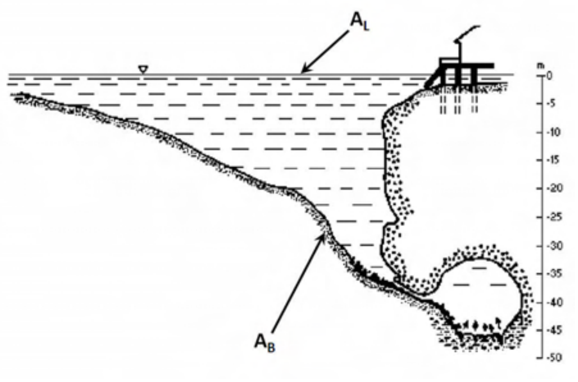

Figure 2: Cross section of the lake

The curative effect of the lake was known to the ancient Romans. Coins were found in the lake, to support the historic writings. The mud which covers the bottom of the lake is especially curative. It occupies an intermediate position between the pure inorganic mud and the tango, which has high organic matter content. The chemical composition of the water is hardly radioactive and contains reduced sulfuric compounds, as well as oxygen in solution. A special kind of bacteria is the dominant life form in the lake.

The water is famous for the positive health effects and the surrounding area has a thriving health/wellness tourism industry. The complex balneological treatment used in Hévíz, has been developed through the centuries as a unique kind of medical treatment. The sophisticated complex balneotherapy and the spa are part of the World’s cultural heritage.

In the early 1980’s the transdanubian karstic water level was lowered due to the forced production of bauxite mines. The flow rate of the Hévíz thermal spring decreased substantially in consequence of the associated drainage Erdelyi (1980). The overwhelming protests of people made the government to stop the mining. It can be understand that a planned geothermal power plant caused great fear amongst people concerning the future of the local economy. It was important and necessary to investigate the possible interaction between the hydrothermal systems of Lake Hévíz and the Ortaháza-West geothermal reservoir.

The natural hydrothermal system of the Hévíz Lake has a worldwide importance in the area of geothermal anomalies. It is interesting to compare its data with other well-known natural hot water springs.

Site **(Country)**	**Flow rate** **kg/s**	**Temp** **°C**	**Thermal power** **MW**
Tongonan (Phillippines)	437	92	149,12
Hévíz (Hungary)	517	38,8	61,26
Yangbajain (Tibet)	155	87	49,65
Cisolok (Java, Indonesia)	84,3	95	29,83
SanKopapnaeng (Thailand)	41,4	56,5	7,97

Fundamental conditions of such a large hydrothermal system are an abundant water supply and the intense geothermal heating.

The water supply originates in the Mesozoic dolomite aquifer of the nearby Keszthely Mountains, and the huge unified karstic limestone reservoir of the Bakony Mountains. The thickness of this Dachstein limestone aquifer is more than 800m. The karstic limestone rocks are uncovered at the surface more than 35% of the mountain area. So the precipitation can percolate to the aquifer easily. This is the recharge area where the permeable reservoir rocks outcrop, permitting the entrance of the rainwater. The recharge area can be calculated knowing the flow rate of the spring, the annual mean of the rainfall and the percent of the percolation. It is calculated that at least 800km^2 recharge area is necessary to provide an adequate water supply for Hévíz Lake. The elevation difference between the uniform karstic water level and the Hévíz hot spring can maintain the underwater flow along a long flow path.

The border of the limestone and dolomite rocks of high thermal conductivities (4-5 W/m °C) are encircled and covered by clay sediment having weak thermal conductivity (1,2-1,5 W/m °C) in the foreground of the mountains. Because of this configuration a very high terrestrial heat flow occurs at the foreground of the mountains. The high heat flow warms the percolated cold meteoric water flowing along from the aquifer to the spring. The length of the path line is long enough to allow the flowing water and the surrounding rocks to have the same temperature. The outflowing hot water in the spring has a temperature of 38,8°C. Taking an average value of the geothermal gradient of 0,05°C /m, it is obtained, that the path line of the karstic water must be at least 600m in depth.

The increased temperature of the water induces an upward flow along a fault system near the lake. The upflowing warm water mixes with cool ground water and finally flows into the lake. The inflowing water has formed a large crater in the bed of the lake. The overflow exits the lake through a spillway Rybach and Muffler (1981).

3. THE THERMAL ENERGY BALANCE OF THE HÉVÍZ HYDROTHERMAL SYSTEM

The operation of the Hévíz hydrothermal system can be modeled mathematically. The mathematical model is based on the previously mentioned conceptual model. The material balance equation, with the thermal energy equation form is contained within the framework of the model. The whole system can be separated into two sub-systems to investigate them separately with greater ease. One system is the lake and the crater of the thermal spring as it is shown in (Fig. 2). A control volume filled by the water of the lake is bounded by a control surface over this volume. This surface consists of two parts: one is the bed of the lake the other is the horizontal free surface of the lake.

The control volume is open: the thermal spring and the occasional rainfall is the supply for the overflow, the evaporation and the percolation into the peaty bed is the loss parameter.

The other sub-system is the recharge area and the fracture system in which the karstic water flows together their rock surroundings. It is extended to a 30x30 km surface area and has a depth of 1km.

First the thermal energy balance of the lake is considered., Bobok (1993). It is convenient to write it in the integral form:

$$\int_V \frac{\partial}{\partial t}(\rho c T)\, dV + \int_{(A)} \rho c T \vec{v} d\vec{A} + \int_{(A)} \vec{q} d\vec{A} = 0 \qquad (1)$$

The volume integral expresses the rate of increase of internal energy within the control volume V. The second term is the convective heat flux across the control surface A. The third term is the conductive heat flux across the control surface A.

Temperature measurements show that the natural convection produces an almost uniform temperature distribution. Thus the derivative in the volume integral can be replaced by an integral mean, thus

$$\int_V \frac{\partial}{\partial t}(\rho\, cT\,)\, dV \;=\; V \cdot \rho \cdot c \cdot \frac{\partial \tilde{T}}{\partial t} \qquad (2)$$

The convective heat flux can be determined as the sum of part-fluxes:

$$\int_{(A)} rcT\vec{v}d\vec{A} = -rcT_1Q_1 + rcT_2Q_2 + rcT_3Q_3 + rQ_4h_e - rcT_5Q_5 \qquad (3)$$

in which Q_1 is the flow rate of the spring, T_1 is its temperature, Q_2 is the outflowing flow rate at the spillway, T_2 its temperature, Q_4 is the flow rate of the percolating flow rate into the peaty bed, Q_4 is the flow rate of evaporation, he is the heat of evaporation Q_5 is the flow rate of the rainfall, T_5 is its temperature. It is an acceptable approximation, that

$$T_2 = T_B = \tilde{T} \qquad (4)$$

Finally we get:

$$\int_{(A)} \rho c T\vec{v} d\vec{A} = \rho c\left[-Q_1T_1 + (Q_2 + Q_3)\tilde{T} - Q_5T_5 + \frac{\rho h_e Q_4}{c}\right] \qquad (5)$$

The conductive heat flux is obtained as:

$$\int_{(A)} \vec{q} d\vec{A} = A_L h_L(\tilde{T} - T_a) - A_b h_b(\tilde{T} - T_s) - A_L q_0 \qquad (6)$$

Where, A_L is the free surface of the lake, Ta is the air temperature h_L is the heat transfer coefficient at the surface of the lake, h_b at the bed. T_5 is the soil temperature, q_0 is the heat flux if the solar indication. The integrated form of the thermal energy equation can be written as:

$$\rho c V \frac{\partial \tilde{T}}{\partial t} = \rho c\left[Q_1T_1 - (Q_2 + Q_3)\tilde{T} + Q_5T_5\right] - $$

$$- A_L h_L(\tilde{T} - T_a) - A_b h_b(\tilde{T} - T_s) + A_L q_0 \qquad (7)$$

These terms naturally vary on a day by day basis and depend on the existing climatic factors Toth (2005). Consider, as an example, a given day 2nd of May when the average temperature of the lake was 1°C/day. The volume of the lake is 124 000m^3, the free surface is 46 000m^3, the area of the bed is 57 000m^2. The daily average temperature was 30°C. The different terms of the thermal energy balance are the following:

- Thermal power of the spring	61.260 kW
- Thermal power loss and the overflow	- 49.550 kW
- Thermal power loss due the rainfall	0.000 kW
- Thermal power loss due the evaporation	- 3.498 kW
- Surface heat loss to the atmosphere	- 8.060 kW
- Thermal power loss to the bed	- 1.356 kW
- Thermal power of solar radiation	7.590 kW
- Temperature increase of the lake	- 5.964 kW

After processing the above variables using the thermal energy model it can be seen that the deficiency is approximately 422kW on this day, so the heat balance seems to be correct. Of course there are less reliable daily balances too Toth (2006).

The conceptual model of the water supply can be shown in (Fig.3). Water flows from the karstic aquifer to the thermal spring under the influence of their elevation difference. The terrestrial heat flow warms up the flowing water along the way. The thermal power of the warming weakens the original terrestrial heat flow. Over the flow path of the supplying stream of the spring this heat flow deficiency occurs as a lower heat flow and a lower geothermal gradient.

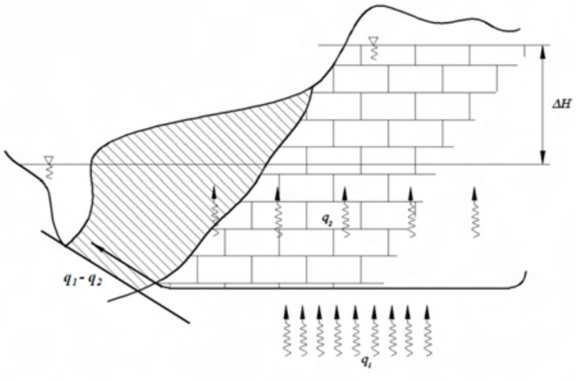

Figure 3: Heat supply of the spring

Thus shallow subsurface temperature measurements can indicate the underground flow paths. Since temperature values were measured in shallow boreholes of different depths, the geothermal gradient is a more characteristic of a given site than the measured temperature:

$$\gamma = \frac{T - T_0}{z} \qquad (8)$$

where T is the temperature at the depth of z, T_0 the surface temperature. The results of the measurements are demonstrated in the form of geothermal gradients referring to the upper shallow region Boldizsar (1958). It can be seen in the water supply routes in (Fig. 4). It is evident that the Hévíz thermal spring have two main supply routes. One of them comes from an Eastern direction; its recharge area is the dolomite outcrops of the Keszthely Mountains. The other path comes from a North and North-Eastern direction. This supply route carries the karstic water from the limestone aquifer of the Bakony Mountains.

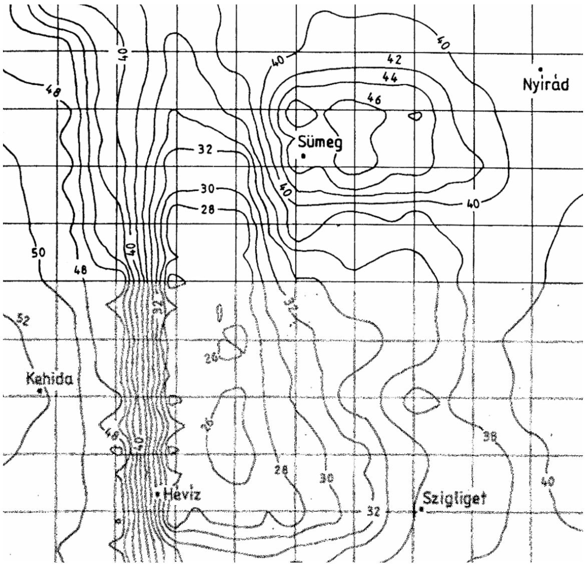

Figure 4: Distribution of geothermal gradient

This geothermal gradient pattern indicates that the water supply of the spring originates from the opposite direction from the chosen site of the pilot power plant. In addition, there is an opportunity to compare the thermal power of the hot spring which can be determined by the flow rate and the temperature of the spring, or alternately, by the areal distribution of the heat flow deficiency.

The heat flow at a given site can be calculated as a product of the heat conductivity and the geothermal gradient as follows:

$$q = k\gamma \qquad (9)$$

The difference of the original terrestrial heat flow q1 and the weakened terrestrial heat flow q_2 in the shallow region over the investigated area obtains the thermal power of the hot spring

$$P = \int_A (q_1 - q_2)\, dA \qquad (10)$$

The integral can be calculated numerically as:

$$P = \sum_{i,j} \left(q_{1ij} - q_{2ij}\right) \cdot \Delta A_{ij} \qquad (11)$$

This thermal power is taken over a 900 km^2 area and it is calculated to be 59,85mW. It is in accordance with the accepted value of 61,26MW. It is certain that the Eastern and Northorn-Northesatern supply routes are sufficient to warm up the water and thus supply the thermal power requirements for the Hévíz hot spring.

4. CONCLUSIONS

The hydrothermal system of the Hévíz Lake has a sufficient recharge area, an abundant water supply and an extremely intense geothermal heat supply. The North, Northeastern and Eastern flow paths are more than satisfactory to meet these requirements. The hot water produced in the Ortaháza field will be reinjected entirely to the same reservoir.

Because of this water and heat supply, Hévíz Lake is completely independent of the Ortaháza deep reservoir and the operation of a geothermal power plant. The pilot plant cannot disturb the hydrothermal system of the Hévíz Lake.

REFERENCES

Bobok, E.: Fluid Mechanincs for Petroleum Engineers, Elsevier, Amsterdam, New York, Oxford, (1993)

Boldizsár, T.: The Distribution of Temperature in Flowing Wells. American Journal of Science Vol. 256, (1958)

Erdélyi, M.: The Flow System of The Pannonian Basin, VITUKI, (1980)

Rybach, L., Muffler, L.J.R.: Geothermal Systems. John Wiley, New York, Brisborne, Toronto, (1981)

Tóth, A.: Heated Region Around Boreholes, Proceedings World Geothermal Congress 2005 Antalya, Turkey, (2005)

Tóth, A.: Heat Losses in a Planned Hungarian Geothermal Power Plant , Thirty-First Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, SGP-TR-179, (2006)