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Injection of Thermal Water into Porous Reservoirs

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ABSTRACT

The injection of heat-depleted brines into clastic sedimentary reservoirs with clay, sand and sandstone sequences has long been reported as a sensitive matter by petroleum and geothermal operators (Ungemach, 2003). The safe reinjection of low-enthalpy geothermal fluids into sandstone has posed a very serious professional problem impeding the utilization of geothermal energy. As stressed by various authors, the precise mechanisms that cause injectivity indexes to drop are not entirely understood. Although both international and domestic examples demonstrate that the injection of thermal waters into porous reservoirs is technically manageable, neither practical knowledge nor a professionally grounded and formalized policy is available at the moment that guarantees the success of reinjection into sandstone. Researchers at the University of Szeged aim to obtain uniform technological knowledge of the economic, safe and standardized procedure of reinjection of used thermal water into Pannonian sandstone.

The results of the first year of a 3 year study are presented, dealing mainly with test measurements of existing reinjection wells and modelling of sustainable operation of production-reinjection well pairs.

1. INTRODUCTION

The Earth's crust is much thinner in Hungary than in other parts of the continent (only 22-26 km). This fact leads to a positive anomaly in geothermal gradient of approximately 50 °C/km, as shown in Figure 1 (Dövényi et. al. 1988). Further, high porosity formations bearing groundwater fill the basin.

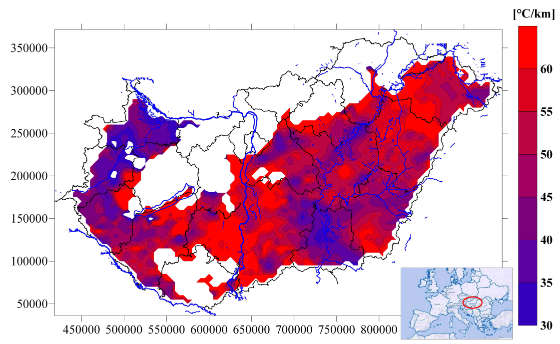

Figure 1: Calculated geothermal gradient in porous layers in Hungary

There are two existing flow regimes in the basin: a shallow, gravity driven flow system and a deeper, overpressure driven system composed essentially of the finer deep sea sediments and underlying formations. The main cause of the high overpressure (up to about 10 MPa above the hydrostatic pressure) is the tectonic compression of the formations, and gas formation during the maturation process of the sediments can also be a factor (Tóth and Almási, 2001).

As a consequence of the high thermal water production, the hydraulic head of the aquifers decreased by 50-70 m, but due to the mentioned decrease of thermal water production, an increase of 5-10 m was observed in the last decade. Most of the wells were free flowing up to 50 m in primer state, but continuous pumping of the wells is now needed. There has been no decrease in water temperatures observed in the bottom of the boreholes so far, but it should be mentioned that only negligible reinjection has been performed in the past (Szanyi et. al., 2009). To assure the sustainable use of thermal water reinjection of thermal waters into the same aquifers has been required by the Hungarian legislation, since 2004. There are currently 5 known injection wells in sandstone which operate successfully.

2. INJECTION TECHNOLOGY

Experts in Hungary have attempted to reinject into Upper Pannonian sandstone for more than 30 years. The main reason for their initial failure was that they tried to transform exiting projection wells into reinjection wells without regard for microfiltration and the sudden formation pressure-float. After many unsuccessful attempts, Aquaplus Ltd. drilled the first well especially designed for reinjection into Upper Pannonian sandstone that can be operated economically.

Following are some of the main points of the well construction and operation:

- Installation of filter pipe instead of posterior perforation,
- Under-reaming and gravel-packing in the filter area,
- Fine-starting and stopping to avoid sudden pressure impact that can cause sand-filling of wells.

It was desired to refine and complete these principles in this study. In order to elaborate the methodology of reinjection into sandstone, the sandstone itself had to be studied, including its petrographic and hydrogeological features. Initial pump tests were carried out, and the hydrodynamic changes of the sandstone caused by the operation of wells were simulated based on the test results.

2.1 Test Investigations

There is an approximately 10 year old tradition of reinjection into the Upper Pannonian sandstone in Hódmezővásárhely, where one of the first such wells was drilled and operated. In the last 6 years, 75-80% of the produced thermal water was reinjected. A new reinjection well was drilled 300 m from an existing one in 2007 that provided a possibility to evaluate the effect of the previous injections and to determine the hydraulic properties of the geothermal reservoir. During the 3 month pumping test, several types of investigations were performed; meanwhile, the temperatures and pressures were measured both at the wellheads and at greater depths (at 1200 and 1450 m) depending on the well casing.

There were several interesting results of the measurements. It was clear that after 10 years of operation of the injection well, there was a negligible decrease in temperature in such a small distance. This could be because of the rather high hydraulic conductivity in the layer and the large area of influence that results from this, but it is also surely determined by the high porosity of the aquifer. We concluded this from the extremely rapid pressure distribution (300 m in less than 20 s) since there was an instant drop of pressure in the observed well after the pumps were started, as shown in Figure 2.

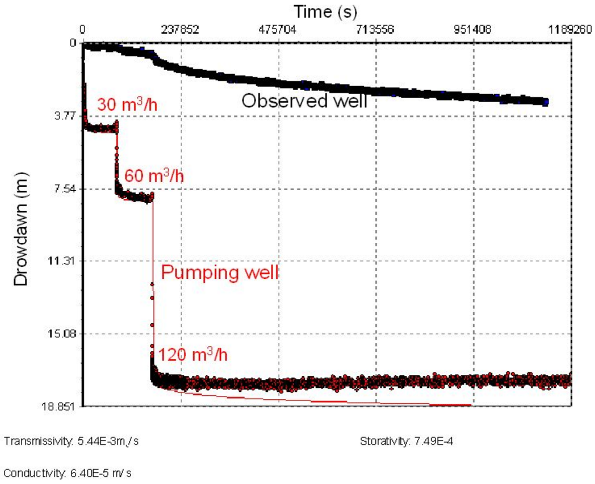

Figure 2: Drawdown after the 3 steps of the pumping period (Theis method)

Based on these results, it was determined that the hydraulic conductivity of sandstone varies between 1 and 6 m/d and its effective porosity is between 15 and 20 %. It was also noted that the well received water not only from the direction of the formation, but also from above. According to estimates, 8-10% of the well yield comes from the aquifer above the filter.

2.2 Modelling of Well Doublets

This analysis included the extent and distance action of drawdown and rises of water level in the aquifers with idealized Upper Pannonian sequences of strata in the area of a production-reinjection well doublet filtered at identical depths. Since the aim of these calculations was mainly the determination of the extent of water withdrawal and reinjection and changes in water levels resulting from leakage from upper layers, it seemed practical to carry out the modelling of an ideal, simplified hydrogeological situation. The hydrodynamic model was made with Processing MODFLOW Pro 7.0, which operates on the principle of finite difference. The analyzed medium was divided into 7 layers of identical thickness, and every other layer was defined as an aquifer (in a downward direction), as shown in Figure 3.

2.2.1 Case 1.

It was determined in this analysis that with the increase of the conductivity of aquifers, the distance from the well was different for 10 cm, 1 m and 10 m changes in water level. The values of hydraulic conductivity were varied in the interval of 1-15 m/day, which corresponds to the 500-1500 m deep sandy aquifers in the Great Hungarian Plain.

In the case where $K_h = 1$, a 25 m drawdown was forecasted in the 10*10 m^2 cell of the production well, and in the case of $K_h = 15$, the drawdown fell below 5 m. The maximum depth of drawdown decreased exponentially with an increase in the hydraulic conductivity such that its value was below 1 m at hydraulic conductivity values above 20 m/day. This relationship is illustrated in Figure 4.

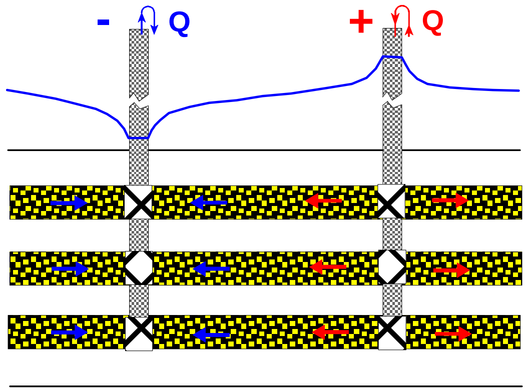

Figure 3: Schematic model (the aquifer is shown in yellow)

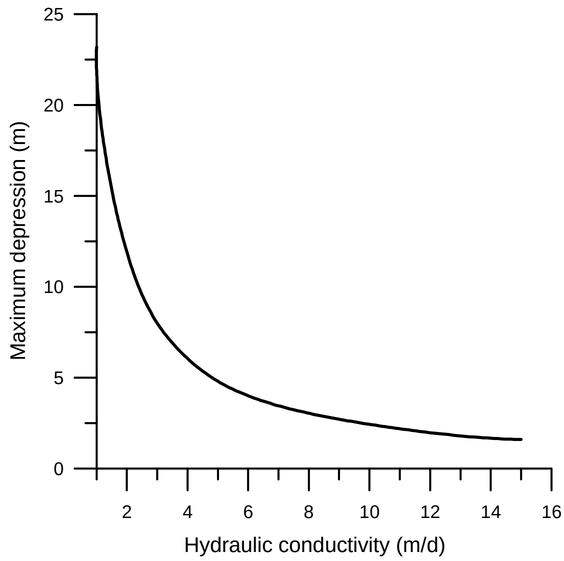

Figure 4: Maximum drawdown versus hydraulic conductivity

The distance from the well decreased monotonically with an increase in K_h, for a water level change of 1 m. However, for a water level change of 10 cm, a maximum distance occurred at $K_h = 3$. This is mainly attributable to the fact that the hydraulic gradient was originally zero in the model, in which case, the water flow is only caused by well production. As a result, the flow velocity near the edge was almost negligible, and the distance action did not increase further in the case of a sufficiently small hydraulic conductivity (Figure 5).

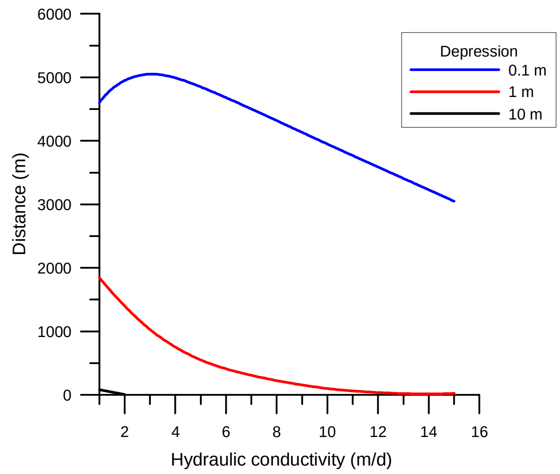

Figure 5: Dependence of drawdown on hydraulic conductivity

2.2.2 Case 2.

The distance action of wells was also determined as a function of changes in the yield of the production-reinjection well pair. The production rates were varied between the extreme values of 500 and 3000 m^3/day.

For small yields, the drawdown of water level did not exceed 10 cm at a distance of more than 3 km, but for large yields, the this drawdown level of 10-cm border was observed at a distance of 5 km. Similarly to the previous case, the maximum distance for the 1 m water level changes increased monotonically with an increase in yield. For a yield of 3000 m^3/day, this border was observed at 2 km, as shown in Figure 6.

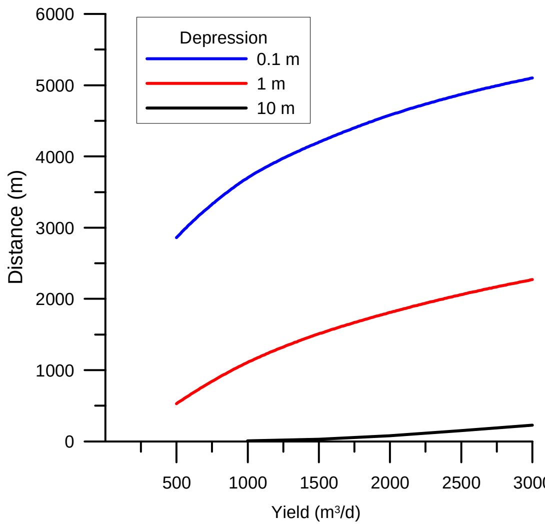

Figure 6: Dependence of drawdown on yield of well

With the increase of yields, the maximum depth of the forming depression shows almost a linear change. At a production rate of 3000 m^3/day, this value exceeds 30 m in the middle aquifer (Figure 7).

2.2.3 Case 3.

During modeling, the boundary conditions were ensured with GHB cells. This facilitated the regulation of the water flowrate at the upper boundary of the model. Thus, the changes of the previously analyzed features were observed as function of the input rate from the upper layers, as shown in Figure 8.

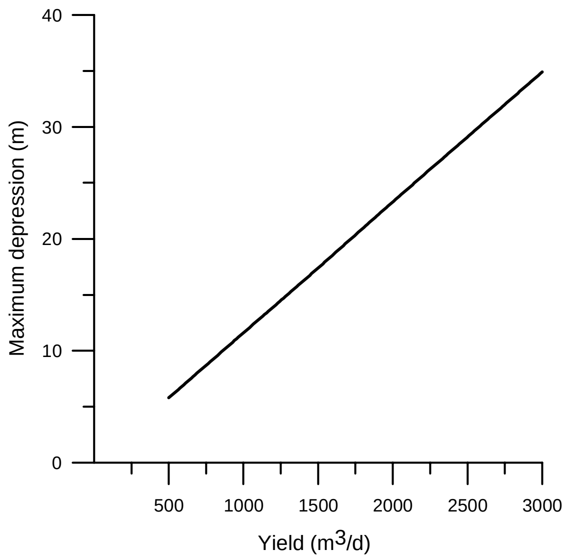

Figure 7: Maximum drawdown versus yield of well

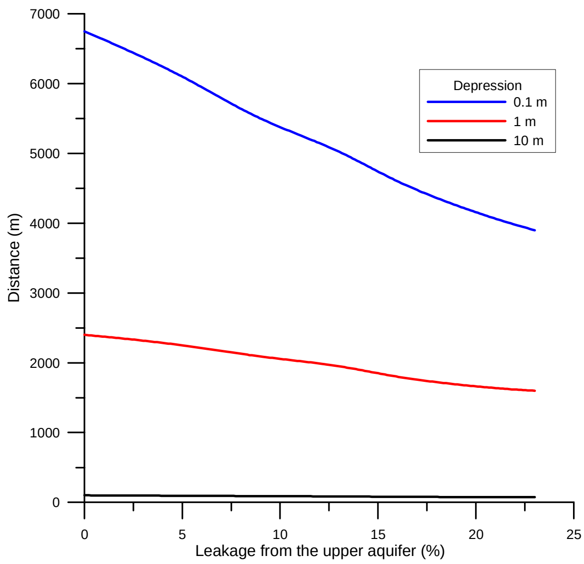

Figure 8: Upper boundary investigation

The border of the 10 cm water level change was drawn 6700 m from the wells. This distance action decreased almost linearly with an increase in the infiltration at the upper boundary. The distance of the 1 m border decreased as well, but to a smaller extent. The depth change of drawdown registered near the wells was negligible, as it stagnated around 23 m.

CONCLUSION

Increasing the number of reinjection wells is an essential condition to increase thermal energy utilization and allow the sustainable operation of thermal wells. Therefore, it is necessary to study the processes that occur in the aquifer during the process of production and reinjection. In the first phase of analyses, the hydraulic effects were studied on a large scale. The pressure distribution in the Upper Pannonian water-bearing layers was determined to be extremely fast (300 m in less than 20 s), and the intrusion of water from the layers above supplies 8-10% of the yield of the production well.

Using the test results, a new hydrodynamic model was constructed, which can help to determine the optimal allocation and operation of well doublets in case different hydrogeological conditions arise.

REFERENCES

Dövényi, P. and Horváth, F.: A review of temperature, thermal conductivity and heat flow data from the Pannonian basin. In: L.H. Royden and F. Horváth (eds.), The Pannonian basin - A study in basin evolution. *Amer. Assoc. Petrol. Geol. Mem*. **45**, (1988) 195-233.

Szanyi, J., Kovács, B., Scharek, P.: Geothermal Energy in Hungary: potentials and barriers, *European Geologist* **27**, (2009), 15-19.

Tóth, J., and Almási, I.: Interpretation of absorved fluid potential patterns in a deep sedimentary basin under tectonic compression: Hungarian Great Plain, Pannonian Basin. *Geofluids* **1**, (2001), 11-36.

Ungemach, P.: Reinjection of cooled geothermal brines into sandstone reservoirs. *European Geothermal Conference* **32**, (2003) 743.