SENSITIVITY ANALYSIS OF A NUMERICAL MODEL OF SEDIMENTARY BASIN GEOTHERMAL SYSTEM

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SUMMARY - Modelling with TOUGH 2 numerical simulator focused on a low temperature sedimentary basin geothermal system identified at Moravske Toplice in north-east Slovenia. Here, the main aquifer is situated in the Pliocene sand but water from the Miocene sandstone is also produced.

After the natural state model with continuous heat inflow was established, sensitivity analysis of various input parameters was performed. Rock density, porosity, permeability and thermal conductivity were changed in order to observe their influence on temperature and pressure distribution in the model. Afterwards, the production model with 6 operating wells was set and sensitivity analysis of parameters of the most important aquifer layers was performed. In this case permeability and porosity effects on temperature and pressure distribution were interpreted.

1 INTRODUCTION

Extensive low temperature geothermal system is identified in the Miocene and Pliocene sandstone and sand deposited in up to 5 km thick sequence in the north-eastern Slovenia in the Mura-Zala sedimentary basin (Pezdič et al. 1995; Kralj & Kralj, 2000). From this part of the Pannonian basin extraction of thermal water has increased significantly over the last years and problems with overexploitation are predicted to arise.

In order to forecast aquifer trends numerical modelling is being applied. In Slovenia, geothermal systems have been modelled using MODFLOW (Pezdič et al. 2006) and TOUGH 2 (Rman, 2007) numerical simulators and in both cases modellers faced problems due to rather scarce well-performance data.

As models could not be properly validated the importance of different rock parameters for sedimentary basin system physical state was investigated.

2 METHODOLOGY

Conceptual model

In the Mura-Zala sedimentary basin deep structures extend in the SW-NE direction (Gosar, 2005) and the heat flow is elevated due to thinner lithosphere (Ravnik et al. 1995). The modelling focused on area of Moravske Toplice with an average elevation of 200 m and north of which Goričko hills extend up to 300 m asl. Three formations and basement rocks were identified here. The uppermost, Mura formation, consists of sandy clay with frequent sand lenses in the lower part and forms the most important thermal aquifer. Below, the Lendava and

Spilje formations with marl and sandstone were deposited on mostly metamorphic basement rocks.

The conceptual model assumes that the heat transfer is conductive, aquifers with hydrostatic pressure distribution are infinite and forced convection occurs. Six of eight existing wells extract water at a constant rate from the time of their commissioning on (Table 1).

Table 1: Input parameters for the production model

WELL	MASS FLOW	WELLHEAD TEMPERATURE	START OF PRODUCTION	PRODUCTION BLOCK
Mt-1/60	3.2 kg/s	70°C	Jan 1962	Spilje formation
Mt-4/74	3.2 kg/s	70°C	June 1974	Spilje formation
Mt-5/82	2.9 kg/s	70°C	March 1982	Spilje formation
Mt-6/83	14.8 kg/s	59°C	April 1983	Mura formation
Mt-7/93	14.8 kg/s	56°C	May 1993	Mura formation
Mt-8/05	24.6 kg/s	55°C	Feb 2006	Mura formation

Numerical model setting

TOUGH 2 code (Pruess et al. 1999) with EOS 1 module was used for the modelling. Symmetric grid of 144 km^2 was made of square blocks (250-2000 m) and 18 layers (100-400 m) with correction for surface topography. Atmospheric block represented a constant pressure boundary with average annual air temperature of 11°C and 1.06 bar of atmospheric pressure. Open boundary was assumed at the bottom of the model as heat inflow of 120 mW/m^2 was assigned to each bottom block without any mass flow. Side boundaries were closed.

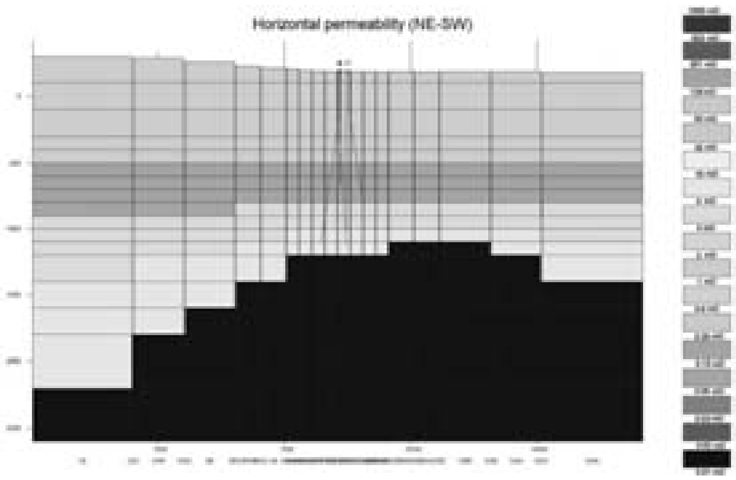

Figure 1: Structure of the model in NE-SW direction

Rock parameters were assigned to each block based on known geological characteristics (Table 2). Natural state model results were compared to measured static pressure and temperature while production model results to enthalpy and aquifer pressure.

3 RESULTS AND DISCUSSION

Sensitivity analysis of the natural state model

In the natural state model rock density and porosity have negligible influence on modelled pressure and temperature. Consequently, if only static data is available the two properties need to be in a realistic range but otherwise do not need to be calibrated in details.

Table 2: Rock parameters for the natural state model

ROCK TYPE	DENSITY (kg/m^3)	POROSITY	HORIZONTAL PERMEABILITY	VERTICAL PERMEABILITY	THERMAL CONDUCTIVITY
CLAY	2100	0.2	1.0 mD	0.4 mD	2 W/mK
SAND	2600	0.2	200.0 mD	20.0 mD	2 W/mK
MARL	2600	0.2	0.1 mD	0.1 mD	2 W/mK
LEND	2600	0.1	5.0 mD	0.5 mD	2 W/mK
SPIL	2600	0.1	10.0 mD	1.0 mD	2 W/mK
BASEM	2700	0.01	0.01 mD	0.01 mD	4.3 W/mK

On the opposite side permeability and thermal conductivity have a significant influence on the temperature distribution but the pressure is still hydrostatic. In the observed example vertical permeability has to be lower than horizontal in order to get a reasonable match with measured temperatures (Figure 2). Increase of vertical permeability of the uppermost (CLAY) layers results in cooling the shallower layers near high topography area (well Mt-3). Further away, cooling is indicated in deeper layers (well Mt-6) due to layer geometry. The same happens if horizontal permeability increases. Cooling occurs when applying it to the uppermost (CLAY) layers while at others it has no influence on the temperature distribution.

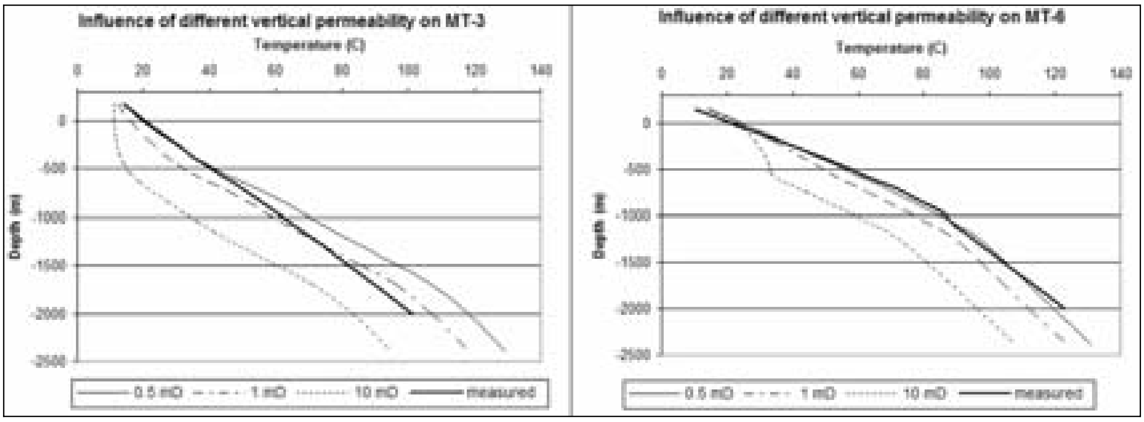

Figure 2: Sensitivity analysis of the vertical permeability influence (CLAY rock type properties are changed)

Thermal conductivity of rocks proves to be the most important factor influencing temperature distribution in the sedimentary basin geothermal system. Measured temperature gradient changes at the contact between sediments and basement rocks, so the latter thermal conductivity (BASEM rock type) differs noticeable from the others (Figure 3). The natural state model is heated predominately by conduction and therefore thermal conductivity is the most important parameter for matching, while due to diverse topography permeability of the shallower layers controls the cold water forced convection flow.

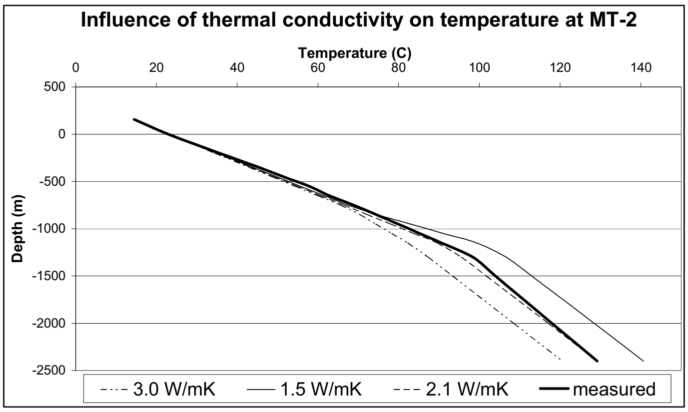

Figure 3: Sensitivity analysis of the thermal conductivity influence (LEND and SPIL rock type properties are changed)

Sensitivity analysis of the production model

Opposite to the parameters controlling the natural state model porosity and anisotropic permeability have an important influence on the reservoir behaviour under production. Here, it was modelled to run for 60 years. Five scenarios with different properties of the most important aquifer (SAND) layers were tested (Table 3) all having reasonable fit to the natural state conditions.

Table 3: Sensitivity analysis parameters of the production model (SAND rock type properties are changed)

MODEL	CHANGING PARAMETER OF SAND ROCK TYPE	POROSITY	HORIZONTAL PERMEABILITY	VERTICAL PERMEABILITY
PR1	porosity	0.05	200 mD	20 mD
PR2	porosity	0.20	200 mD	20 mD
PR3	porosity	0.40	200 mD	20 mD
PR4	horizontal permeability	0.20	20 mD	20 mD
PR5	vertical permeability	0.20	200 mD	1 mD

The temperature profiles do not differ much between the scenarios (Figure 4). The water temperature in well Mt-1, situated in the deeper aquifer (SPIL layers), increases due to hot recharge while for the shallower aquifer (SAND layers) captured in well Mt-8 it decreases. Porosity does not affect temperature much but lower horizontal permeability results in faster cooling due to colder vertical inflow while decreased vertical permeability forecasts slower cooling due to stronger warm horizontal flow.

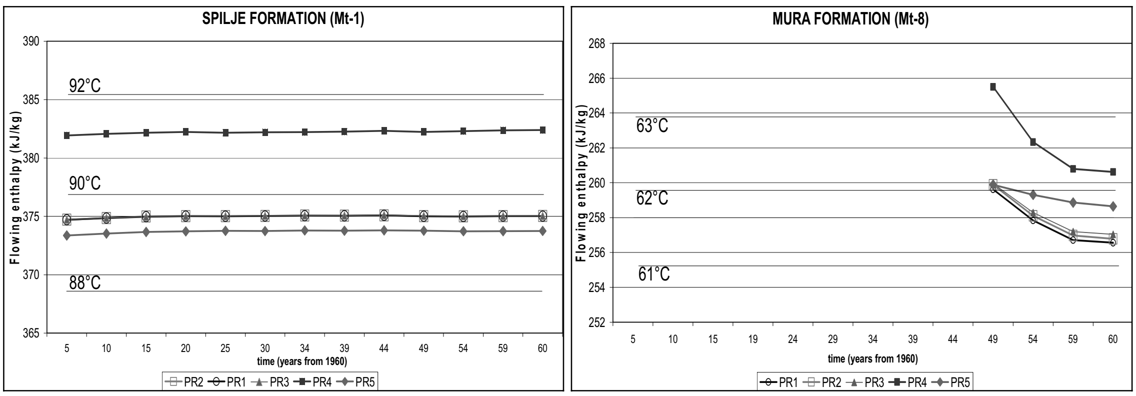

Figure 4: Flowing enthalpy of wells Mt-1 and Mt-8 for different scenarios

Pressure distribution in the most important aquifer (SAND) layers indicates cca. 10 bar decrease, what is underestimated for the PR4 model (Table 4). Restricted vertical permeability results in relatively high pressure in the top (CLAY) layers but the aquifer (SAND) layers have higher pressure drop due to less recharge than in the first three scenarios.

Table 4: Pressure distribution down well Mt-8 for different scenarios

ELEVATION (m)	**BEFORE PRODUCTION** (bar)	**PR1** (bar)	**PR2** (bar)	**PR3** (bar)	**PR4** (bar)	**PR5** (bar)
146	5.67	4.88	4.89	4.90	4.07	4.93
0	20.32	17.28	17.30	17.35	14.04	17.46
-200	40.26	34.67	34.71	34.81	28.11	35.04
-450	64.97	56.73	56.78	56.91	42.88	57.49
-650	84.43	74.20	74.24	74.38	54.31	72.78
-850	103.80	94.29	94.35	94.50	90.55	93.74
-1050	122.99	112.75	112.80	112.96	110.68	112.32
-1300	146.78	137.13	137.19	137.36	135.37	136.74
-1500	165.71	156.55	156.62	156.80	155.00	156.19
-1700	184.57	175.75	175.82	176.01	174.34	175.41
-2000	212.72	204.24	204.32	204.53	202.97	203.94

Drainage radius is the narrowest at high porosity scenario since the amount of stored water is the largest but difference to other porosities is small (all approximately 3 km at -1000 m). Restricted vertical permeability results in enhanced lateral recharge (radius of 4 km), while restricted horizontal flow causes significant vertical water flow.

4 CONCLUSIONS

Thermal water in sedimentary basin geothermal system is mostly stagnant, so the temperature distribution depends on two factors: permeability of the surface layers which controls the cold forced convection flow and thermal conductivities of all rock types which control the temperature gradient. Investigated system contains no steam, so the hydrostatic pressure increases constantly with depth.

The sensitivity analysis of production scenarios has showed that horizontal permeability of the aquifer layers has a distinctive effect on the temperature and pressure distribution at depth over the production model time. Moreover, adjustments of porosity and vertical permeability of the aquifer layers are worth considering if only good matching data is available.

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