Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Thermal Energy Exploitation From Salt Domes

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Keywords: thermal energy extraction, heat exchange processes, salt domes, numerical modeling

ABSTRACT

Based on numerical model of the salt dome "Gora", thermal energy exploitation has been simulated. The numerical model is based on available archive materials and scientific literature.

The model has been created using commercially available numerical simulator TOUGH2. The heat exchange process and thermal characteristic of the salt dome in three dimensions under the steady stay conditions have been described. Exploitation has been modeled in the two dimensional space using cylindrical coordinates under non-isothermal conditions. Energy extraction is a leader in a system that assumes brine exploitation from a chamber.

Nine variants for different exploitation parameters have been taken into account. Finally it has been found that thermal power of up to 1 MW and temperature of up to 30°C can be to reached. Taken into account such thermal characteristic of the energy source it is possible to use it directly or by using heat pumps.

1. THERMAL ENERGY EXPLOITATION FROM SALT DOMES – TECHNICAL ASPECTS

By anomaly high value of the thermal conductivity, rock-salt is characterized. Average value of this parameter for rock-salt oscillates with the range of 4,5 up to 5,8 W/mK (Plewa S, 1994). Other common geological materials have thermal conductivity that is almost two times lower (Plewa S, 1994). Because of uncommon thermal properties of distribution, salt domes create natural thermal bridges causing thermal anomaly. The paper presents the numerical model of the "Gora" salt dome. Figure 1 shows the salt dome localization on the schematic map of Poland.

Figure 1: The "Gora" salt dome localization (red frame)

Rock-salt from the salt dome is mined by the leaching technique. Leaching generates caverns at the mined area. The leaching process is leaded by water (or non saturated brine) injected into a casingless well. Water contacts with rock-salt directly and salt is rinsed out. The brine is pumped out of the well and used on the surface according to an appropriation. Because two holes are drilled to one cavern the process can by leaded simultaneously. One stub of the pipe is localized on the roof and one on the floor of the chamber (Figure 2). During the mining process the volume of the chamber increases. Under high pressures and temperature rock-salt becomes plastic and closes any fractures or pores. Because of that the chamber creates tight tank. The pressure of brine prevents clenching out of the chamber. The clenching process proceeds in time but its speed is not high. After salt mining the cavern can be used as a storage tank for natural oil, petrol or waste materials etc.

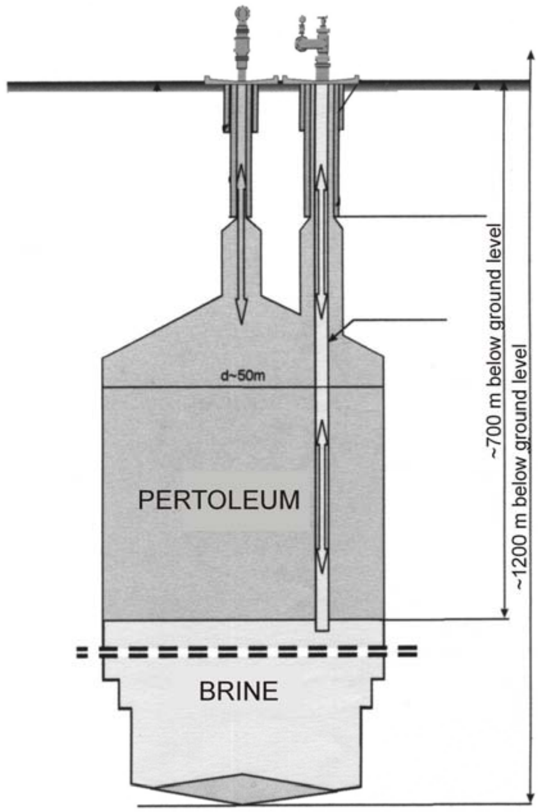

Figure 2: The scheme of the storage chamber (based on archival materials of "SOLINO" Salt Mine).

When injected liquid has lower temperature then chamber's walls, it can give up the thermal energy to the cooler liquid injected from the surface. Finally the system similar to the borehole heat exchanger (BHE) is created. When working fluid does not cause further chamber enlargement (e.g. the working fluid consists with saturated brine) it can be assumed that only thermal energy is extracted from a chamber and its neighborhoods. Two operating schemes are possible: (1) brine injection at the lower part of a chamber and pumping out from the upper part of it, (2) brine injection at the upper and pumping out from the lower part of a chamber.

Many method of thermal energy exploitation had been described in the literature. Most of them include only basic schemes without any calculations or estimations. But some of them take advantage of numerical method e.g. (Malaga M. and Chylarecki R, 1993). Because of rapid computer technology development nowadays it is possible to make calculations faster and more precisely (limited by less restrictive simplified assumptions).

2. NUMERICAL MODEL DESCRIPTION

The heat exchange processes bound with salt domes are complicated because of irregular geometry (usually recognized only near the ground surface – in the salt production zone) and mixed thermal parameters distributions in space. Additionally, taking into account heat energy extraction makes an analytical description of the heat exchange processes arduous and limited by many assumptions that simplify the process. An alternative is numerical methods. Numerical solution can be achieved by using one of the commercially available simulators. Authors used well known in the geothermal branch numerical simulator TOUGH2 (Pruess K. et al, 1999).

The simulation of heat exploitation process was divided into two parts. The first one is the simulation current natural conditions, the results of which create an initial conditions for the second part – simulation of the thermal energy exploitation.

2.1. THE GEOMETRY OF THE "GORA" SALT DOME

The geometry of the "Gora" salt dome of up to 1600 m depth is described precisely. Deeper geometry is not unequivocally described. During the conceptual model creation, the author was using geological maps of horizontal cutting at the depth: of 5, 4, 3, 2, 1 km and 500 m (Kotanski Z, 1997). The side of the salt dome was created by straight lines that connect the horizontal cuttings. Because of low precision of literature data some corrections to the salt dome geometry were made. Information about gypsum cap origin came from "SOLINO" Salt Mine's archive. The cross-section through the salt dome along NW-SE direction is presented on Figure 3.

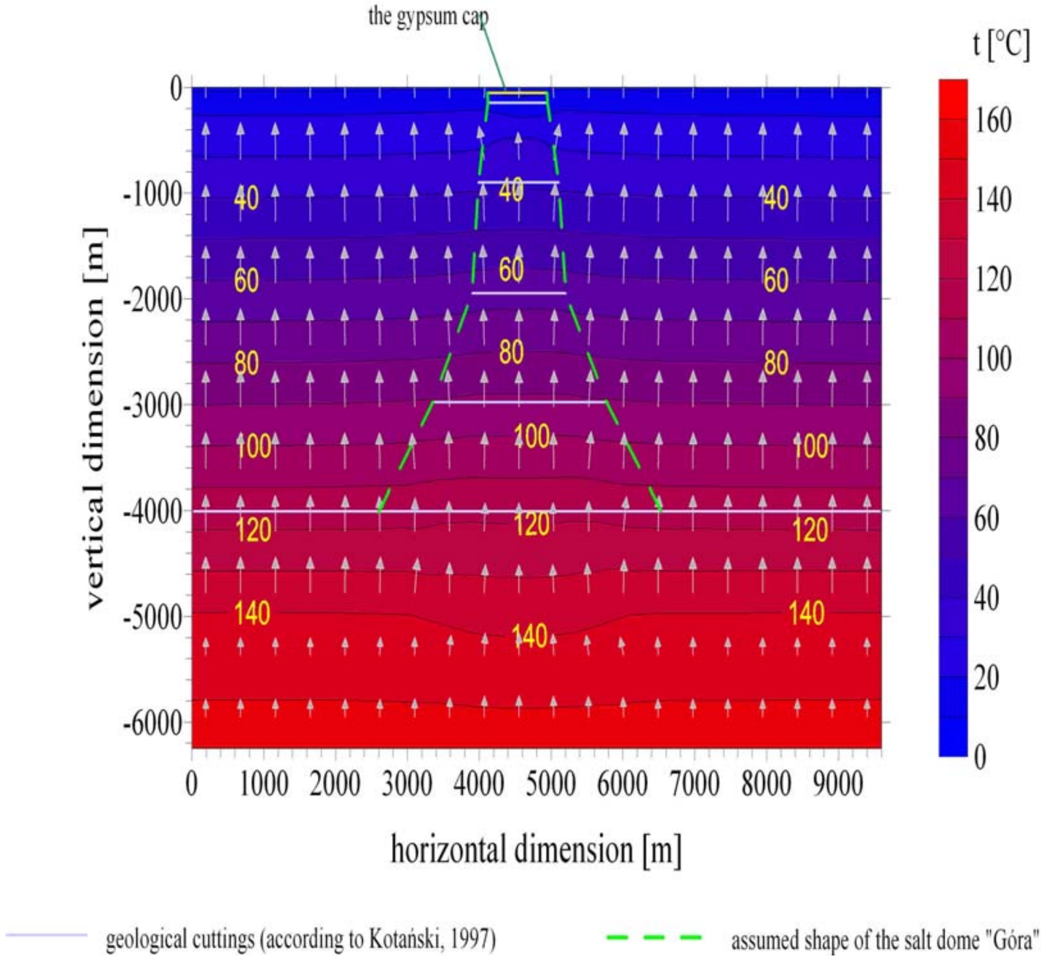

Figure 3: Temperature distribution and heat flow scheme in the salt dome "Gora" surroundings – the result of calculations (NW-SE direction)

Table 1. Thermal properties of the modelled space components

Name of geological component	Density [kg/m^3]	Porosity [%]	Permeability [mD]		Thermal conductivity [W/m·K]	Heat capacity [J/kg·K]
			horizontal	vertical		
Soil	2000	10	100	1	1.00	2000
Gypsum cap	2300	5	10	0.1	0.80	1100
Clay cap	2300	5	10	0.1	0.60	1100
Rock-salt	2600	10^{-2}	10^{-3}	10^{-5}	6.40	1050
Surroundings rock	2600	10	50	0.5	2.91	850

2.2. Thermophysical Properties of Geological Components

Based on conceptual model, the distribution of geological components and its properties were estimated. Thermal properties were fixed based on numerical experiments taking into account the ranges of their variation described in the literature (Plewa S, 1994). Capability of the numerical results with measurement data was the prime target of the numerical experiments. During the numerical model calibration, the original data from well's thermal profiles were used. The comparison of numerical results and measured data is shown in Figure 4. Properties of geological components are shown in Table 1.

2.3. BOUNDARY CONDITIONS

Two types of boundary conditions are used in the numerical model. The first one is fixed on the upper surface limiting modeled space. The second one is on the bottom surface, where Dirichlet boundary condition is fixed by setting up constant temperature of 156°C at the depth 6250 m below the ground level. On the upper surface which is in contact with atmosphere, Neumann boundary conditions are used. The heat flux density is fixed at 75 mW/m^2 (Plewa S, 1994). It is assumed that sides of model space are ideally insulated. The mentioned value was chosen by numerical experiments taking into account the literature.

2.4. TEMPERATURE DISTRIBUTION AND HEAT EXCHANGE SCHEME IN THE SALT DOME AND ITS NEIGHBOURING AREA – STEADY STATE CONDITIONS

The results of numerical simulations are presented on Figures 3, 4 and 5.

As was mentioned before, salt dome and its neighborhoods are characterized by abnormal temperature distribution. Isotherms at the upper part indicated abnormally high temperature. On the other hand, deeper part is characterized by abnormally low temperature. The dome's area with temperature equal to neighboring rocks occurs at the depth of 4400 m below ground level. Isotherms of high concentration are localized directly under the gypsum cap. It indicates rapid temperature increase after gypsum cap is drilled. It is confirmed by temperature profiles of the wells (Figure 4). Calculations results indicate possibility of thermal surface disturbance caused by salt dome notification by ground temperature measurements (Figure 5).

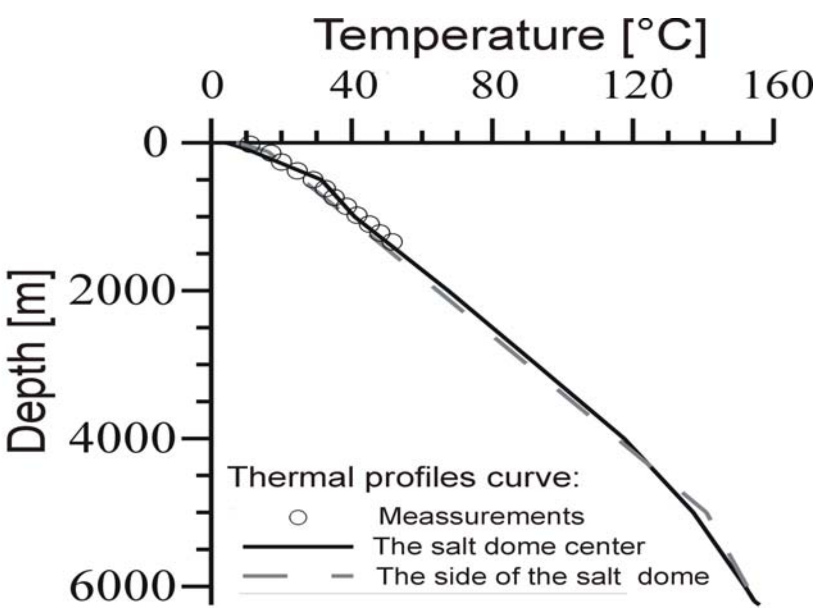

Figure 4: Thermal profiles for the Gora salt domes, comparison of measurements and calculated data

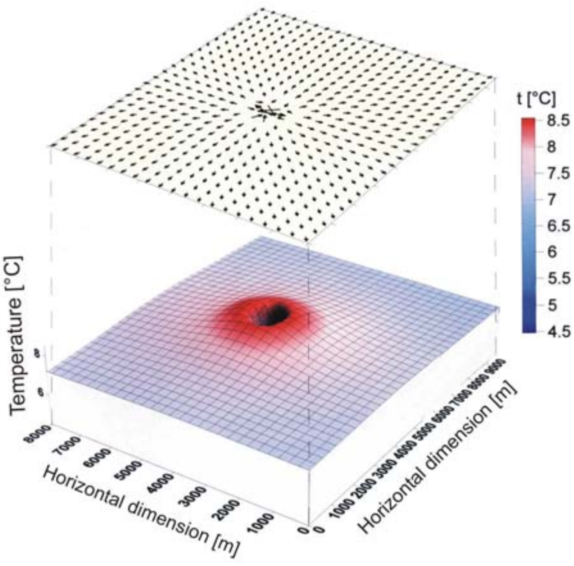

Figure 5: Temperature distribution and heat flux scheme at the depth with 1,5 m.

The highest temperature occurs on the side of a salt dome, in the lowest part of the center. There are no thermal anomalies in the further neighborhoods. These results confirm the insulating property of the gypsum cap. According to numerical simulations in the center of the "Gora" salt dome at the depth of 1,5 m, the temperature equals to 4,5°C, while on the side it amounts to 8,5°C. Because of considerable differences in temperatures between the center and the side of the salt dome, it should be possible to locate domes using the ground temperature measurements. Of course, presented results are idealized. For example, because of the underground water flow the results can be less distinct.

3. THERMAL ENERGY EXPLOITATION

Based on results obtained from described model, the heat energy exploitation process in two dimensions has been simulated. It was assumed that the thermal energy is extracted from the storage chamber presented on Figure 2. The chamber has diameter of 50 m and the height of 800 m. Ceiling of the chamber was localized at 400m below ground level. It was assumed that the chamber is filled with brine. The working scheme was based on cold brine injection near the floor and exploitation near the roof of the chamber.

Based on the numerical results, it was found that the highest and stabile in time parameters can be reached when the temperature of injected brine is equal to about 5°C and injection and production stream are from 30 up to 50 m^3/h. The maximal initial thermal power for this parameter was 1,4 MW (for 50 m^3/h) and 0,8 MW (for 30m^3/h). Taking into account long-term thermal exploitation, it is reasonable to reach constant thermal power of 1 MW. The forecasts of thermal power change with time and are presented on Figure 6.

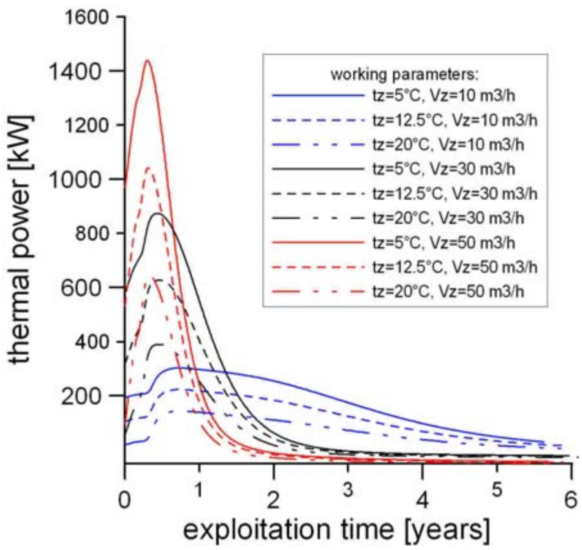

Figure 6: Thermal power with time - forecasts

SUMMARY

Results of numerical simulations confirm the possibility of thermal energy extraction from salt domes. Thermal power of MW and temperature of about 30°C creates interesting heat source for medium scale commercial installation, e.g. it creates the possibility of heating up the swimming pools with infrastructure or it can be used by the Salt Mine. Because the price of thermal energy, produced by using low temperature heat source highly, depends on energy consumer, it is hard to estimate it without choosing a concrete solution.

Insulating properties of the gypsum cap cause anomaly high temperature increase just below it. According to thermal energy, depth interval that starts just below the gypsum cap is the most interesting.

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