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LOW-ENTHALPY GEOTHERMAL WATERS IN COAL-MINES, UPPER SILESIA COAL BASIN, POLAND

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ABSTRACT

The paper presents the potential of utilization of low-enthalpy waters (20-45 °C) from 54 coal-mines of the Upper Silesia (Southern Poland). The estimate of geothermal energy in water filling post-mining excavations of abandoned and existing coal mines of Upper Silesia Coal Basin has been carried on according to geothermal gradient 23 - 40°C/km and terrestrial heat flow 54 - 74 mW/m^2 in the region. The numerical modelling of the heat transfer by conduction and convection has been used to simulate the heat flux from surrounding rocks into the water in geothermal reservoirs created in coal-mines up to 1000 m deep with capacity of several millions m^3 each. It shows that heat flux induced by the water-rock temperature difference in mine openings is of much higher range of W/m^2 than the terrestrial heat flow. In practice geothermal energy is provided within a range of up to 20 MW$_t$ per one coal mine. The sensitivity analysis shows that the geometry and depth of the mine as well as the thermal properties and permeability of surrounding rocks have a principal influence on the thermal power possible to obtain from the mine. The modelling presents high geothermal potential of lock-outed as well as existing mines, where for many years dewatering of mines provides up to 50 m^3/min water at temperature of about 20 °C. The heat pumps combined with gas burners using methane extracted from deep coal seams in the region are proposed for utilization of geothermal heat in the district heating systems. Reduction of CO_2 will benefit due to utilization of geothermal energy in this most polluted area of Poland.

1. INTRODUCTION

The hard coal mining is one of the most important branches of industry in Poland. The main Polish coalfield is located in the Upper Silesia region (south-central Poland, Figure 1), where coal is extracted from Upper Carboniferous deposits in 54 mines. The coal mining has been going on for many decades and some of the mines have already been closed down due to coal seams having been totally exploited. At present there are plans to shut down additional 6 coal mines before the year 2002 and in 36 coal mines exploitation will be stopped at some depth. The abandoned mines are partially back-filled during closing down procedure and flooded by water. Water in the underground spaces deep in the mines in a short time will approach the temperature of surrounding rock massive, which has an average geothermal gradient of about 33°C/km. This volume of water is a potential source of geothermal energy.

The Upper Silesia region is the most polluted area in Poland because of the coal-mining and steel industry, and additionally is also the most densely populated region in Poland due to concentration of heavy industry located there. The region therefore needs cleaner energy sources. The abandoned mines are one of the possible sources of such energy. Partially filled with water and often located directly below cities and towns they can take on a new role as source of warm water in the Upper Silesian Coal Basin. Furthermore, coal mining is expected to expand to depths of 1000-1200 m under ground in the near future. At such depths the rock temperature varies between 38-50°C, and large-capacity cooling and air-conditioning systems will be installed for removing heat from mine workings by air and water. This heat should be utilised at the surface for space heating, recreation (swimming pools), in agriculture and industry. Warm water from the mines can be directly used for snow melting systems.

1.1 Geological background

The Upper Silesian Coal Basin (USCB) is one of the units of the Palaeozoic platform north of the European Alpine system. The sedimentary basin (Figure 2) filled with coal-bearing deposits was developed in Upper Carboniferous. The stratigraphy of the deposits is very well examined by mining works and numerous exploration boreholes.

The sequence of coal-bearing molasse deposits of Upper Carboniferous is composed of conglomerates, sandstones, siltstones and claystones interbeded with coal seams which make about 9 % thickness of the stratigraphic column (KOTAS, 1990). The coal-bearing rocks of the USCB are mostly covered by younger deposits. Some outcrops occur only in the central part of the basin. The thickest (up to 1000 m) sedimentary cover is located in southern parts of the area and it consists mostly of claystones and siltstones with low permeability, formed during Miocene. These deposits act as a cap rock formation for the geothermal fluids in sedimentary basin. In the southern part of the USCB positive

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thermal anomalies have been identified beneath the Miocene cover.

The hydrogeologic properties of the sedimentary rock formations within the USCB have been investigated as a part of exploration research done for the coal mining industry. In the 2,200 m deep section investigated several aquifers have been found, mainly in sandstones (ROZKOWSKI & WAGNER, 1988). The average porosity of the deep aquifers varies between 5 and 15 % and the average permeability between 0.14 and 17 mD decreasing with depth. Mineralization of water from Carboniferous aquifers is different and depends on depth of aquifers and the type and thickness of overlaying rocks. In parts of USCB without thick cover of cap rocks the mineralization of water is low, and generally increases with the depth of the aquifers. In deep, closed aquifers under thick series of overlaying sediments, ascending waters have very high mineralization and contain 40 to 250 g/dm^3 of chlorides.

1.2 Geothermics of the region

The temperature distribution within the USCB has been studied for the last 30 years because of its importance for the mining operations. Temperatures within coal mines have a significant influence on the working conditions of miners under ground, as well as on the thermomechanical properties of rocks around mine workings. The highest air temperature in mine headings allowed by Polish mining rules is 28°C in order to ensure an optimal working conditions. Underground temperatures in the USCB can be simply characterised by a geothermal gradient varying between 40°C/km in the positive geothermal anomalies and about 23°C/km in negative ones. Geothermal anomalies have been identified in USCB on the basis of temperature logs and underground measurements of temperature in the mine workings. Isothermal maps have been prepared (KARWASIECKA, 1996; KNECHTEL et al., 1980; MALOLEPSZY, 1999). Temperature anomalies (both negative and positive) correlate with terrestrial heat flow measurements in the Upper Silesia region (Figure 1). There are six measurement points of the terrestrial heat flow (PLEWA, 1991) varying between 54 and 74.3 mW/m^2.

In most of the coal mines, underground temperature measurements are carried out on a regular basis (KUROWSKA, 1999; MALOLEPSZY, 1998). The temperatures are measured in order to detect hazardous temperature conditions especially at exploitation levels deeper than 450 m and isothermal maps of the undisturbed rock temperature are prepared for different levels of the mine. The underground temperature measurements are commonly carried on at freshly excavated mine walls. The optimal conditions for data collecting are in the mine headings which usually progress faster than the cooling front in the rock mass can migrate. Additionally some water temperature measurements are collected in the mine workings (Figure 3).

2. GEOTHERMAL RESOURCES

Abandoned coal mines have a significant, but little studied, potential as a source of geothermal energy. This potential primary arises from the heat energy stored in the rock formations surrounding the mine. For preliminary estimate of the thermal power potential of abandoned coal mines the numerical modelling was carried out using the parameters of a typical Upper Silesian coal mine (MALOLEPSZY, 1998). A two-step approach was taken to the modelling. In the first step, the heat exchange between water in a mine tunnel and the surrounding rock formations was investigated using a numerical code TOUGH 2 which takes into account both the conductive and convective aspects of the heat transfer. The sensitivity of this process to changes in geometry and thermal parameters of the model tunnel was investigated. In the second step the model was expanded to simulate the thermal output of a whole mine. For this purpose a special simulation program HEAT MINE was developed by author. It is based on a simple analytical model of the heat exchange, which does not take convective heat transport into account.

Based on those simulations the temperature drop in mine was calculated (Figure 4). The mine is assumed to have a volume of more than 1,000,000 m^3, distributed at three levels (200 m, 450 m and 650 m) with underground workings size less than 0.5 m. The thermal properties of the host rocks are the same for all levels: thermal conductivity of 2 W/m°C and thermal diffusivity of 1.1×10^{-6} m^2/s. Warm water from the mine was assumed to be extracted at a constant rate throughout the year, to be cooled in heat pumps and the cooled water to be reinjected into the mine. The figure shows that during the 50-year period the temperature of the water filling the mine decreases from 22°C to about 15°C due to the heat extraction. The second curve in the figure shows the results of numerical modelling by TOUGH. In this model energy was extracted at a rate of 20 W/m^3 from 1 m long mining tunnel with radius 0.5 m, which gives 20 MW_t when multiplied by the volume of the mine. The temperature decline during the 50-year period, is almost the same, the small positive difference can be explained by the additional heat transferred by convection, not taken into account in program HEAT MINE. On Figure 5 is presented impact of the underground workings geometry on the thermal power output of mine. The output power increases with increasing total volume of the mine and decreasing dimensions of the working spaces (volume-area relation).

Additional heat can be supplied to the coal mine reservoirs from heat pumps at the surface used for cooling purposes. In such case, the temperature of the water flowing from the heat pump outlets will be higher than the inflow of water from the mine reservoir. Reinjecting this warm water amounts to storing heat energy in the mine until it is needed during the cold season. This can significantly improve thermal efficiency of the reservoir.

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3. UTILISATION

Lock-outed and existing, partially flooded hard coal mine in the Upper Silesia Coal Basin constitutes a reservoir of low-enthalpy geothermal water at a temperature of up to 45°C, depending on depth. In order to extract and utilize the heat energy stored in the reservoir, the water must be drawn from the mine. Presently in all coal mines (both existing and lock-outed) in the region, dewatering pump stations draw out of the single mine up to 50 m^3/min. warm water. This water can be used in heat pumps systems. Water can be extracted from the mine also through wells drilled to deep mine levels. After the heat has been extracted the water must then be reinjected into the reservoir because of its high mineral content. Another method is to extract the heat energy by a system of loop heat exchangers installed within the mine itself. Heat pump systems of energy extraction from the mine waters are used in Canada (JESSOP, 1995) and in Germany (ROTTLUFF, 1998).

At present, warm outtake mine air at a temperature of 15 to 19°C is used as an input source for heat pumps installed in "Julian" hard coal mine in Piekary Slaskie town in Upper Silesia. Thermal power output of the heat pump is 60 kW_t (0.96 TJ/year) and it is used for space heating of workshop and bathroom buildings. The capital cost of the heat pump system, air heat exchangers and modernisation of old heating system was 37,000 USD. This new system saves 22,500 USD per year over the old coal burner and it gave payback period less than two years.

Utilization of geothermal energy from mines can be combined with methane burning which is more environmentally friendly than coal. Methane is common in coal mines and is often collected from the mine ventilation systems. In the southwestern part of the Upper Silesia, there is a coalfield where methane is exploited using drill holes. In that area the highest thermal anomaly in the region has been localized, with a thermal gradient of 40°C/km.

Heat pumps utilizing water from coal mines can also be used for space cooling during the summer season. In that case water reinjected into the mine will carry heat from the surface and store it in the mine reservoir.

The possibilities of directly using warm water from mines seem to be limited due to the high concentration of dissolved solids in the water. However, a possible use seems to be in snow melting systems for pavements, city squares and parking places.

Utilisation of geothermal heat as a clean and renewable source of energy has the potential of becoming very important part of environmental management in the Upper Silesia. In that region the concentration of combustion gases in the air is the highest in Poland. Levels of carbon and sulphur oxides are also high because of electrical and thermal power generated in coal fired power plants, which use coal with a high sulphur content. A reduction in the use of this type of conventional fuels will significantly reduce the emission of polluting gases. The use of waste water in heat pumps can improve the water management in coal mines and reduce the release of salty waste waters to the rivers. Furthermore, ventilation air from the mines carries considerable heat energy and proper use of this heat can also limit the environmental impact of coal mining.

4. CONCLUSIONS AND RECOMMENDATIONS

Abandoned, water-filled mines in the Upper Silesian Coal Basin contain reservoirs of low-enthalpy geothermal water at a temperature of up to 45°C. They constitute a significant, but little-studied, geothermal resource which can be used with application of heat pumps for space heating, recreation, agriculture and industry. Direct use of warm water from the mines is possible in snow melting systems..

The utilisation was assumed to take the form of pumping water from the mine, heat extraction in heat pumps installed at the surface, and reinjection of the cooled water into the mine. The numerical modelling indicates that a maximum of 20 MW_t can be extracted from a 1,000,000 m^3 volume of coal mine spaces over a period of 50 years with temperature drop of 7°-8°C in the reservoir. The most important parameters influencing the thermal output of an abandoned coal mine are: total volume of mine openings and their size, depth distribution of volume of mine.

The environmental benefits of partly replacing existing coal-fired thermal power plants, and coal based heating individual houses, with geothermal heat energy derived from coal mines in Upper Silesia region should be studied and quantified as helpful for reduction of combustion gases (mainly CO_2) emission. This also applies to the expected reduction in the release of brine from the mines into the rivers of the region. The feasibility of using the coal mines of Upper Silesia as geothermal reservoirs depends on the economics of utilisation. The economics of different geothermal utilisation schemes should be estimated and compared.

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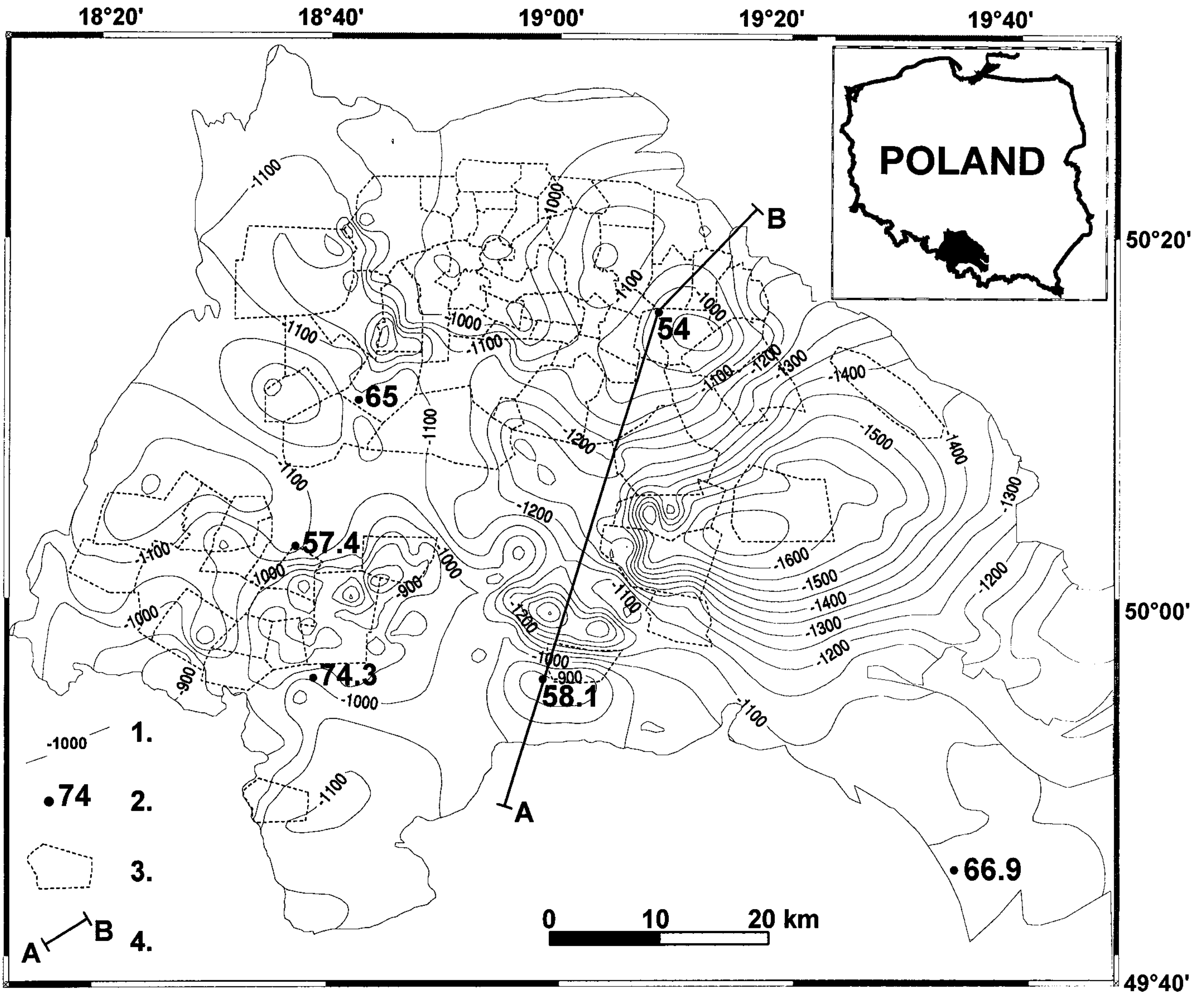

Figure 1: Map of the Upper Silesia Coal Basin.
1 - isolines of depth to a constant temperature of 40 °C, unit: meters under ground;
2 - terrestial heat flow measurements, units: mW/m^2 (after PLEWA, 1991);
3 - areas of hard coal mines;
4 - line of cross-section (Figure 2).

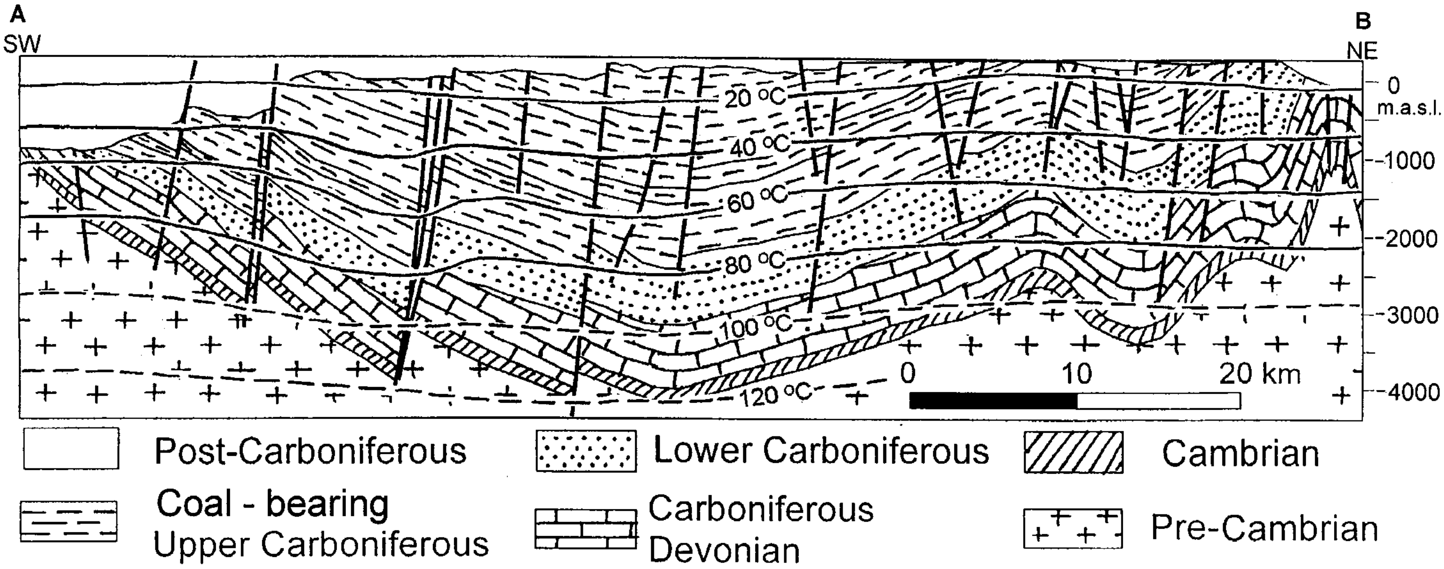

Figure 2: Cross-section of the Upper Silesia Coal Basin.

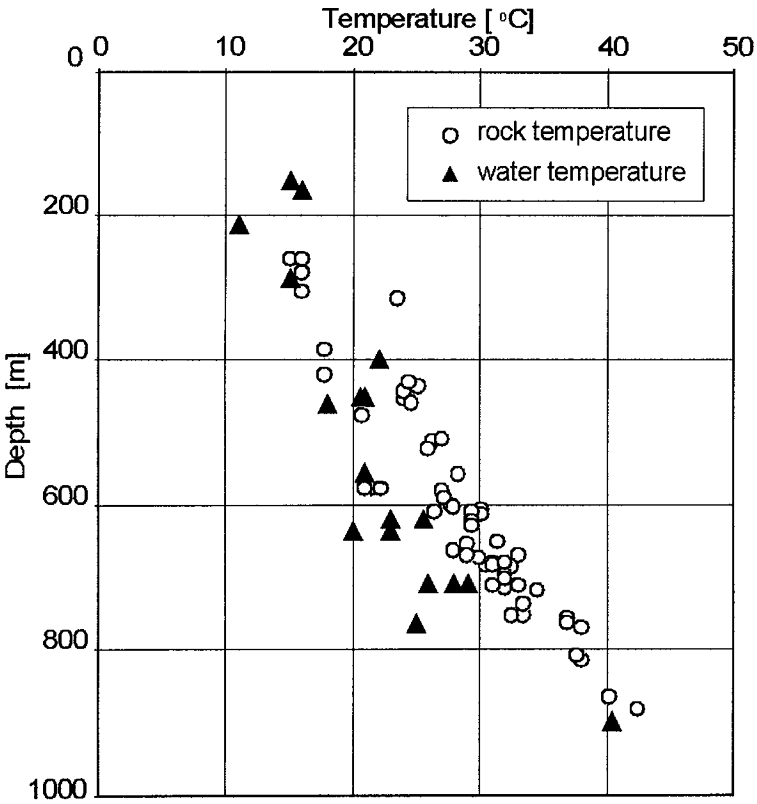

Figure 3: Temperatures of rock and water in selected hard coal mines.

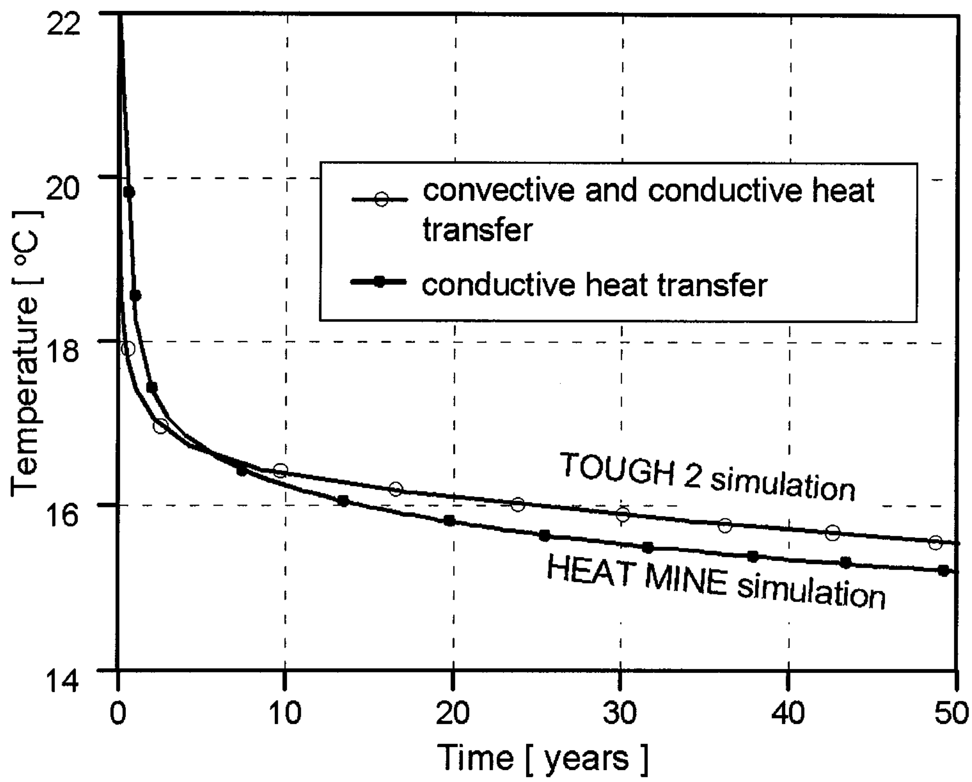

Figure 4: Predicted temperature drop in a typical mine (volume of water reservoirs higher than 1 mln cubic meters) calculated by numerical modelling assuming an extraction rate of 20 MW_t energy in a period of 50 years.

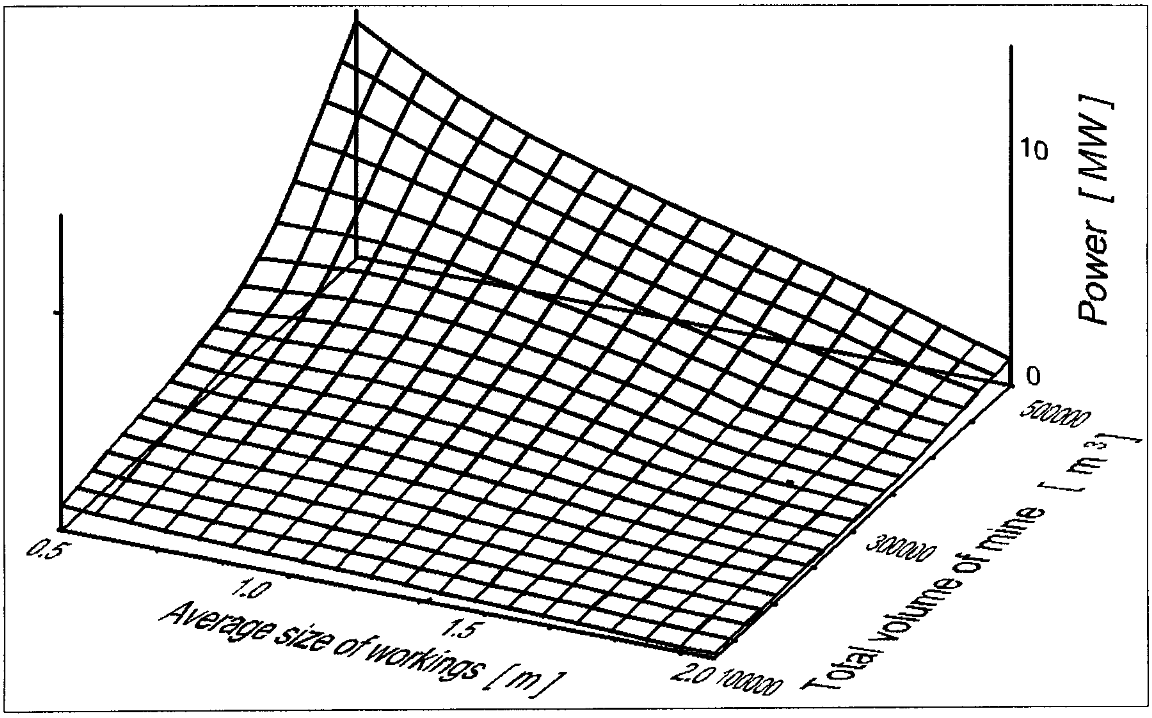

Figure 5: Impact of total volume and average size of mine workings on geothermal heat power of the mine.

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