

Geothermal potential of the Upper Silesian Coal Basin, Poland

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ABSTRACT

Heat-flow density in Poland varies from 20 to 90 mW/m², as indicated by temperature surveys in several dozen deep wells. Temperatures at 1000 m depth vary from 35 to over 50°C. The geothermal heat is relatively easily available in deep mine workings, where terrestrial heat flow exceeds 50 mW/m²; initial depth-dependent temperatures reach 15 to 45°C. Numerical modelling of heat transfer by conduction and convection has been used to simulate the heat flux from surrounding rocks into water in a geothermal reservoir created in mines at up to 1000 m depth with a capacity of several million cubic meters. It is shown that heat flux induced due to the water rock temperature difference in mine openings is much higher of the order of W/m² rather than the mW/m² of terrestrial heat flow. Damp backfillings may be also utilized as heat collectors, loaded with heat recovered at the surface in summer from both space and parking pavement cooling systems. Productive coal mines in the Silesian region of southwest Poland are cooled down by gravitational water inflow and, artificially, by ventilation air. Considerable contributions to the rise of temperature in mines come from the oxidation processes of sulfides and coal matter, the exhaust heat of electric engines and even the body heat of hard-working miners. In abandoned, dormant mines, the ventilation system ceases, water becomes stagnant and the temperature rises. Mine heat energy can be extracted from rocks, pumped-up waters (especially those from deep wells made for methane extraction), ventilation air and backfilling in abandoned underground spaces.

KEYWORDS

Geothermal resources, coal-mine heat, utilization, heat storage, Poland

1. Introduction

The current goal in energy management should be to diminish global pollution by developing renewable energy systems (SOKOLOWSKI 1996). However, geothermal energy as a clean alternative to traditional fossil fuels in a coal-powered economy is still considered as dubious and unreliable. With the support of the Polish Geothermal Association (PGA), the University of Silesia, which is sited in the most polluted region of Poland, aims to convince the local public of the availability and economic reliability of clean heat energy in their locality.

The reduction of CO₂ emission and the resulting improvement of everyday quality of life requires a long-term strategy. Reduction of CO₂ emission will be achieved by the replacement of open-fire coal furnaces, commonly used for space and water heating, by geothermal heating, both in individual home appliances and in the huge district heating systems. Personal comfort can also be improved by the promotion of air-conditioning installations, which are very rare in Poland. In the future, snow-melting systems, defrosting and drying of important road crossings, city-bus stop areas, parking places etc., if efficiently promoted, may reduce the extensive use of potassium or calcium chlorides for snow melting on pavements and streets during the winter. Conversely, installations could be used in the summer for cooling down tarmac surfaces, hitherto reducing the dangerous indentations caused by the wheels of heavy vehicles. A side effect of this would be the extension of the life of dormant coal mines, thereby saving the jobs of some mine workers.

2. The Upper Silesian Coal Basin (USCB)

The region of Silesia is situated in southern Poland (figure 1) at the margin of a neotectonic active zone separating the young Alpine mountain system of the Carpathians and their foredeep. The Silesian Coal Basin, of Carboniferous age, is gently folded and densely cut by younger fault systems. Despite extensive geothermic surveys carried out by the mining industry, there has been a lack of systematic geothermal exploration. The available geothermal data (CHMURA 1968, KARWASIECKA 1980, KNEHTEL 1980, KUROWSKA 1998, MALOLEPSZY 1998) generally indicate a positive geothermic anomaly for Silesia. Initial temperatures down mines reach 15, 35 and up to 45°C, judging from the high temperature gradient due to cooling of mining walls at depths exceeding 1000 m. Heat-flow density in the Silesian Coal Basin varies between 54 and 74 mW/m² (PLEWA 1994). Basic data were collected from well-temperature logging and freshly excavated rocks in mine workings. Significant local geothermal anomalies in Silesia are not known; however, in wells reaching 3000 m in Sosnowiec and Goczałkowice, temperatures exceeding 100°C have been recorded.

The hydrogeologic properties of the sedimentary rock formations within the USCB have been investigated as a part of exploration research carried out for the coal-mining industry. In the 2200-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 aquifer and the type and thickness of overlying rocks. In parts of the USCBA without a thick cover of cap rocks, the mineralization of water is low, and generally increases with the depth of the aquifer. In deep, closed aquifers under thick series of overlying sediments, paleowaters have very high mineralization and contain 40 to 250 g/dm³ of chlorides.

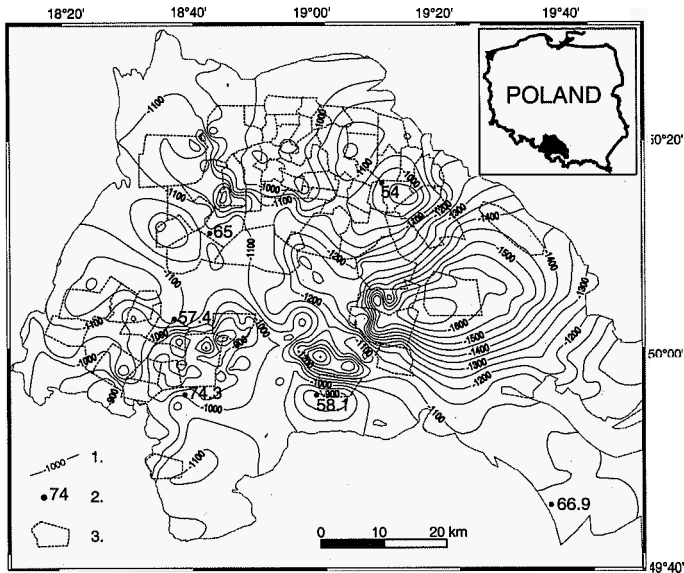


Figure 1: Map of Upper Silesian Coal Basin.

- 1 - isotherms of depth to a constant temperature of 40°C; unit: meters under ground;
- 2 - terrestrial heat-flow measurements; units: mW/m² (after PLEWA 1994);
- 3 - areas of hard coal mines.

The Carboniferous coal basin in Silesia covers an area of about 6000 km² of Poland. Much of the surface area is strongly urbanized and industrialized. Direct exploitation, which intensified in the last century, expanded from near-surface levels to horizons over 1000 m deep in some modern mines, leaving underground spaces with fills or rubble from roof

break-down. These, saturated with water, form natural reservoirs of geothermal heat, which could be recoverable by heat exchangers or direct pumping of the waters.

In 1996, the potential reserves of coal were estimated at 51 billion tonnes, while the 61 coal mines had over 21 billion tonnes of recoverable reserves, over an area of 1750 km². During two centuries of mining in the Silesian region, 9.17 billion tonnes of coal have been extracted, accompanied by recovery of about 4 billion tonnes of rock waste, which in total contribute to about 7 billion m³ of empty space successively covered up, 50% with filling material and with goaf rubble. According to estimations, up to 20%, or 1.4 billion m³, of original mining openings remain in fracture and pore systems, mostly saturated with waters. Recent exploitation of coal is accompanied by pumping out of about 1 million m³ waters daily from down-mine, of which 600,000 m³ daily is let into rivers.

3. Geothermal resources

Abandoned mines have a significant, but little studied, potential as a source of geothermal energy (JESSOP 1995, ROTTLUFF 1998). This potential primarily arises from the heat energy stored in the rock formations surrounding the mine. In order to obtain a preliminary estimate of the thermal power potential of abandoned coal mines, 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 Z. Malolepszy. It is based on a simple analytical model of the heat exchange, which does not take convective heat transport into account.

Based on these simulations, the temperature drop in a mine was calculated (figure 2). The abandoned mine is assumed to have a volume of more than 1,000,000 m³, distributed at three levels (200, 450 and 650 m) with underground openings of size less than 0.5 m. The thermal properties of the host rocks are the same for all levels: thermal conductivity 2 W/m °C and thermal diffusivity 1.1%10⁻⁶ m²/s. Warm water from the mine is assumed to be extracted at a constant rate throughout the year, to be cooled in heat pumps, and the cooled water to be re-injected into the mine. Figure 2 shows that over a 50-year period the temperature of the water filling the mine decreases from 22 to about 15°C due to the heat extraction. The second curve in figure 2 shows the results of numerical modelling by TOUGH. In this model, energy was extracted at a rate of 20 MW/m³ from a 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 the program HEAT MINE. Figure 3 presents the impact of the

geometry of the underground workings on the thermal power output of the mine. The output power increases with increasing total volume of the mine and decreasing dimensions of the working spaces (volume area relation).

4. Heat potential and its possible utilization in the Silesian region

Not surprisingly, the high amount of produced energy and huge amount of waste heat energy cause psychological difficulties in the development of economic geothermic installations in the Silesian region (OSTAFICZUK 1996). Moreover, most of the data relating to energy economy, pollution and waste is confidential or simply not available because of its potential importance in possible environmental compensation claims. Therefore, popularization of the geothermal heating program must begin from the small-users end (RYBACH 1998). Small, impressive installations may have greater impact on public knowledge than the most documented publications. A change of public and municipal authorities' attitudes towards utilization of low-temperature heat energy for domestic purposes must be followed up by the redesigning of existing space-heating systems, or with the supplementing of existing systems by heat pumps. In a new design, floor-heating pipe-coils will be recommended for low-temperature heating media. This, however, needs to be understood and agreed upon by architects and builders.

4.1 Waters pumped out from mines

Heat from waters pumped out from mines may be recovered using heat

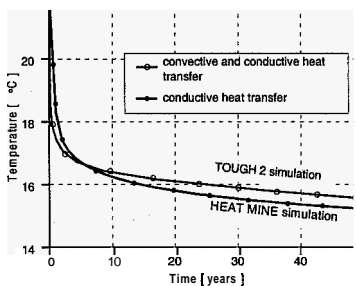


Figure 2: Predicted temperature drop in a typical mine (volume of water reservoirs higher than 1 mln cubic meters) calculated by numerical modelling assuming an extraction rate of 20 MW, energy in a period of 50 years.

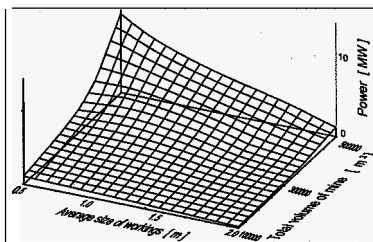


Figure 3: Impact of total volume and average size of mine workings on geothermal heat power of the mine.

exchangers situated near the surface outlets without any disturbance to mining facilities. Waters of relatively low temperature may be distributed to a distance of several kilometers without significant loss of temperature in normally insulated pipelines, thus providing heat energy directly to users, e.g. recreational facilities, fish farms, greenhouses, gardens and, especially, road and sports-facility snow-melt systems (figure 4).

4.2. Outtake ventilation shafts

Heat from ventilation shafts can be recovered at the surface outtake via air/water heat exchangers with the support of heat pumps, for local use.

In non-methane mines, air from ventilation systems can be utilized for inflating balloon stadiums, defrosting and snow-melt systems within a close proximity to the outtake shaft.

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 the Julian hard coal mine in Piekary Śląskie, Upper Silesia. The 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 modernization of the old heating system was 37,000 US\$. This new system saves 22,500 US\$ per year over the old coal burner, with a payback period of less than two years.

4.3. Down-mine heat exchangers

Down-mine heat exchangers would provide heat at temperatures ranging from 20 to 45°C via water/water or water/antifreeze liquid to the surface heat pump or direct-use facilities. Reversible systems seem the most appropriate, providing heat to the surface during the cold season and collecting heat from the surface during the hot season. Again, utilization of that heat in storehouses, recreational and sports facilities and parking places is recommended. In particular, gardening and, successively, fish farming would benefit from being in close proximity to a mine shaft with a down-mine heat exchanger.

Heat at a temperature of 40°C delivered to the surface could be applied in various installations, with supporting heat pumps, for space heating, domestic water heating, greenhouses, etc. Further on, the remaining heat could be extracted for swimming pools (26 to 21°C), fish farming (20 to 15°C) and, finally, for snow melting and pavement drying (15 to 5°C). In the summer, the same heat exchange system could be used for space air conditioning, cooling of stores and tarmac pavements (figure 4). Because of the relatively low supply and low temperatures, heat from coal mines can be most efficiently used in isolated, small and medium locations road bridges, sports courses and stadiums, individual office buildings, schools, swimming pools, factory offices or horticultural farms which are common in industrialized Silesia.

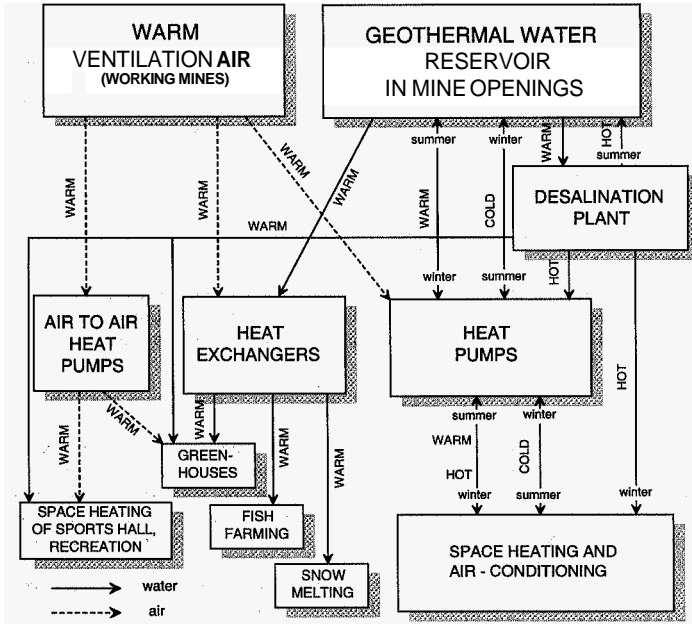


Figure 4. Possible utilization of geothermal heat from the Upper Silesian coal-mines.

With the use of heat pumps, the estimated useful temperature drop could be within the range 10 to 20°C. Thus, the total power output would be more than 60 to 120 kW from a single closed loop with 3 l/s flow of water throughout the heat exchanger. If only 10 such heat exchangers were located in a single coal mine, the total output of heat energy could be within the range of 5 to 10 GWh annually.

A combination of heating and cooling systems working all the year round, connected to down-mine loops, would protect the heat source against cooling too fast. The cooling side of the system, which would be working mostly during the summer, would provide heat for

storing around one pipe loop down in the mine, while its collecting side would use the already-cooled-down heat source developed around the other loop.

4.4 Desalination plants

According to available information (SOKOŁOWSKI 1997), the district heating administration in the Silesian township of Oświęcim (Auschwitz) was offered hot water from a desalination plant under one condition: the delivered water must be collected in constant quantities throughout the whole year. Heat from that water could be utilized in winter as admixture to the district heating system (figure 4). In the summertime, however, an excess of hot water would be a nuisance. A reasonable solution could be underground storing of either hot water by direct injection to shallow porous spaces or heat via spiral heat exchangers. Cooled water could be either disposed of or used for irrigation or recreational purposes. Stored heat could be used the next winter as an additional source of heat energy, exploited in a reverse way by existing installation injection pipes or spiral heat exchangers.

Another opportunity for utilizing waters from the coal-mine-waters desalination plant would be at an existing nearby sports complex an Olympic swimming pool, ice-hockey stadium, gymnasium and a huge car park. The swimming pool and ice-hockey stadium alone could consume all of the excess heat.

4.5 Proposed demonstration/experimental installations

Utilization of geothermal energy is unavoidable in the near future, because of its economic, ecological and technological advantages. However, traditional thinking, particular interests of various lobbies, and a natural aversion against the "unknown", effectively slow down its development in Poland. A breakthrough may be made after successful installations and good publicity provided for particular solutions. The PHARE projects already under consideration may prove helpful in this respect.

- Snow-melt and cool-down installations under the pavement of an accident black-spot road bridge and under the pavement of the open-air district bus depot.
- **Greenhouse** with tropical plants, sports and recreational centre with ice hockey, athletic training stadium, salt baths and swimming pools located near the mine desalination plant.
- Heat store sited down inside mine spaces related to one of the above projects.

5. Conclusion

Geothermal heat is relatively easily available in the mine workings in the Silesian region. Heat energy can be extracted from rocks, pumped-up waters (especially those from deep wells made for methane extraction), ventilation air, and damp-filling in abandoned underground spaces. Initial depth-dependent temperatures reach from 20 to over 40°C. Damp fills in mine spaces may be utilized as heat collectors, loaded by heat recovered from

cooling systems at the surface in summer air-conditioning systems and parking places, bridges and pavements.

Promotion and development of clean, alternative energy sources can be achieved by establishing a demonstration/educational geothermal station at the University of Silesia. The extensive application of geothermal heat energy, available in excess in Silesia in subsurface coal mines, will reduce the emission of CO₂ and improve the quality of life. Open-fire coal furnaces (with approximately 20% efficiency), commonly used in household space and water heating, must be replaced with geothermal heating systems.

The high amount of energy produced and wasted in Silesia makes the conditions for development of geothermal installations difficult. Thus, small impressive installations open to the public are planned for improving the publicity of geothermal heating programs.

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