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GEOLOGICAL AND TECHNICAL ASPECTS OF GEOTHERMAL ENERGY UTILIZATION IN SOUTH-EAST POLAND

The paper discusses the geological and technical aspects of geothermal energy utilization in south-east Poland, such as the availability of thermal aquifers and the techniques for putting the latter into practical use. The geological and geothermal features of the region are presented within the context of existent aquifers whose geothermal resources could be used for heating and recreation. Particulary favourable hydrogeological conditions exist in the Inner Carpathians, in the Podhale Trough, where one geothermal plant and thermal pools that exploit geothermal energy can be found. Equally interesting are the areas north of the Cracow–Tarnów–Rzeszów line, where in the Tertiary, Mesozoic and Paleozoic aquifers of the Miechów Trough and the Carpathian Foredeep a water temperature ranges from 20 to 60 °C (in Poland, thermal water is defined as a water with well-head temperature of above 20 °C). The paper presents technological solutions for the recovery and management of heat in this area, together with the examples of how heat pumps and combined heat and power units are used in Poland.

In order to assess the geothermal potential of a given area, we must first determine whether the extraction of geothermal heat there is economically viable. To answer this question we must consider two basic elements, i.e. the type of thermal aquifer involved and the technological solutions that can be applied to utilize the source [1], [2].

1. GEOLOGICAL AND GEOTHERMAL FEATURES IN SE POLAND

Four main geological units, the Carpathians, the Miechów Trough, the Carpathian Foredeep and the Silesian-Cracow Monocline, are distinguished within the region (figure 1). A general geological description of these units follows, focusing on the aquifers that can be used for space-heating and/or recreation and that guarantee the stability of operating parameters over a long period of time.

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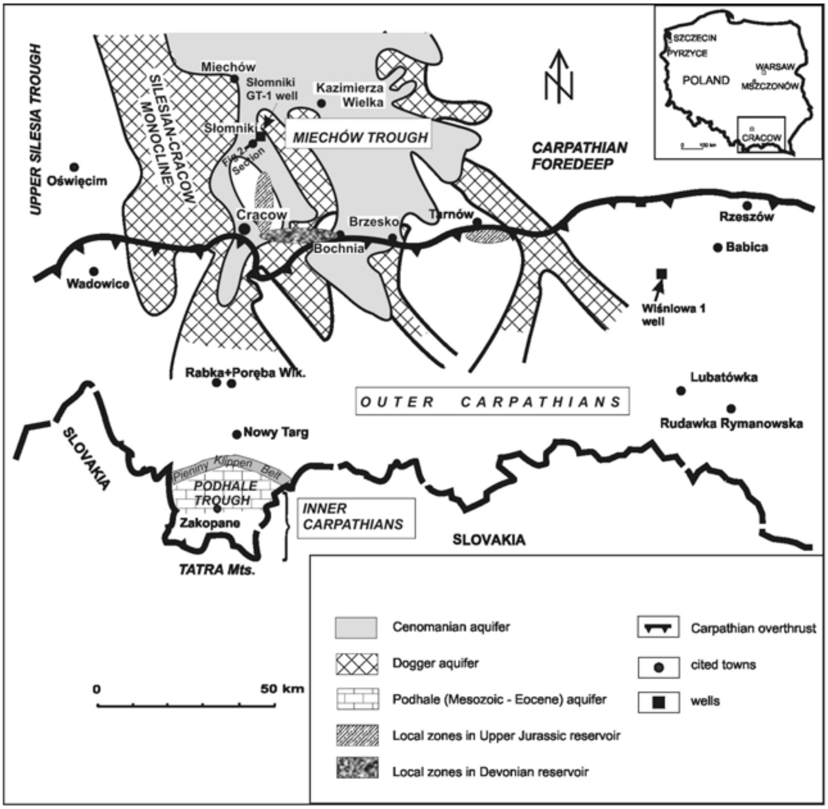

Fig. 1. Main thermal aquifers of south-east Poland

1.1. CARPATHIANS

The Carpathians can be divided into two entirely different parts in terms of structure and hydrogeology: the vast flysch belt of the Outer Carpathians and the Inner Carpathians including the Pieniny Klippen Belt, the Tatra Mountains and the Podhale Trough (figure 1).

The average heat flow in the area after PLEWA [3] amounts to about 55 mW/m^2, and after KARWASIECKA and SZEWCZYK [15] the heat flow ranges from 40 to 65 mW/m^2. Particularly favourable geothermal features were found in the Triassic and Eocene aquifers that stretch across the Podhale Trough (the Inner Carpathians). Thermal waters have been exploited there since 1991 at depths of up to 2900 m. The temperature of these waters, flowing at an average well-head pressure of 2.6 MPa, is close to 90 °C. Some boreholes yield up to 800 m^3/h, while water mineralisation does not exceed 3.0 g/dm^3. Thermal waters can be found within the system made up of the

Tatra Mesozoic Layers (mainly carbonates) and deposits of the Eocene sedimentary basin (flysch Szaflary Beds and basement nummulitic limestones), which are hydraulically interconnected [4], [10].

The thermal waters from these aquifers are exploited in a space heating system that is currently being extended. Moreover, in recent years some recreation pools based on thermal water were put into operation (e.g. Szaflary, Bukowina Tatrzańska).

Apart from the Podhale thermal aquifer of the Inner Carpathians, thermal waters occur only locally in the Outer Carpathians and their temperatures and output are too low to warrant wide-scale use [5]. A number of local geothermal aquifers have however been discovered while drilling sandstone layers of flysch formations. The limited size of the reservoir zones and complex water refilling conditions are probably the main reason why aquifers within these formations are characterised by low yields. It is also uncertain whether their flow-rate parameters would remain stable during exploitation. A unique exception is the Wiśniowa 1 borehole (figure 1), where an artesian outflow of 180 m^3/h at a temperature of 84 °C occurred at a depth of 3790 m. However, the stability of its production capacity over time was not evaluated. In view of these limitations and the difficulty in locating favourable reservoir zones, the significance of the Outer Carpathian flysch as a geothermal target is limited to particular zones where thermal waters may be exploited on a local scale. The thermal water in the flysch deposits have been identified and documentated in the following local zones (location in figure 1): Rabka (water temperature (wt.), 28 °C), Poręba (wt, 42 °C, outflow, 20 m^3/h), Rudawka Rymanowska (wt., 40 °C, total dissolved solids (TDS), 6.7 g/dm^3), Lubatówka (wt., 24 °C, TDS, 2.4 g/dm^3, outflow, 0.4 m^3/h).

1.2. MIECHÓW TROUGH AND CARPATHIAN FOREDEEP

The Miechów Trough and the Carpathian Foredeep occupy the area north of the Carpathians overthrust (figure 1), where Mesozoic aquifers form a part of the regional reservoir structure of the Polish Lowland stretching all the way north to Szczecin (north-west Poland, figure 1). The average heat flow in the area approaches 60 mW/m^2 [15].

Three main sandstone aquifers (Cenomanian, underlying Dogger and locally Miocene) and two carbonate (Upper Jurassic and Devonian) for a prospective geothermal exploitation were found in this area [6], [7].

A space-heating plant, to utilize the low-temperature water from the Cenomanian aquifer, was being built 20 km north of Cracow, at Słomniki, where the geothermal well, Słomniki GT-1, was drilled in 2001 to a depth of 300 m (figure 2A). This plant operates on the basis of a compression heat pump of 320 kW (figure 2B), [8].

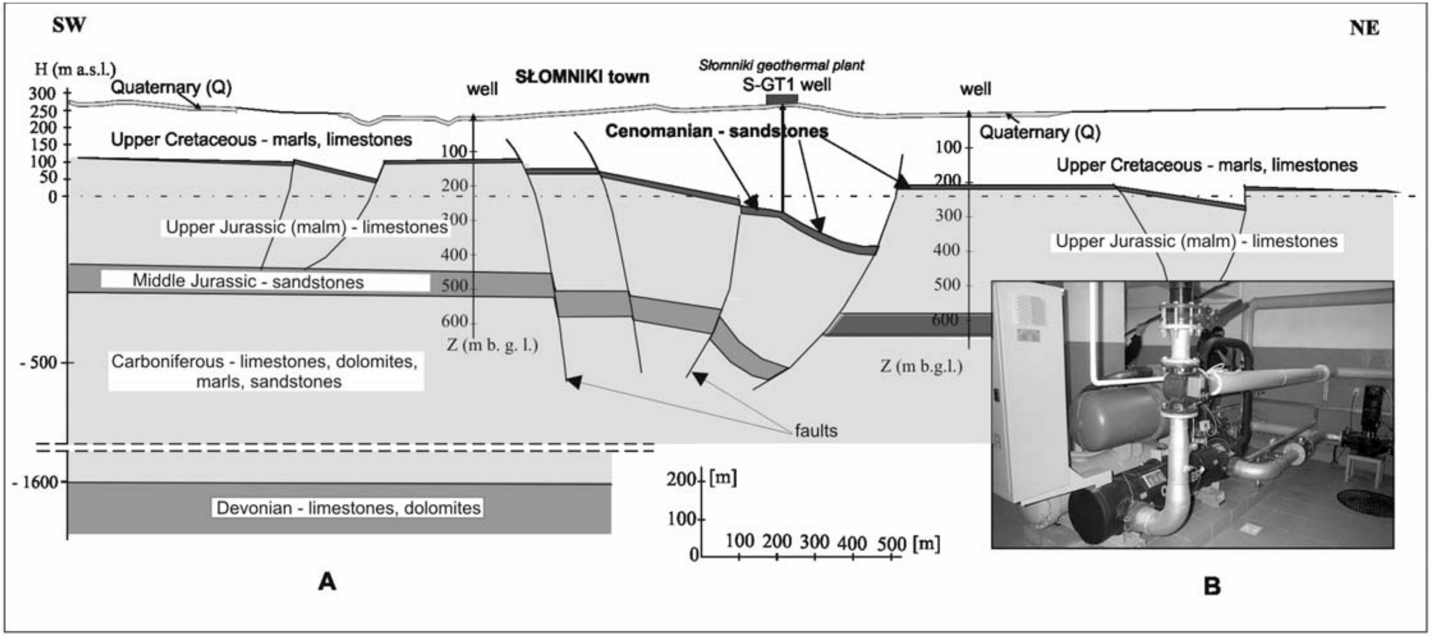

Fig. 2. Geological cross-section across the Miechów Trough near Słomniki (A) (location in figure 1). Compression heat pump (Ochsner, 320 kW) in Słomniki geothermal plant (B)

Further south, near Bochnia and Brzesko (figure 1), artesian flow from the Cenomanian aquifer, with yields from a dozen to several dozen cubic meters per hour, was recorded at a depth of 800–1000 m. Water temperature ranges from 35 to 40 °C, and the average mineralisation is close to 20 g/dm^3.

In the areas, where the Cenomanian deposits are wedging out, geothermal aquifer is locally replaced by sandstones of the Dogger (e.g. in the Miechów zone) [9].

The geothermal potential of the Upper Jurassic carbonate aquifer in the vicinity of Cracow and Tarnów also requires serious consideration. In Tarnów, a temperature of the waters at a depth of about 2000 m reaches 55 ºC and their yield is 50 m^3/h. In the Cracow region, the temperature of the thermal water is 30 °C and the output is about 25 m^3/h.

Paleozoic deposits, which are rarely taken into consideration due to the difficulty in location of reservoir zones, should also be mentioned; however, only a few boreholes with strong outflows have been drilled to date, such as those near Cracow and Bochnia, where the thermal waters come from the Devonian aquifer.

The reservoir parameters of Miocene sandstone aquifer in the Carpathian Foredeep are insufficiently recognized, but there are some zones of interest in terms of their geothermal exploitation, e.g. in the vicinity of Przemyśl, Rzeszów and Jarosław.

1.3. SILESIAN-CRACOW MONOCLINE

The Silesian-Cracow Monocline occupies the north-western part of the region of interest (figure 1), but its geothermal potential is limited because of the shallow-lying Mesozoic and Paleozoic aquifers. The average heat flow in this area according the latest analysis amounts to 70 mW/m^2 [15].

Although geothermal aquifers were formed in the Carboniferous sandstones and Devonian carbonates, the fracture porosity of such water-bearing beds makes their assessment in terms of extension and yields difficult. The temperatures of the thermal waters of the Carboniferous and Devonian aquifers do not exceed 40 °C. There are also Triassic and Jurassic aquifers, but they are characterised by waters with temperatures between 10 and 15 °C.

2. TECHNOLOGICAL SOLUTIONS

The above review shows that many types of aquifers, whose temperature ranges from about 10 to 90 °C, can be exploited in the south-east part of Poland. The quality of these waters is equally variable, ranging from fresh water to strongly mineralised brines; the former can be used without treatment. However, apart from the Podhale aquifer and some other local aquifers, the temperatures of thermal waters range from less than 20 to 60 °C and hence such waters are particularly suitable for heating systems that use heat pumps (of compressive and absorptive types), and directly for thermal pools [11], [12].

2.1. GEOTHERMAL PLANTS OPERATING IN POLAND

The technological solutions adopted in geothermal heating plants in Poland are altered according to hydrogeological properties and chemical characteristics of the thermal aquifers, the level of heat demand and temperature parameters which depend on the type of end-user needs.

Up to now, in Poland, we have 6 geothermal plants (Pyrzyce, Mszczonów, Podhale, Słomniki, Uniejów, Stargard) and a few recreation pools. Although these plants are located (figure 1) outside the area of interest, the characteristics of the geothermal plants of Mszczonów and Pyrzyce are presented as the examples of using absorption heat pumps, possible to apply in hydrogeothermal conditions of SE Poland.

These plants meet end-user needs by utilizing a geothermal resource and back-up gas boilers. The systems operating in these two plants consist of combined heat pumps of the absorptive type (AHP) and low-temperature gas-fired boilers, which are used at peak load in the coldest days when heat pumps cannot generate enough heat to meet end-user needs.

In the geothermal plant at Pyrzyce, there are two AHP units, each of the capacity of 10 MW [13], while at Mszczonów one AHP generates 2.7 MW (figure 3A). In Mszczonów, the heat source for the pump is the thermal water produced by the well at a flow rate of 55 m^3/h and temperature of 42 °C. To improve the economic efficiency of investment, recreation pools based on thermal water were put into operation in 2008.

The heating system in Podhale Region consists of a thermal water source in Szaflary, gas-fired boilers used at peak load in boiler house in Zakopane (figure 3B), and units generating both heat and electric energy (co-generator unit) from natural gas (figure 3C). The differences in the technological solutions between these three plants lie mainly in the temperature of the thermal waters. The Podhale waters reach a temperature of about 88 °C, while those at Pyrzyce and Mszczonów have temperatures of 64 °C and 42 °C, respectively.

2.2. TECHNICAL SOLUTIONS FOR SOUTH-EAST POLAND

Given the fact that water temperature plays a key role in the space-heating industry, especially from the economic point of view, the technical solutions for exploiting ground waters whose temperature ranges from less than 20 to 60 °C (i.e. the waters commonly found in south-east Poland – except Podhale Region) will be discussed below.

A

B

C

Fig. 3. Absorption heat pump (Sanyo, 2.7 MW) cooperating with high-temperature boiler (Viessmann, 1.9 MW) in Mszczonów geothermal plant (A). Peak-load bolier house in Zakopane (B). Co-generator unit (Jenbacher, 0.54 Mw_e + 0.7 Mw_t) in bolier house in Zakopane (C)

Waters in the temperature range typical of south-east Poland are particularly suitable for use in heat pumps (compressive CHP and absorptive AHP types). The range of heat pump applications depends on the relation between the end-users' needs and the technical parameters of such pumps, as well as on a comparison of the investment outlays and operating costs with those typical of other heat sources.

Of a wide variety of energy sources for compression heat pumps (CHPs), the most popular are natural sources that use the energy accumulated in the soil. The thermal properties of these sources make them particularly suitable for the small heat pumps (up to 20–30 kW) used to heat single houses. However, exploitation of soil with an average annual temperature in south-east Poland of about 8 °C as the source of heat for a standard CHP can lead to COP (coefficient of performance, i.e., the ratio of the heat energy delivered to the primary energy used) as low as ca. 3.5. Moreover, using soil as the source of heat requires a sufficient space to construct a collector (about 25–100 m^2 per 1 kW of energy from a heat source for a CHP). These restrictions are reduced if groundwater at a temperature of around 20 °C is used as the heat source for a CHP, as was the case at Słomniki (COP of ~5.0).

One fact emerging from any analysis is that the driving force behind the future use of compression heat pumps is their economic viability. Assuming the cost of electric energy on the level of ca. 167 € (550 PLN)/1 MWh (average price valid in 2008 in Poland), the cost of producing a unit of heat (1GJ) from electricity is ~ 45 € (150 PLN). It is equally easy to calculate the cost of 1 GJ generated by a compression heat pump, i.e. the cost of electrical driving energy: 45 € (150 PLN)/COP.

It should be remembered, however, that the cost so calculated will represent only the expenditure on the electricity used to drive the CHP (exploitation cost). For CHP supplied with energy from soil, COP approaches 3.5, hence the cost of 1 GJ is 13 € (43 PLN). For CHP based on groundwater COP ranges from 4.0 to 5.0, so the cost of 1 GJ ranges from 9 € (30 PLN) to 11 € (38 PLN). For example, a gross cost of 1 GJ drawn from natural gas for domestic use ranges at present from 15 to 18 € (ca. 50–60 PLN). The profitability of CHPs depends thus on the value of COP and current costs of energy from various sources (coke, coal, natural gas, furnace oil, electricity).

Optimal conditions for using groundwaters as a heat source for CHPs exist along the Bochnia–Kazimierza Wielka line (figure 1). The groundwaters of the Cenomanian qualifier there have temperatures from 15 to 30 °C and a low salt content (0.2 g/dm^3).

If water temperatures exceed 35 °C (e.g. near Cracow, Bochnia, Brzesko, Tarnów, figure 1), it is more profitable to make use of the absorption heat pumps (AHP) fed with groundwaters. AHPs are capable of generating temperatures up to 90 °C and have the capacity of more than 1 MW (as at the Pyrzyce and Mszczonów plants). Thermal waters emerging in the vicinity of Bochnia, Brzesko and Tarnów (the Cenomanian, Jurassic and Devonian aquifers), with temperatures ranging from 35 to 55 °C and flow rates higher than 60 m^3/h, would be particularly useful as the heat source for absorption heat pumps.

An interesting way of using conventional energy in geothermal plants is the application of co-generator units, also known as electricity–heat units [14], [16]. Usually, gas-driven co-generators generate electric energy in a common way (also for the plant own needs) and the heat produced as a result of generator cooling is distributed by heat system. Three units of the Jenbacher JMS 312 type, each with the capacity of 540 kW_{el} and 700 kW_{th}, have been put into service in the peak-load boiler house in Zakopane (figure 3C). An economic analysis has demonstrated that the outlays on the purchase and assembly of these units can be paid back in two or three years. A particularly cost-effective solution is to combine the co-generator unit with CHPs and use the electricity thus generated as the driving force for these devices and for the plant own needs.

3. CONCLUSIONS

This paper describes the conditions and hydrogeological parameters of some geothermal aquifers in south-east Poland. The geological conditions are particularly favourable for using a geothermal heat in the Podhale Trough. On a countrywide scale, this area has unique geothermal conditions. The area north of the Cracow–Tarnów–Rzeszów line also offers many opportunities for harnessing geothermal energy stored in vast thermal aquifers (the Cenomanian, Dogger, Upper Jurassic, Devonian, Miocene), whose waters are characterised by large differences in temperature (from less than 20 to 60 °C), mineralization (from 0.2 to 150.0 g/dm^3) and flow rate (up to 60 m^3/h, documented during production tests). In most cases, conditions are particularly suitable for applying heat pump technology (even for Podhale Region, where in some places temperature of groundwater does not exceed 25 °C, e.g. the vicinity of Krokiew, Kiry, Cyrla).

The temperatures of water in SE Poland allow their direct use in recreation pools. In spite of this, for economic viability of geothermal plants, recreation pools and other facilities based on thermal water should be connected to the heat-space systems (the case of Podhale, Mszczonów and Uniejów).

Both technological progress and various technological solutions have provided new opportunities for drawing heat from low-temperature thermal waters, occurring in south-east Poland. The paper shows that several energy sources can be combined in one heat-generating plant. It is, however, of critical importance that such a project should be preceded by technical and economic analyses carried out a priori.

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