Antoni P. Barbacki*

Technical Aspects of Geothermal Energy Utilization in Małopolska Region

1. Introduction

In Małopolska Region particulary favourable hydrogeological conditions exist in the Inner Carpathians (Podhale Trough), where there are already one geothermal plant and thermal pools exploit geothermal energy. Equally interesting are the areas north of the Cracow – Tarnów line, where in Tertiary, Mesozoic and Paleozoic aquifers (reservoirs) of Miechów Trough and Carpathian Foredeep water temperatures range from 20 to 60°C (in Poland, thermal water is defined as a water with well-head temperature above 20°C). These waters require special technological solutions for the recovery and management of heat (for example heat pumps or combined heat and power units).

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.a. the type of thermal aquifer involved and the technological solutions that can be applied to utilize this resource [4, 6]

Here there is a brief description of the technological solutions available to exploit the thermal aquifers typical of Małopolska Region.

2. Geothermal Plants Operating in Poland

The technological solutions adopted in geothermal heating plants in Poland are customised to the differences in 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.

* Faculty of Mining Surveying and Environment Engineering, AGH University of Science and Technology, Krakow

Up to now, in Poland operate 6 geothermal plants (Pyrzyce, Mszczonów, Podhale, Słomniki, Uniejów, Stargard) and a few recreation pools.

Despite of their location, outside the analysed area, the characteristics of the geothermal plants of Mszczonów (near Skierniewice) and Pyrzyce (near Szczecin) was presented as examples of absorption heat pumps use, possible to apply in hydrogeothermal conditions of Małopolska.

a)

b)

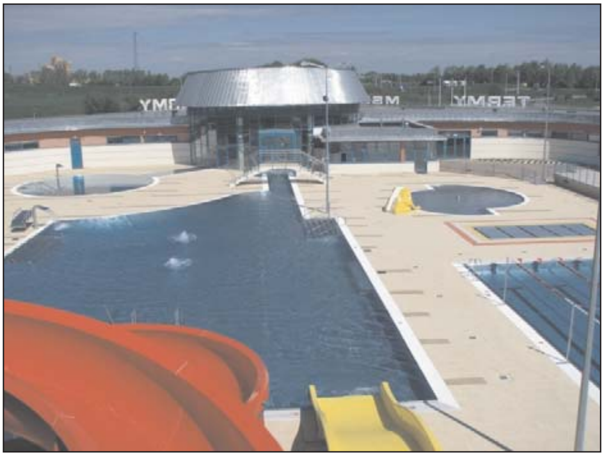

Fig. 1. Absorption heat pump (Sanyo, 2.7 MW) cooperating with high-temperature boiler (Viessman, 1.9 MW) in Mszczonów geothermal plant (a). The thermal pool "Termy Mszczonów" located near the plant (b)

The geothermal heating plants at Pyrzyce and Mszczonów 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 on the coldest days when heat pumps cannot generate enough heat to meet end-user needs. An additional component of these plants are the boilers, generating water up to 150°C, which supply the driving energy for the absorption heat pumps.

In the geothermal plant at Pyrzyce there are two AHP units of 10 MW each [10], while at Mszczonów there is a capacity of 2.7 MW. As mentioned before, the geothermal plant at Mszczonów consists of an absorption heat pump, low--temperature boilers used at peak-load, and a high-temperature boiler (Fig. 1a).

A single Sanyo absorption heat pump of 2.7 MW is operated, using the aqueous solution of lithium bromide. 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. The AHP extracts heat from groundwater by cooling it to 14–30°C (depending on the outdoor temperature). During two years of operation its energy efficiency COP (coefficient of performance, i.e., ratio of the heat energy delivered to the used primary energy) has oscillated between 1.2 and nearly 1.8 (expressed in relation to the quantity of gas used to drive the AHP). After adding the AHP to the Mszczonów plant there was a 33–35% reduction in the quantity of gas burned, thus determining the economic and ecological success of the investment. The third component of the geothermal plant are two low-temperature gas-fired boilers of 2.4 MW each, which are used at peak load when outdoor temperatures are at their lowest. After cooling the thermal water is used for drinking purposes and the remainder is discharged into surface streams (single-well arrangement). Also, to improve economic efficiency of investment, recreation pools based on thermal water were put into operation in 2008 year (Fig. 1b).

In the Inner Carpathians (Podhale Trough) one geothermal plant and few thermal pools exploit geothermal energy from Tatra rocks.

Figure 2a presents a seismic cross-section of the Podhale Trough, according to a time-scale selected so as to provide a real picture of the geology of the region. The thermal waters from these aquifers are exploited by the Geotermia Podhalańska S.A. plant by means of heat exchangers (Fig. 2c), in a distribution system that is currently being extended. Moreover, in recent years some recreation pools based on thermal water were put into operation (one of them, located in Szaflary village, using cooled thermal water from the above-mentioned space heating system is shown on figure 2b).

The heating system in the Podhale consists of a thermal water source in Szaflary, gas-fired boilers used at peak load in boiler house in Zakopane (Fig. 3), and units generating both heat and electric energy (co-generator unit) from natural gas.

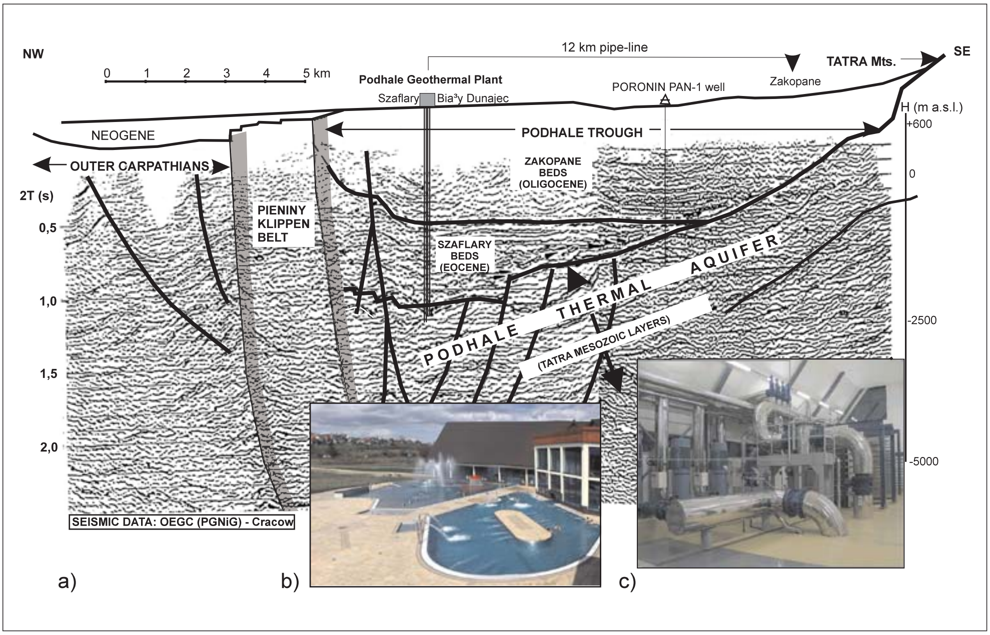

Fig. 2. Time-seismic section across the Podhale Trough (a).
Thermal pool "Termy Podhalańskie" in Szaflary (b).
Geothermal heat exchangers 5 × 8 MW in Podhale geothermal plant (Szaflary) (c)

The geothermal resources are managed by Geotermia Podhalańska S.A. This is thought to be one of the biggest geothermal projects in Europe, at an estimated cost of above 80 million USD. The target capacity of the plant constructed as part of this project is 125 MW (93 MW of which will come directly from thermal waters), with an energy output of 1.2 million GJ per year (by now about 0,5 mln GJ). The project will cover an area of about 70 km^2.

The differences in the technological solutions for these three plants are mainly dictated by 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.

A space-heating plant, to utilize the low-temperature water from the Cenomanian (Middle Cretaceous) 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 (Fig. 4a). This plant operates on base compression heat pomp of 320 kW (Fig. 4b). Despite the low temperature of the water (16.8°C), the Słomniki region is characterised by a high production capacity (53 m^3/h at a wellhead pressure of 0.4 MPa), low mineralisation (348.7 mg/l) and a water composition suitable for domestic uses [5].

a)

b)

Fig. 3. Peak-load boiler house in Zakopane (a).
Co-generator unit (Jenbacher, 0.54 MW_e + 0.7 MW_t) in boiler house (b)

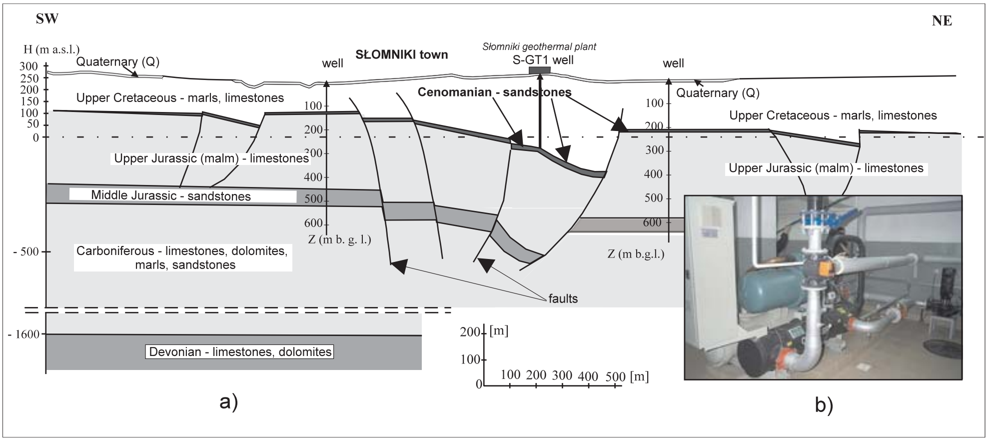

Fig. 4. Geological cross-section across the Miechów Trough near Słomniki (a).
Compression heat pump (Ochsner, 320 kW) in Słomniki geothermal plant (b)

Similar hydrogeothermal conditions occur further south, near Bochnia and Brzesko, where artesian flows from the Cenomanian aquifer were recorded, with yields of a dozen to several dozen cubic meters per hour from a depth of 800–1000 m. Water temperatures range from 35 to 40°C, and the average mineralisation is around 20 g/l [1, 2, 3].

3. Technical Solutions for Małopolska

Many types of aquifers can be exploited in the Małopolska, with temperatures ranging from about 10 to 90°C. Equally variable is the quality of these waters, 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 thermal waters show temperatures ranging from less than 20 to 60°C and hence are particularly suitable for heating systems that use heat pumps (compressive and absorptive types), and directly for thermal pools [8, 11].

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 with temperatures ranging from less than 20 to 60°C (i.e. the waters commonly found in Małopolska – except Podhale region) will be discussed below.

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 the heat pumps, as well as on a comparison of the investment outlays and operating costs with those typical of other heat sources.

Out 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 homes.

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 an energy efficiency ratio (COP) only of about 3.5. Moreover, using soil as a source of heat, requires of sufficient space to construct a collector (about 25–100 m^2 per 1 kW of energy from a heat source for a CHP). Alternatively, we can use borehole heat exchangers.

These restrictions are reduced if subsurface water at a temperature of around 20°C is used as the heat source for a CHP, as was the case at Słomniki.

The advantages of the solution presented above are the following:

– relatively high thermal power of intake (several hundreds kW_{th});
– a permanent and relatively high water temperature, which is conducive to a high energy efficiency ratio (COP) of about 4.0–5.0;
– low operating costs (higher COP, lower cost of driving energy), particularly for a single well operation (without reinjection power).

The disadvantages of using groundwater as a source of heat for CHPs include:

– the high investment costs that depend on the hydrogeological features of the area;
– the depth of the water-bearing horizon and water quality (wells, exchangers); the high investment costs related to drilling wells greatly increase the payback time;
– problems with injecting the water back into the water-bearing reservoir (in the case highly saline fluids that cannot be used for drinking purposes and cannot be discharged into surface waters); reinjection of saline brines also increases the managament costs and may cause problems linked to corrosion and scaling.

One factor emerging from any analysis of these advantages and disadvantages is that the driving force behind the future use of compression heat pumps is their economic viability.

Assuming energy cost from electricity ca. 167 € (550 PLN) / 1 MWh (average price valid in 2008 in Poland), cost of producing unit of heat (1 GJ) from electricity is ~ 45 € (150 PLN). Also, it is easy to calculate the generating cost of 1 GJ using 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 is ca. 3.5, hence cost of 1 GJ amount 13 € (43 PLN). For CHP based on groundwater COP is ranging from 4.0 to 5.0, so cost of 1 GJ: 11 € (38 PLN) – 9 € (30 PLN). For example brutto cost of 1 GJ from natural gas for domestic use amounts at present 15–18 € (ca. 50–60 PLN). Profitability of CHPs depend 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 ground waters as a heat source for CHPs exist near Słomniki and in the vicinity of Kazimierza Wielka. The thermal waters there have temperatures from 15 to 30°C, a low salt content (0.2 g/l) and the Cenomanian aquifer occurs at an average depth of about 350 m.

Where water temperatures exceed 35°C (e.g. near Cracow, Bochnia, Brzesko, Tarnów), it is more economical to use above mentioned absorption heat pumps (AHP), in which ground waters are used as heat sources. AHPs are capable of generating temperatures up to 90°C and have a capacity of more than 1 MW (as in the above mentioned Pyrzyce and Mszczonów plants). Thermal waters emerging in the vicinity of Bochnia, Brzesko and Tarnow (Cenomanian, Jurassic and Devonian aquifers), with temperatures ranging from 35 to 55°C and flow-rates of more than 60 m^3/h, would be particularly useful as the heat source for absorption heat pumps. However, the drawbacks with AHPs are the same as in the case of CHPs using subsurface water as heat source.

An interesting way of using conventional energy in geothermal plants is the application of co-generator units, also known as electricity-heat units [7, 9]. Usually, co-generators use the gas for common generating the electricity (also for the plant's own needs) and heat of cooling is distributed by heat system. Three units of Jenbacher JMS 312, each with a capacity of 540 kW_{el} and 700 kW_{th} have been put into service in the peak-load boiler house in Zakopane (Fig. 3b). An economic analysis has demonstrated that the outlays for the purchase and assembly of these units will be paid back in two or three years. To achieve this goal, co-generator units have to be used for both heat and electricity production and they have to be run in a commercially viable way. 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's own needs.

Co-generator units should be considered for geothermal plants in programme in South-East Poland, as a combined source of heat and electricity. Though their use could be a financial success, each technological solution has to be carefully analysed beforehand.

4. Conclusions

This paper has described the conditions and hydrogeological parameters of some geothermal aquifers in Małopolska Region. The geological conditions are particularly favourable for geothermal uses in the Podhale Trough. On a countrywide scale, this area has unparalleled geothermal features. The area north of the Cracow–Tarnow line also offers many opportunities for harnessing geothermal energy, comprising vast thermal aquifers (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/l) 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, where in some places temperature of groundwater doesn't exceed 25°C – e.g. Krokiew, Kiry, Cyrla).

A project at Słomniki started after a natural free outflow of fresh water was recorded from the Cenomanian with a temperature of about 17°C and flow-rate of 53 m^3/h. Analyses determined that this water resource could be used in space--heating by means of a CHP system and, after cooling in CHPs, for domestic use.

The range of water temperatures in Małopolska shows the possibilities of using them directly in recreation pools. In spite of this, for economic viability of geothermal plants, recreation pools and other users of thermal water should be joined to the heat-space systems, as in the case Podhale, Mszczonów and Uniejów.

Technological progress and the introduction of various solutions have provided new opportunities for using the energy from thermal waters, including the low enthalpy fluids of this region. Paper shows that several energy sources can be combined in one heat-generation plant. It is, however, of critical importance to the succes of such a project that a technical and economic analysis be carried out a priori.

References

[1] Barbacki A.P.: *Zbiorniki wód geotermalnych niecki miechowskiej i środkowej części zapadliska przedkarpackiego* [The aquifers of geothermal waters of the Miechów Trough and central part of the Carpathian Foredeep]. IGSMiE PAN, Kraków 2004.

[2] Barbacki A.P., Bujakowski W., Pająk L.: *Atlas zbiorników wód geotermalnych Małopolski* [Atlas of Geothermal Water Reservoirs in Małopolska]. IGSMiE PAN, Kraków 2006.

[3] Barbacki A., Uliasz-Misiak B.: *Geothermal Energy of the Mesosoic Basin in the Carpathian Foredeep, Kraków Region, Poland*, Energex '2002, 9th International Energy Conference, Applied Energy Elsevier Science Ltd., vol. 74, 2003, 65–73.

[4] Barbier E.: *Geothermal energy and current status: an overview.* Renewable & Sustainable Energy Review, Pergamon, 2002, pp. 3–65.

[5] Bujakowski W.: *Regionalna analiza i badania geotermalne jury środkowej i cenomanu w województwie małopolskim* [Regional analysis and geothermal study of the Middle Jurassic and Cenomanian in the Małopolskie Voivodeship]. Archiwum IGSMiE PAN, Kraków 2001.

[6] Fridleifsson I.B.: *Geothermal Energy amongst the World's Energy Sources.* Proceedings of World Geothermal Congress, Antalya (Turkey) 2005.

[7] Lucas K.: *Efficient energy systems on the basis of cogeneration and heat pump technology.* International Journal of Thermal Sciences, vol. 40, issue 4, 2001, pp. 338–343.

[8] Lund J., Sanner B., Rybach L., Hellstrom G.: *Ground Source Heat Pumps – Geothermal Energy for Anyone and Anywhere.* Proceedings of World Geothermal Congress, Antalya (Turkey) 2005.

[9] Rosen M., Le M., Dincer I.: *Efficiency analysis of a cogeneration and district energy system*. Applied Thermal Engineering, vol. 25, 2005, pp. 147–159.

[10] Sobański R., Kabat M., Malenta Z., Maliszewski N., Grabiec R.: *Ocena pracy ciepłowni geotermalnej w Pyrzycach na podstawie wyników eksploatacji z 1999 r.* [Assessment of the geothermal heating plant in Pyrzyce based on the operating results from 1999]. Proceedings of the Symposium "Rola energii geotermalnej w zrównoważonym rozwoju regionów mazowieckiego i łódzkiego", Osuchów 04–06.10.2000.

[11] Yihan C.: *The Research Work of Low Temperature Geothermal Space Heating*. Proceedings of World Geothermal Congress, Antalya (Turkey) 2005.