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

Geological and Technical Aspects of Geothermal Energy Utilization in Małopolska Region (South Poland)

Antoni P. Barbacki, Wiesław Bujakowski

Polish Academy of Science, 30-950 Kraków, Wybicki 7 Street, Poland

barbacki@min-pan.krakow.pl

Keywords: Małopolska-Poland, Space-heating, Heat pumps, Prospective areas, Geothermal aquifers

ABSTRACT

The paper discusses the geological and technical aspects of geothermal energy utilization in Małopolska Region, such as the availability of thermal aquifers and the techniques for putting them to practical use. The geological and geothermal features of the region are presented within the context of the existence of aquifers containing geothermal resources that could be used in space heating. Particulary favourable hydrogeological conditions exist in the Inner Carpathians, in the Podhale Trough, where there is already one geothermal plant exploiting geothermal energy. Equally interesting are the areas north of the Cracow - Tarnów line, where in Mesozoic aquifers water temperatures range from 20 to 60^{o}C. The paper includes technological solutions for the recovery and management of heat in this area, together with examples of how heat pumps and combined heat and power units are used in Poland**.**

1. INTRODUCTION

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 the source.

This paper outlines these two elements with reference to conditions in Małopolska Region. The first part describes the geothermal aquifers in the area occupied by the three geological units of the Carpathians, Miechów Trough and Silesian-Cracow Monocline; the second part gives a brief description of the technological solutions available to exploit thermal aquifers typical of this region.

2. GEOLOGICAL AND GEOTHERMAL FEATURES OF MAŁOPOLSKA REGION

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

2.1 Carpathians

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

The average heat flow density of the Carpathian region is about 56 mW/m^2 (Plewa, 1994). Particularly favourable geothermal features were found in the Triassic and Eocene aquifers that are distributed throughout the Podhale Trough. 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^{o}C. Some boreholes yield up to 800 m^3/h, while water mineralisation does not exceed 3.0 g/L. 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 (Fig. 2). The thermal waters in the Tatra Mesozoic Layers reside in a karst-fissured type aquifer, while those in the Eocene basin reside in a porous-fissured aquifer (Sokołowski *et al*., 1993). The uniqueness of the Podhale aquifer consists mainly of the homogeneous distribution of reservoir parameters throughout the Podhale Trough (there were high artesian flows from the Triassic and Eocene in nearly all boreholes). The stability of these parameters is due to the strong karstification and fissuring of the Tatra Mesozoic Layers underlying the entire Podhale Trough. The location of the piezometric surface at 950 m above sea-level ensures favourable artesian conditions (average elevation of the wellheads is about 750 m a.s.l.) and contributes to stable production.

Figure 2 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. Characteristic features of the Podhale aquifer include strong tectonic deformations of the Tatra Mesozoic Layers (lower aquifer), contrasting with less-deformed and nearly horizontal flysch (Szaflary Beds) at the centre of the Podhale Trough (upper aquifer). The thermal waters from these aquifers are exploited by the Geotermia Podhalańska S.A. plant in a distribution system that is currently being extended.

Apart from the Podhale thermal aquifer of the Inner Carpathians, which has features that are unique in Europe, thermal waters occur only locally in the Outer Carpathians and their temperatures and output are too low to warrant widescale use (Chowaniec *et al*., 2001). A number of local geothermal aquifers have however been discovered while drilling sandstone layers of flysch formations (Fig.3). A characteristic feature of this folded flysch system is the lack of typical water-bearing strata and fragmentation into local reservoir zones (the average porosity of the sandstones is about 6% and their permeability ranges from 0 to 15 mD). The limited size of the reservoir zones and complex water recharge 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 (Fig. 3), where an artesian outflow of 180 m^3/h at a temperature of

84°C occurred at a depth of 3790 m. The stability over time of its production capacity was however, 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.

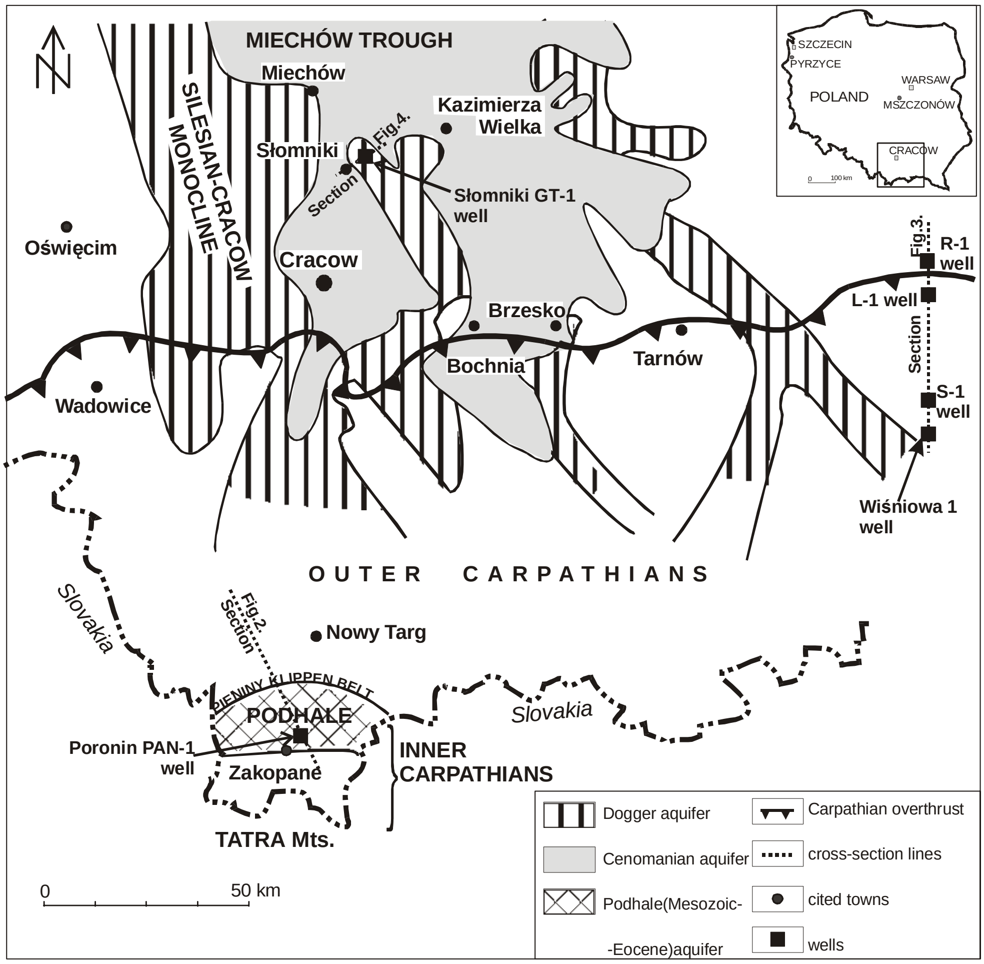

Figure 1: Main thermal aquifers of Małopolska Region

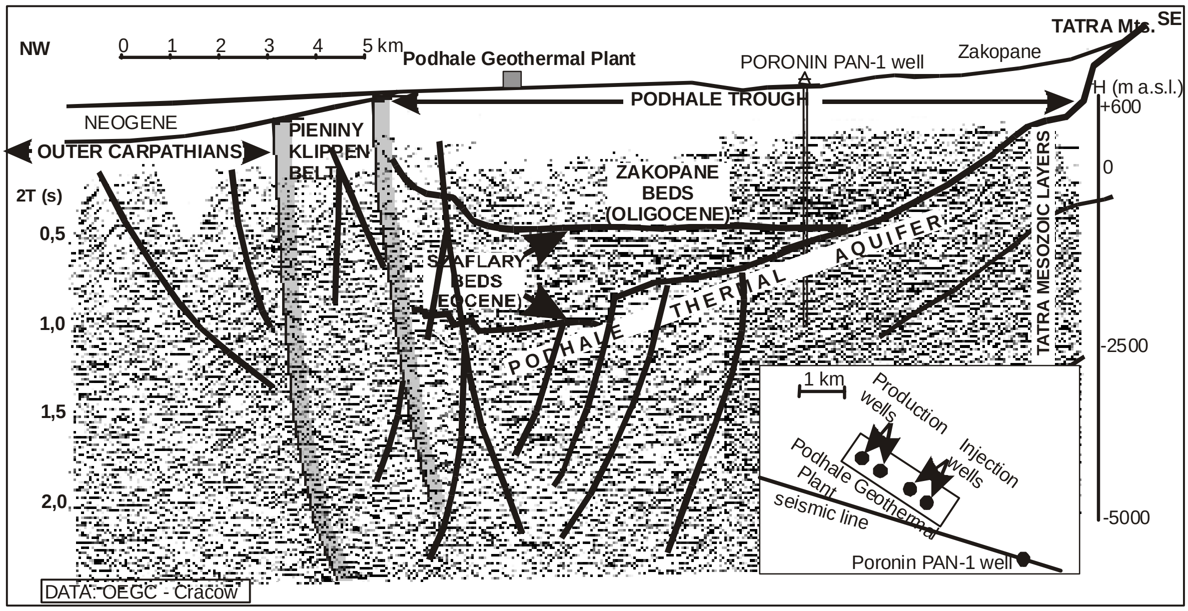

Figure 2: Time-seismic section across the Podhale Trough

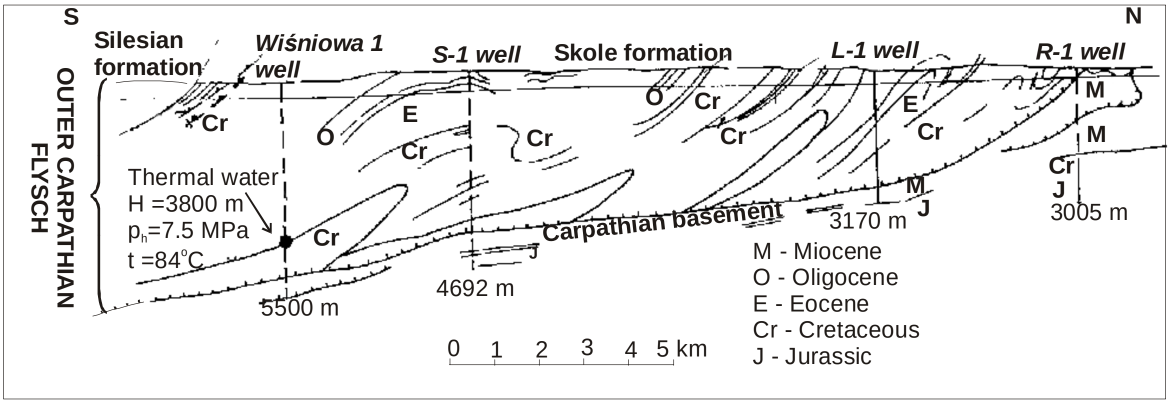

Figure 3: Geological cross-section accross the Carpathians (see Fig.1)

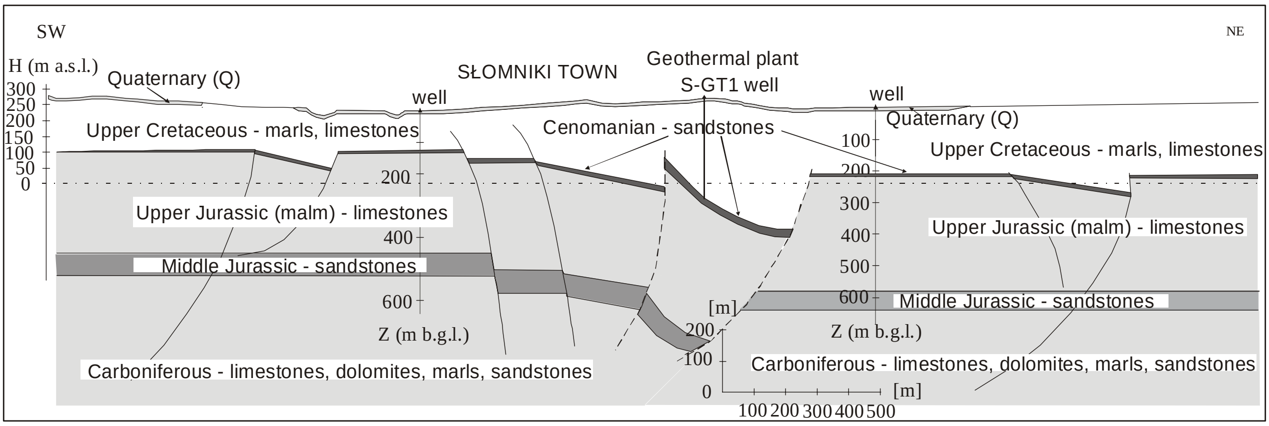

Figure 4: Geological cross-section accross the Miechów Through near Słomniki (see Fig.1)

2.2 Miechów Trough

The Miechów Trough occupies the area north of the Carpathians overthrust (Fig.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, Fig.1). The average heat flow of the Miechów Trough is about 50 mW/m^2 (Plewa, 1994). Two main sandstone aquifers (Cenomanian and the underlying Dogger) and one carbonate (Upper Jurassic) of interest for geothermal exploitation were found in this area (Barbacki and Kazanowska, 2001a,b; Barbacki, 2002). These aquifers lie at great depth beneath the Outer Carpathian flysch in the south (Fig.1); however, it is only north of the Carpathians, in the Miechów Trough area, that they show favourable reservoir parameters. An unstable tectonics and differential dip are typical of these reservoir structures (Fig.4). Senonian (Upper Cretaceous) deposits provide thermal insulation for the Cenomanian aquifer, while the Dogger aquifer is insulated by the impermeable marly formations of the Upper Jurassic.

The average porosity and permeability of the Cenomanian sandstones are 20% and 500 mD, respectively. The thickness of the aquifer ranges from a few m to over 150 m. The depth of the top of the Cenomanian aquifer there varies from 200 m (northern zone) to 2300 m (southern zone), while water temperature ranges between 20 and 70°C. Unfortunately, high temperature zones occur under the Carpathian overthrust, where the aquifer shows low yields (below 10 m^3/h)

A space-heating plant to utilize the low-temperature water from the Cenomanian aquifer is currently 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.4). 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 (Bujakowski, 2001).

Further south, near Bochnia and Brzesko (Fig.1), artesian flow from the Cenomanian aquifer, with yields of a dozen to several dozen cubic meters per hour, were recorded at a depth of 800-1000 m. Water temperatures range from 35 to 40°C, and the average mineralisation is around 20 g/l.

In the areas where the Cenomanian deposits are wedging-out, the main geothermal aquifer is hosted by sandstones of the Dogger (e.g. in the Miechów region where natural outflows of thermal waters with a mineral content below 1.0 g/l and temperatures of about 35°C have been recorded, Fig.1). The average porosity and permeability of the Dogger sandstones are 13% and 300 mD, respectively, and their thickness ranges from a few m to 100 m. The Dogger aquifer has lower yields than the Cenomanian, but its waters have higher temperatures due to their deeper structural position and higher mineralization. The top of the Dogger aquifer lies at a depth ranging from 500 m in the Miechów Trough to 2300 m in the Carpathian zone; however, the aquifer only locally shows favourable geothermal parameters (e.g. near Miechów and Tarnów, where the thermal water temperatures are 30°C and 55°C, respectively, and the average yield amounts to about 10 m^3/h).

The geothermal potential of the Upper Jurassic aquifer in the vicinity of Cracow and Tarnow requires serious consideration. The Upper Jurassic near Tarnów forms an interesting carbonate reservoir structure (Late Oxfordian limestones with an average porosity of 10%), but the waters there have a high salt content (about 100 g/l). The temperature of waters at a depth of about 2000 m is to 55ºC and their yield is 50 m^3/h. In the vicinity of Cracow, where Oxfordian (Upper Jurassic) aquifers occur, the temperature of the thermal water is 30^{o}C and the output is about 25 m^3/h.

Paleozoic deposits, which are rarely taken into consideration due to the difficulty in localising reservoir zones, should also be mentioned when evaluating the geothermal situation in Małopolska Region. However, only a few boreholes with strong outflows have been drilled to date, such as those near Bochnia (Fig.1), where the thermal waters come from the Devonian aquifer.

2.3 Silesian-Cracow Monocline

The Silesian-Cracow Monocline occupies the north-western part of the study region (Fig.1), but its geothermal potential is limited because of the shallow-lying Mesozoic and Paleozoic aquifers. The average heat flow of this area is 55 mW/m^2 (Plewa, 1994). A geothermal aquifer has formed in Carboniferous sandstones, but is of the fissured type and hence difficult to assess in terms of extension and yields. The temperatures of the thermal waters of the Carboniferous aquifer do not exceed 40^{o}C. There are also Triassic and Jurassic aquifers, but they are characterised by waters with temperatures between 10 and 15^{0}C.

3. PROPOSALS FOR TECHNOLOGICAL SOLUTIONS

The above review shows that many types of aquifers can be exploited in the central part of Małopolska Region, with temperatures ranging from about 10 to 90^{o}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 40^{o}C and hence are particularly suitable for heating systems that use heat pumps (Barbacki, *et al.*,2001a,b; Barbacki, 2002).

3.1 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.

The geothermal heating plants at Pyrzyce and Mszczonów (Fig.1) 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^{o}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 (Sobański *et al.,* 2000), 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.5). A single Sanyo absorption heat pump of 2.7 MW is operated, using the aqueous solution of lithium bromide (Kubski, 2001). 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^{o}C. The AHP extracts heat from groundwater by cooling it to 14 – 30^{o}C (depending on the outdoor temperature). During two years of operation its energy efficiency COP (coefficient of performance, i.e., ratio of the primary energy used to the heat energy delivered) 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 (Balcer, 2000), 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).

Figure 5: Absorption heat pump (Sanyo, 2.7 MW) co-operating with high-temperature boiler (Viessman, 1.9 MW) in Mszczonów geothermal plant.

The heating system in the Podhale Trough consists of a thermal water source , gas-fired boilers used at peak load, and units generating both heat and electric energy (co-generator unit) from natural gas. 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 about US$ 80million. The target capacity of the plant constructed as part of this project is 125 MW (93 MW_t of which will come directly from thermal waters), with an energy output of 1.2 million GJ per year. The project will cover an area of about 70 km^2 (Długosz, 2001).

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 86^{o}C, while those at Pyrzyce and Mszczonów have temperatures of 64^{o}C and 42^{o}C, respectively.

3.2 Proposals for technical solutions for Małopolska

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^{o}C (i.e. the waters commonly found in Małopolska Region) will be discussed below.

Waters in the temperature range typical of Małopolska are particularly suitable for use in heat pumps. 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 Małopolska Region of about 8^oC 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). These restrictions are reduced if subsurface water at a temperature of around 20^oC 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 :

- a relatively high thermal power of intake (several hundred 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, particularly for a single well operation (without reinjection)

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

- 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 of 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. Optimal conditions for using ground waters as a heat source for CHPs exist near Słomniki and in the vicinity of Kazimierza Wielka (Fig.1). The thermal waters there have temperatures from 15 to 30^oC, a low salt content (0.2 – 14.0 g/l) and the Cenomanian aquifer occurs at an average depth of about 350 m.

The drawbacks to this solution are high investment costs, the salinity of the waters, the troubles and cost related to reinjection, and the temperature and capacity limitations of CHPs. Where water temperatures exceed 35^oC (e.g. near Cracow, Bochnia, Brzesko, Tarnów, Fig.1), it is more economical to use absorption heat pumps (AHP), in which ground waters are used as heat sources. AHPs are capable of generating temperatures up to 90^oC 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 and Jurassic aquifers), with temperatures ranging from 35 to 55^oC 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. Three units of Jenbacher JMS 312, each with a capacity of 540 kW_e and 700 kW_{th}, have recently been put into service in the Podhale geothermal plant (Fig.6). 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. In this case, the price of one GJ is 60% lower than the price of energy from gas-fired boilers.

Figure 6: Co-generator unit (Jenbacher, 0.54 MW_e + 0.7 MW_t) in the Podhale geothermal plant.

Co-generator units should be considered for geothermal plants currently in programme in Małopolska, 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 thermal aquifers in Małopolska Region. The geological conditions are particularly favourable for geothermal uses in the Podhale basin. 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), whose waters are characterised by large differences in temperature (from less than 20 to 60^oC), 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 in Małopolska. A project is currently under way at Słomniki, which started after a natural free outflow of fresh water was recorded from the Cenomanian with a temperature of about 17^0C and flow-rate of 53 m^3/h;analyses determined that this resource could be used in space-heating by means of a CHP system and, after cooling in CHPs, for domestic use.

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 Southern Poland. We show 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

Balcer, M.: Technical infrastructure of the geothermal heating plant at Mszczonów. *Proceedings* of the Symposium on the Role of Geothermal Energy in the Sustainable Development of the Mazovian and Lodz Regions. Published by the Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Cracow, Poland (2000)

Barbacki, A.: Upper Jurassic geothermal basin in the central part of the Carpathian Foredeep and SE part of the Miechów Trough – geological setting and hydrogeothermal conditions. *Przegląd Geologiczny* 9, Warsaw, Poland (2002)

Barbacki, A., and Kazanowska, A.: Thermal waters in the Cenomanian of the Carpathian Foredeep and adjacent areas. *Przegląd Geologiczny* 6, Warsaw**,** Poland, (2001a)

Barbacki, A., and Kazanowska, A.: Middle Jurassic geothermal basin in the central part of the Carpathian Foredeep and neighbouring areas (Southern Poland).*Przegląd Geologiczny* 10/1, Warsaw, Poland (2001b).

Bujakowski, W.: Regional analysis and geothermal study of the Middle Jurassic and Cenomanian in the Małopolskie Voivodeship. *Archives* of the Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Cracow, Poland (2001)

Chowaniec, J., and Poprawa, D.,Witek, K.: Occurrence of thermal waters in the Polish part of the Carpathians. *Przegląd Geologiczny* 8, Warsaw, Poland (2001)

Długosz, P.: The project for using geothermal heat for heating purposes in the Podhale region. *Proceedings* of the Symposium on the Role of Geothermal Energy in the Sustainable Development of Regions. The Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Cracow, Poland (2001)

Kubski, P.: The geothermal heating plant in Mszczonów. *Heat Engineering and Ventilation 1*, Warsaw, Poland (2001)

Plewa, S.: Distribution of geothermal parameters on Polish territory. *Published by* the Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Cracow, Poland (1994)

Sobański, R., and Kabat, M., and Malenta, Z., and Maliszewski, N.,and Grabiec, R.: Assessment of the geothermal heating plant in Pyrzyce based on the operating results from 1999. *Proceedings* of the Symposium on the Role of Geothermal Energy in the Sustainable Development of the Mazovian and Lodz Regions. Published by Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Cracow, Poland (2000)

Sokołowski, J., and Bujakowski, W., and Długosz, P.: Present state and programme of geothermal energy utilization in the Podhale region. *Proceedings* of the International Seminar on Environmental Protection by the Use of Geothermal Energy. Technika Poszukiwań Geologicznych 5/6, Cracow, Poland (1993)