INTERNATIONAL GEOTHERMAL DAYS
SLOVAKIA 2009
CONFERENCE & SUMMER SCHOOL

II.2.

GEOTHERMAL DISTRICT HEATING SYSTEM IN PODHALE AND ZAKOPANE, POLAND – A NEW AND ENVIRONMENTALLY BENIGN SOLUTION FOR A TOURIST CENTRE

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ABSTRACT

The Podhale region (S-Poland) is a main tourist and recreation centre in the country. Along with the neighbouring areas on the Slovakian side of the Tatra Mts. it forms a very attractive international tourist and leisure destination in Central Europe.

The Podhale region is also treated as a cradle for geothermal energy use for heating in Poland. The project has been developed since the end of 1980s starting from the exploration stage through the Experimental Geothermal Plant to large commercial scale. It is of essential significance to stop the degradation of Podhale ecosystem affected by intensive pollution caused by burning large quantities of hard coal for heating. The target geothermal heat sales will be around 600 TJ. Currently the system supplies considerable part of heat receivers in Zakopane (main town of the region) and some receivers in other localities. Further connections are underway.

More than fifteen years of the project development brought many results of both cognitive and practical meaning for the proper long-term exploitation of the geothermal reservoir and the heating network operation.

Apart from heating, important prospective geothermal uses are bathing and balneotherapy. However, for many years recreation and healing facilities and services based on geothermal waters were missing. Till 2001 only one geothermal bathing pool operated in Zakopane. In several recent years a long-awaited investments started and some recreation centres were launched. It is a very important line of applications since an extremely big demand for such kind of tourist offer. It extends the scope of geothermal energy uses and contributes to economic development of the region.

The paper introduces main geological and geothermal aspects of the Podhale project, main project's assumptions, technological, environmentally benign, economic and some other issues. It points out an importance of geothermal energy implementation both for ecological heating and recreation in the areas of special natural and tourist values. The experiences and lessons learned during the project realization are important for the cases of other similar systems and projects also in Central Europe.

1 INTRODUCTION

The Podhale region is located in southern Poland, within the Inner Carpathians. In the south it borders Slovakia - through the Tatras, the only mountains of Alpine character in Central Europe with the highest peaks of Rysy (2499 m a.s.l.) on the Polish side and Gerlach (2655 m a.s.l.) on the Slovakian side. The central part of the region is occupied by the Podhale Basin – the structure, which contains geothermal aquifers.

The Podhale Region and Zakopane – its main town, are extremely popular tourist and sport destinations visited by more than four million tourists annually. It belongs to the most valuable regions in the country towing to the variety of landscape, geological structure, unique flora and fauna, tourist values and a vital folk culture.

On the other hand, Podhale has been affected by intensive pollution of natural environment caused by burning large quantities of hard coal for heating (heating season lasts even 8-9 months). Therefore, the project of a geothermal heating network having been realized since the end of 1980s is of essential significance to stop the degradation of the Podhale ecosystem, and to conduct sustainable management of the environment (Kepinska 2004). When completed, it's yearly heat sales will be around 600 TJ. The Podhale geothermal heating system is the biggest one among 5 currently operating in Poland and one of the largest in Europe for its target geothermal capacity and heat sales (Kepinska, 2005).

Apart from the district heating, important prospective geothermal uses are bathing and balneotherapy. However, for many years geothermal recreation and healing facilities and services were missing. Till 2001 only one geothermal bathing pool operated in Zakopane. Earlier (mid 1800s – mid 1900s), a natural warm spring served for recreation. In several recent years a long-awaited investments started and some recreation centres were launched. It is a very important line of applications both for widening the scope of geothermal uses and economic development of the region.

2 THE PODHALE REGION – GEOLOGICAL AND GEOTHERMAL CHARACTERISTICS

The Podhale geothermal system belongs to the Polish part of the extensive Inner Carpathian Palaeogene systems located mostly within the Slovakian territory. The following geo-structural units have been distinguished within this region (Fig. 1, Fig. 2): the Tatra Mts, the Podhale Basin, the Pieniny Klippen Belt.

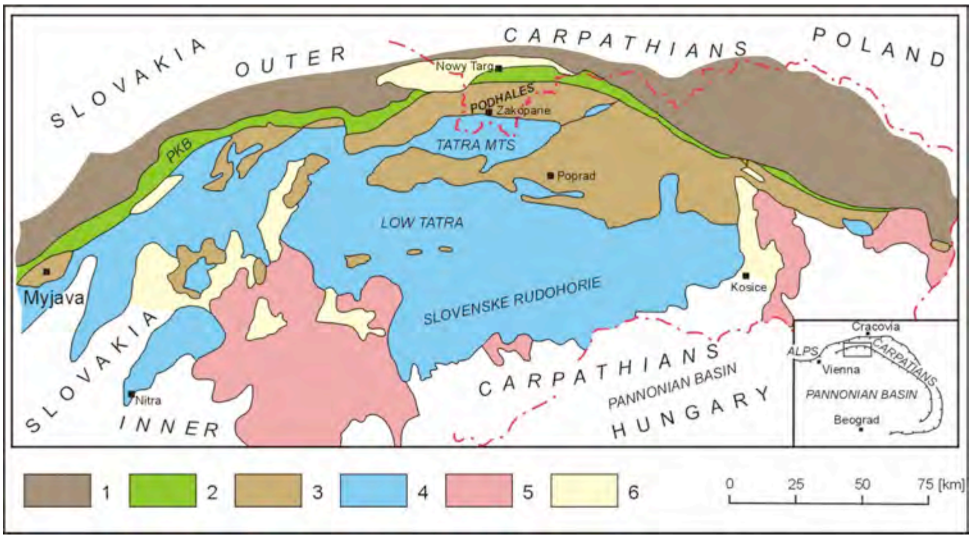

Fig. 1. Location of the Podhale region within the Carpathians (geology based on Samuel and Salaj 1968)

1. Outer Flysch Carpathians; 2. Pieniny Klippen Belt; 3. Inner Carpathians Palaeogene depressions (containing geothermal aquifers); 4. Palaeozoic-Mesozoic massifs of the Inner Carpathians; 5. Neogene volcanites; 6. Neogene sediments in intra-montane depressions

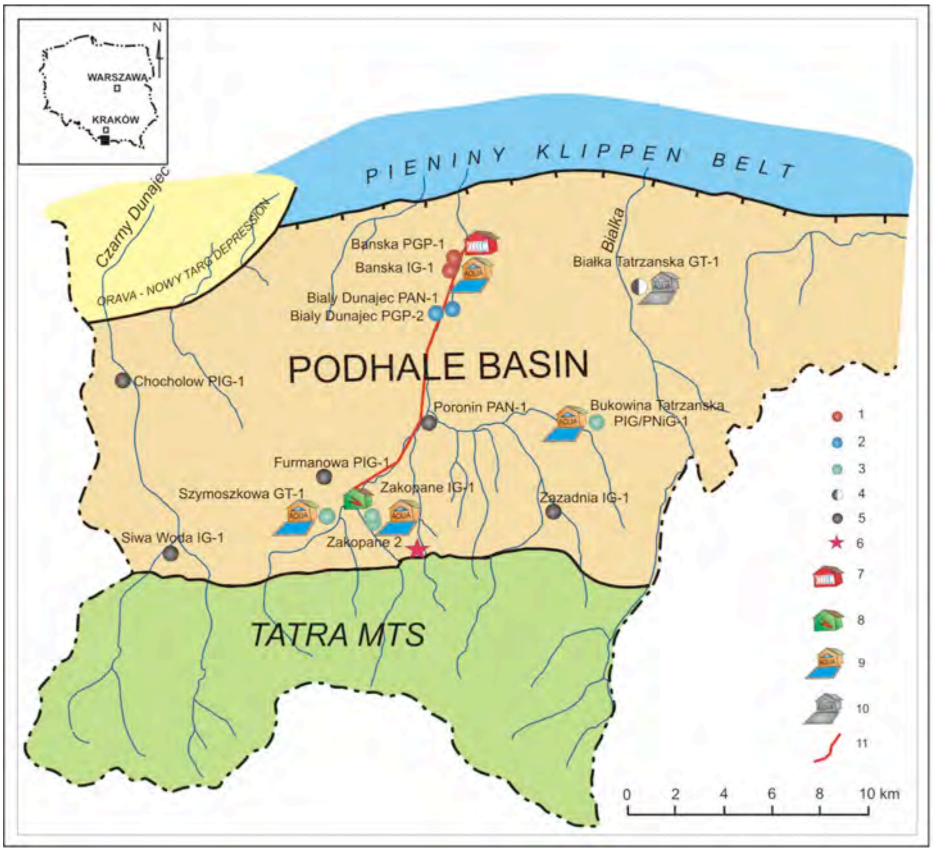

Fig. 2. The Podhale region: geothermal wells, heating network under construction and recreation centres

1—5: geothermal wells: 1 – production, 2 – injection, 3 – used in recreation; 4 - planned for the use, 5. other wells; 6. warm spring Jaszczurowka; 7. Geothermal Base Load Plant Banska Nizna - Szaflary; 8. Central Peak Load Plant Zakopane; 9. geothermal recreation centres; 10. geothermal recreation centres under construction; 11. main transmission pipeline

The Podhale Basin was formed in Palaeogene. Its basement is composed of Mesozoic formations outcropping on the surface in the Tatra Mts. The profile of Palaeogene formations includes conglomerates and limestones of variable thickness (0–350 m), and the Podhale flysch of maximum thickness 2.5–3.5 km. Mesozoic rocks have a typical Alpine structure – nappes and scales overthrusted and folded during the Upper Cretaceous-Palaeocene orogenic events. The Palaeogene series were deposited *in situ* on the basement of the overthrusted Mesozoic units. At present, they form a structural depression (through).

The described system has complex tectonic structure. Beside the nappes and overthrusts there exists a network of deep faults. Consequently, the system reveals a block structure.

The faults and fractures control the water and heat circulation and their upflow from the deeper parts of the system. These displacements and discontinuities need to be taken into account for proper field development planning and siting of wells.

The reservoir rocks for geothermal waters are mainly Triassic carbonates, sometimes Jurassic sandstones and carbonates (Fig. 3). The most prospective aquifer (being exploited for heating purposes since the 1990s) occurs within the Middle Triassic limestones and dolomites and in overlying Middle Eocene carbonates at the depths of 1 – 3.5 km. These formations are found over the entire Podhale system, prolonging to the Slovakian territory. Usually their total thickness is considerable ranging from 100 to 700 m.

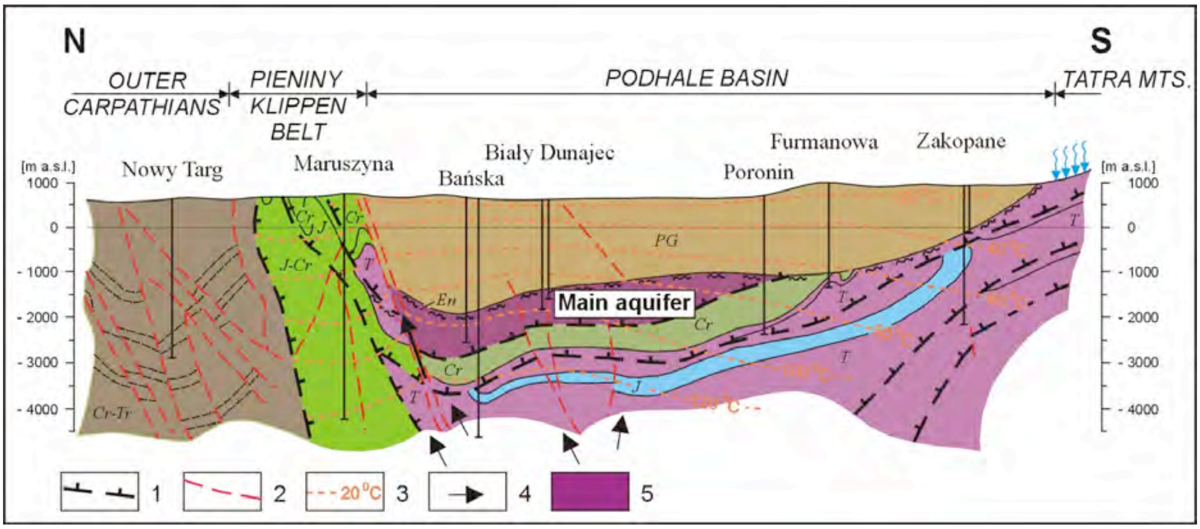

Fig.3. Geological – thermal cross-section through the Podhale region
(geology based on Sokolowski 1993)
1. Main overthrusts; 2. Faults; 3. Isotherms; 4. Directions of increased heat upflow; 5. Main geothermal aquifer. PG - Podhale Flysch, En - Middle Eocene Nummulitic carbonates, Tr - Tertiary, Cr - Cretaceous; J - Jurassic; T - Triassic

The water circulation and high flow rates are primarily conditioned by the secondary fractured porosity and permeability since the reservoir rocks are fractured and brecciated due to the long tectonic transportation, vertical movements, weathering, karstification, and secondary dolomitisation processes (Kepinska, 2003). The secondary fractured porosity of 10-20% and intrinsic permeability up to 1000 mD supported by the presence of fractures and voids of karstic origin are of the main importance to high production from the wells. In contrary, the values of primary porosity and intrinsic permeability reach up to 3-4% and 0.01-1 mD, respectively.

The terrestrial heat flow amounts to 55-60 mW/m^2 (Plewa, 1994). The average geothermal gradient varies between 1.9 and 2.3°C/100 m. The Podhale system has thermal properties similar to the neighbouring systems in Slovakia (i.e. the Skorusina, the Poprad, the Liptov systems) (Remsik and Fendek, 2005).

The maximum reservoir temperatures within the main aquifer (depths of 2-3.2 km) are as high as 90-95°C, while the wellhead temperatures reach 82 - 87°C. Within the deeper parts of the system, the measured formation temperatures reach 120-130°C (depths of 4.5-4.8 km).

The artesian flow rates from individual wells vary from several to 550 m^3/h. The highest flow rates (up to 270 - 550 m^3/h) were obtained after acidizing treatment of carbonate reservoir rocks. The wellhead static pressure amounts to 26-27 atm.

The TDS are at the level of 0.1 – 2.5 g/dm^3. The water types are Ca-Mg-SO_4-Cl or Ca-Mg-HCO_3, with a small admixture of H_2S and hydrocarbons. Water contains several elements (H_2S, sulphides, silica, iodine) of curative properties (see chapter 7). Water is predominantly of meteoric origin, the age of which is from 10 years to 10 – 20 thousands of years (Quaternary, Holocene).

The main recharge area of the geothermal aquifers is situated on the northern slopes of the Tatra Mts. Generally, the water flows in the NW and NE directions, and such a distribution is controlled by the impermeable northern barrier of the Pieniny Klippen Belt. The Tatra Mts. act as a recharge area for geothermal aquifers occurring both in the North (the Podhale system) and in the South (the Slovakian systems). However, there are some differences in the chemistry of geothermal waters on the North and South due to the asymmetric lithological structure of the Tatras.

3 HISTORY OF GEOTHERMAL EXPLORATION AND ITS USE

Since the 19th century ca. 20°C spring in a suburb of Zakopane has been known. The water was used in a swimming pool, particularly popular at the beginning of the 20th century. In the 1950s, the spring disappeared due to the mixing with cold water from a nearby brook. The spring was a surface manifestation of the geothermal system occurring in the Podhale area. More surface manifestations appear on the Slovakian side, e.g. in Oravice (a spring), on the southern side of the Tatra Mts. and specially east of the Tatra Mts – in Vyzne Ruzbachy locality known from warm water outflows and travertine precipitations (Tertiary – rec.).

In 1963 the first exploration well, Zakopane IG-1 (3073 m) was drilled (Sokolowski, 1973). It revealed several geothermal aquifers. The main ones belong to the Eocene carbonates (990 – 1113 m) and the Jurassic marls and limestones (1540–1620 m). In 1973 the second well, Zakopane-2, was drilled. Till 2001, water at temperatures of 26°C and 36°C, produced by these two wells (artesian outflows) was used for bathing. At the end of 2006 a big recreation centre (Aqua Park Zakopane) was opened there. Geothermal water is used in an outdoor pool while the centre is warmed by geothermal heat supplied by PEC Geotermia Podhalanska SA company.

In 1970s – 1980s, several wells were drilled along the southern boundary of the Podhale system, close to the Tatra Mts. In some cases, artesian outflows of water close to 20ºC were obtained.

In 1979 – 1981, a breakthrough step in the development of geothermal use for heating was taken when the Banska IG-1 well (total depth 5263 m) was drilled. It confirmed the existence of geothermal waters with advantageous reservoir parameters. The main aquifer was found in the Middle Triassic limestones and dolomites and in overlying Eocene carbonates (2565 – 3345 m) with the following parameters: artesian water outflow 60 m^3/h, wellhead temperature 72°C, TDS 3 g/dm^3, wellhead static pressure 27 bar (Sokolowski, 1993).

Geothermal water revealing such parameters was proved useful for local space heating. It brought possibility to replace coal-based heating system, poorly effective and polluting the environment.

In 1987 – 1995 the preliminary estimation of geothermal potential was carried out, followed by intense exploration activities and the project to evaluate the geothermal water reserves (Sokolowski, 1993). The project comprised desk studies and new operations including drilling five wells (2394 – 3572 m) within the Podhale basin in 1988-1992. The wells confirmed the occurrence of geothermal reservoirs in the Middle Triassic and Eocene carbonates. It gave a solid basis for further work aimed at geothermal heating system construction.

In 1989-1994, the first in Poland Experimental Geothermal Plant Banska - Bialy Dunajec was put into operation by the team from the PAS MEERI. In the 1993/94 it started to supply geothermal heat to first six dwellings in the village of Banska Nizna and R&D cascaded uses facilities (Sokolowski et al., 1992). It was a milestone of the activities directed towards the geothermal space heating both in the Pod-hale and Poland.

In 1994, upon completion of this experimental stage, the joint stock company “Geotermia Podhalanska SA” was founded to conduct all the work concerning the construction of the regional geothermal heating network. The shareholders were some local communities, the Polish Academy of Sciences, the National Fund for Environmental Protection and Water Management (main stakeholder), Hydrotrest SA, and other smaller ones. In June 1998, the "Geotermia Podhalanska SA District Heating Company" was established as a result of fusion with municipal District Heating Company in Zakopane. It took over the project development.

Since 1994 geothermal activities in the Podhale region have been carried out on two basic paths: (i) construction of the geo-thermal space heating system – by PEC Geotermia Podhalanska SA, and (ii) basic research, monitoring, R&D work on cascaded uses, education - by the PAS MEERI Geothermal Laboratory (which superseded the Experimental Geothermal Plant to continue the research work).

4 GEOTHERMAL WATER EXPLOI-TATION AND HEAT-EXTRACTI-ON METHOD STATEMENT

The Podhale project assumed a closed system of geothermal water exploitation, heat extraction and distribution. It was de-cided to extract the heat from geothermal water through heat exchangers while cooled geothermal water had to be injected back to the reservoir. Such a method would assure long-term sustainable water and heat pro-duction from the field. In the exploited sec-tor of the Podhale system, geo-thermal aqui-fer is situated at a depth ranging from 2048 - 2113 m (top) to 2394 – 3240 m (bottom).

In 1992 – 2001, i.e. in the pilot stage of the project and at the beginning of its main stage, the exploitation based on two wells: Banska IG-1 (production) and Bialy Dunajec PAN-1 (injection). The production was 30–60 m^3/h of 70-80°C water. Geothermal heat was trans-mitted to the district heating water through two plate heat exchangers of PAS MEERI (installed capacity was 4 MW$_t$, the real one in the heating season up to 2 MW$_t$).

These wells ("doublet") served the heating network in about 200 dwellings (1000 inha-bitants), school, church in Banska Nizna village and PAS MEERI cascaded uses. Maximum geothermal heat production was ca. 30 TJ/y. The sketch of the geothermal doublet working in 1992 – 2001 is given in Fig. 4.

In October 2001, the mentioned wells were included into extended exploitation system put into operation thanks to two new wells: Banska PGP-1 (production) and Bialy Dunajec PGP-2 (injection) along with other facilities. The wells were drilled in 1996-1997 by PEC Geo-termia Podhalanska SA company. Since that time, geothermal water has been produced by two wells Banska PGP-1 and Banska IG-1. The maximum self-outflow from PGP-1 well amounts to 550 m^3/h of 87ºC water. The TDS are low, ca. 2.5 g/dm^3, while the static artesian pressure equals 27 bar. The maximum self-outflow from Banska IG-1 well amounts to 120 m^3/h of 82ºC water. The TDS are ca. 2.6 g/dm^3, static artesian pressure 26 bar. Main data on exploited wells are given in Table 1.

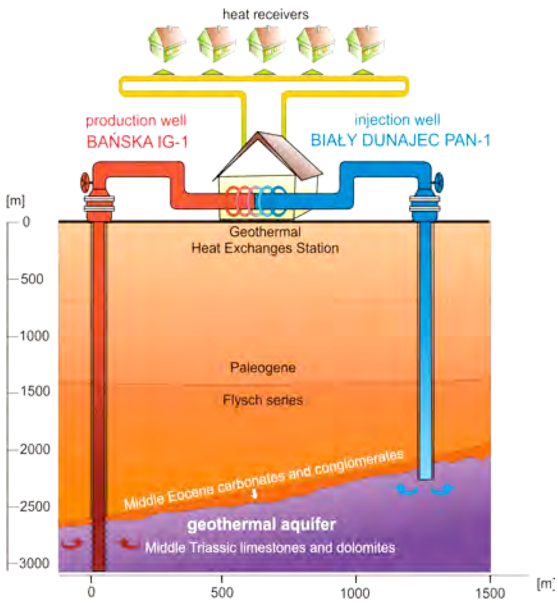

Fig. 4. The sketch of the geothermal doublet working in 1992 – 2001, PAS MEERI Geothermal Laboratory (Kepinska 2004)

Geothermal water is transported to the plate heat exchangers (ca. 38 MW$_t$ of installed capacity) in the Base Load Plant in Banska Nizna – Szaflary. Heated up to 70-83ºC the network water is supplied by transmission and distribution pipelines to the receivers (who have individual node heat exchangers to consume heat from the main pipeline). Cooled geo-thermal water of a temperature drop not exceeding 25-30ºC is sent through a pipeline to the pumping station and injected back to the reservoir. The distance between production and injection wells is 1.2 –1.7 km.

Before fall 2003 two injection wells were in use: Bialy Dunajec PAN-1 and Bialy

Dunajec PGP-2. Their maximum injectiveties were 400 m³/h and 200 m³/h, respectively. Since that date only one injection well has been used (PGP-2) due to the damage of casing in PAN-1 well. Since 2007/2008 a part of cooled geothermal water is not injected back but disposed (after additional cooling in a special installation) into the river. Moreover, since mid 2008 some amount of water (50 - 60ºC) after passing through heat exchangers has been sent to the nearby geothermal recreation centre "Termy Podhalanskie" and after usage is disposed into sewage water pipeline. Therefore, since 2007/2008 the geothermal system has not been operated in a closed mode.

5. THE PODHALE GEOTHERMAL HEATING PROJECT – AN OVERVIEW

5.1 Main objectives

The main objective of the Podhale geothermal heating project is to reduce air pollution and to improve the state of the natural environment. The project assumes that geothermal energy will replace the consumption of considerable amounts of fossil fuels – in particular coal – for heating and domestic warm water. It is of fundamental importance to the further development of this region, because of its values and tourist character.

As mentioned before, the project was initiated by the Polish Academy of Sciences - Mineral and Energy Economy Research Centre (Ney and Sokolowski, 1987). In 1989 – 1993 the Experimental Geothermal Plant was built. In late 1993, the first six houses in the village of Banska Nizna were connected to the plant. This was the pilot phase of geothermal heat implementation in the Podhale region and in Poland in general (Sokolowski et al., 1992). Since 1994, after the pilot stage had succeed, PEC Geotermia Podhalanska SA has been conducted the full scope of activities related to construction of regional geothermal heating network within the Podhale region.

TABLE 1**.** The Podhale region – main data on geothermal wells exploited for heating (Kepinska 2004, updated)

Well	Banska IG-1	Banska PGP-1	Bialy Dunajec PAN-1 (not in use since fall 2003)	Bialy Dunajec PGP-2
Year of drilling	1979-1981	1997	1989	1996-1997
Year of starting	1992	2001	1992	2001
Role in the system	Production	Production	Injection	Injection
Total depth	5261 m	3242 m	2394 m	2450 m
Reservoir depth	2565 - 3345 m	2740 - 3240 m	2113 - 2394 m	2048 - 2450 m
Lithology	Limestones, dolomites (Middle Eocene – Middle Triassic)			
Production casing	Casing 6 5/8", perforated interval 2588 - 2683m	Casing 6 7x75/8", perforated 2772 - 3032m, open hole 3032 - 3242 m	Casing 9 5/8", perforated interval 2117 - 22132 m, open hole 2132 - 2394 m	Casing 9 5/8", perforated interval 2040 - 2450 m
Maximum production	120 m³/h	550 m³/h	-	-
Maximum wellhead temperature	82ºC	87ºC	-	-
Wellhead pressure	26 bar (static)	27 bar (static)	55-60 bar (injection)	55-60 bar (injection)
TDS	2.5 g/dm³	2.7 g/dm³		
Maximum injectivity	-	-	200 m³/h	400 m³/h

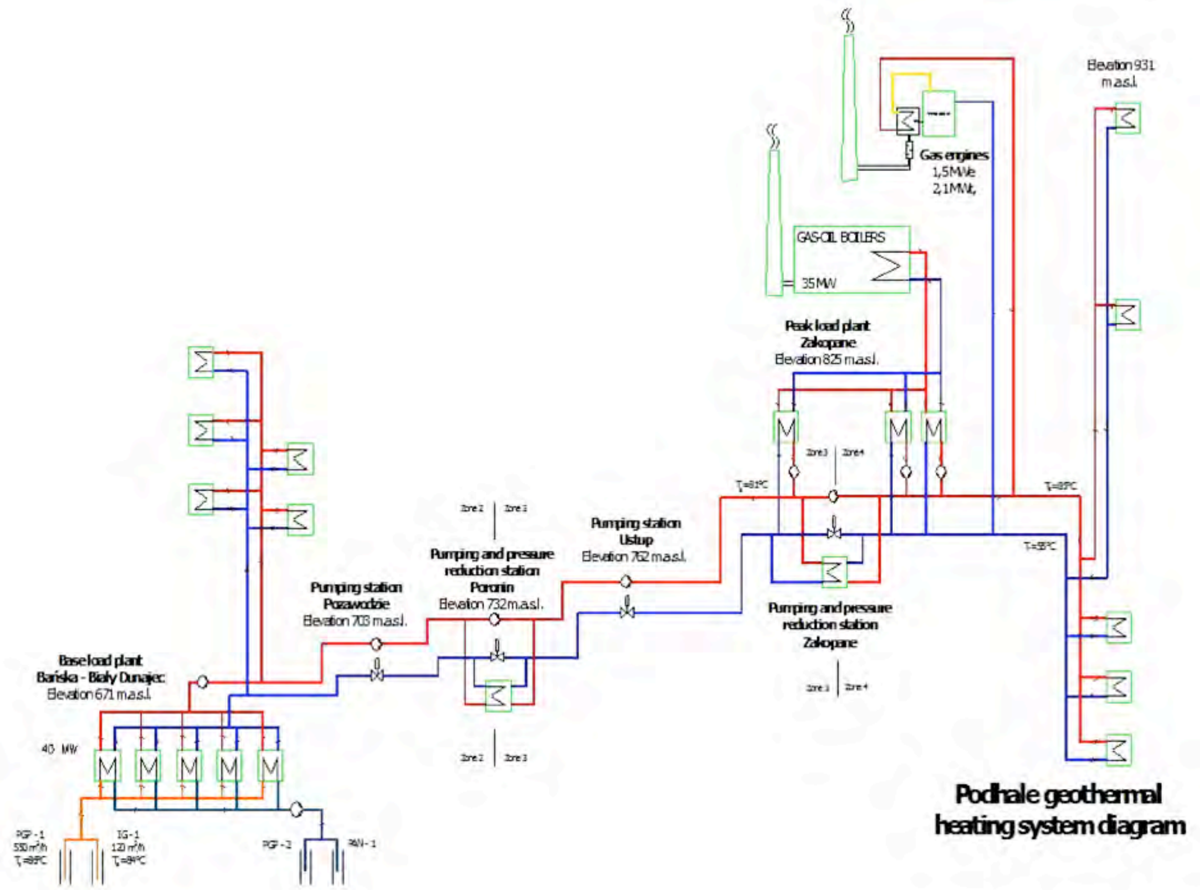

Fig. 5. The technical diagram of the geothermal heating system under construction in the Podhale region (source: PEC Geotermia Podhalanska SA)

It should be stressed that along with the use of geothermal water for heating, the wide prospects and benefits of wide applications including bathing and balneotherapy were pointed out by the Project initiators. However, it took almost twenty years when this line of geothermal uses started to develop and since 2006 – 2008 a real investments can be observed. On the contrary, over that span of time on the Slovakian side several geothermal recreation centres have been extended or built from scratch (Fendek and Fendekova, 2005), directed mostly to the visitors from Poland.

5.2 Background

In 1993 the feasibility study for geothermal heating in the Podhale region was elaborated by the team from the PAS Mineral and Energy Economy Research Centre and House & Olsen Thisted Ltd., Denmark. It was assumed that 60 – 80% consumers in villages would be connected to the network and 100% in towns of Zakopane and Nowy Targ (Sokolowski, 1993). That percentage was successively corrected and optimised in the course of the project realization.

The state of reservoir exploration, the number of existing wells, and the most dense population caused that the first step towards geothermal heating was taken in the central part of the Podhale region (the Central Valley System) where Zakopane (population 30, 000) is located and where the Experimental Geothermal Plant was launched. The project was expected to be finished in 2000 – 2005 (corrected plans indicate the year 2011).

The part of a second main town of the region, Nowy Targ, was (and still is) hoped to be partly connected to the network in the coming years. Initially, the installed thermal power for the Central Valley System was estimated at 150 MW_t (including about 78

MW_t from gas peak boilers). In the successive years optimisation works were carried out and, according to the recent ones, the target thermal capacity of the geothermal system will amount to 80 MW_t and the heat sales will reach a level of 600 TJ/y by 2011. The technical diagram of the geothermal heating system under construction is shown on Figure 5.

5.3 Energy sources

Geothermal space heating system is based on two energy sources (location: Figs. 3. 5):

- Geothermal Base Load Plant Banska Nizna – Szaflary;
- Gas and Oil Peak Load Plant in Zakopane.

Geothermal Base Load Plant, Banska Nizna – Szaflary:

Geothermal heat is transmitted to the district heating water through plate heat exchangers (current installed capacity ca. 40 MW_t, about 7 MW_t each, 25-30°C cooling of geothermal water). The plant is based on two production wells Banska PGP-1 and Banska IG-1 (Table 1). In Geothermal Base Load Plant other technological facilities are installed, i.e. the circulation water treatment system with a capacity of ca. 50 m^3/h, the expansion system protecting particular pressure zones, and the circulation pumps of a capacity of 3 x 470 m^3/h pumping network water towards Zakopane.

Central Peak Load Plant, Zakopane:

The Plant is equipped with three gas and gas-oil boilers (total 35 MW_t capacity), with economizers (1 MW_t capacity each) to recover the condensation heat of the outlet combustion gases, and three co-generation gas engines (2 x 15 MW_e and 2 MW_t). The boiler system is hydraulically separated from the network by three plate heat exchangers (each of 17 MW_t capacity).

In 1998 – 2001, i.e. until geothermal heat has been delivered to Zakopane by the main transmission pipeline from Geothermal Base Load Plant in Banska Nizna – Szaflary, the Central Peak Load Plant was working as a basic gas heat source for the buildings connected to the district heating system in the town.

5.5 Heating networks

Prior to the geothermal project, most of dwellings both in Zakopane and Podhale's villages were heated by individual heat sources. Only the part of Zakopane town was provided with a heating network. Due to the great area of the developed project, the construction of the heating networks involved a major amount of expenditures. A 90/50°C heating network between energy sources and consumers was built practically from scratch. The main pipeline towards Zakopane is built of pre-insulated pipes with small heat losses. The temperature drop is ca. 2°C on a distance of 14 km. Because the temperature of network water after passing through heat exchangers is 82 – 83°C, that gives a temperature of ca. 80°C for the feed to major customers in Zakopane. In summer, to ensure warm tap water, the temperature of the supply will be not lower than 60 – 55°C. All pipelines of DN 100 and more in diameter are equipped with the leakage detection system.

Generally, the system consists of three circulation loops:

- Geothermal circulation, with a standard pressure of 40 bars in a Base Load Plant and 64 bars behind injection geothermal pumps;
- Network water circulation with a standard pressure of 16 bars;
- Boiler circulation in Peak Load Plant with a standard pressure of 6 bars.

To compensate the large differences in ground topography and to keep pressure not exceeding 16 bars, the network water system was divided into four pressure zones (Fig. 5).

5.6 Heat consumers

The geothermal heat consumers are divided into two main groups depending of the thermal power demand:

- Individual households with capacities from several to a dozen kilowatts. Equipped with compact dual-function heat exchangers (warm-water production both for central heating and domestic water, in a flow system without a hot-water bunker);

- Medium and large consumers (boarding houses, offices, schools, public buildings, etc.). Equipped with compact dual-function plate heat exchangers, and with an automatic weather-sensitive system, with the possibility of programming many functions (night drop, wind impact, etc.).

5.7 Sources of project financing

The investment has been financed from the Polish and foreign sources including share capital, grants, loans, and credits. The Polish sources involved: the capital of the company PEC Geotermia Podhalanska SA; Ekofund, the National Fund of Environmental Protection and Water Management, Bank PKO. The foreign sources included: the World Bank, PHARE EU, Large-Scale Infrastructure Projects EU, the Global Environment Facility (GEF), the Bank of Environmental Protection, the Danish Environmental Protection Agency (DEPA). It shall be added that the World Bank credit was fully paid back in 2006. The total expenditures by 2008 were about 243 million PLN (1 USD = 3.7 PLN in April 2009), including ca. 27 mln PLN for *stricte* geothermal part of the heating system (wells, geothermal water pipeline, heat exchangers' station, pumping station for geothermal water injection, other geothermal infrastructure). The great benefit for the project is a high percentage of grants (ca. 41%) in the financing (Ignacok et al., 2008).

5.8 Environmental effects

Environmental benefits were the main arguments for geothermal heating development in the Podhale region. By the end of 2007, about 600 individual consumers, 170 multi-family buildings, 70 hotels and boarding houses, 27 schools and 165 other buildings (including over 100 blocks of flats) have been connected to the geothermal network (www.geotermia.podhalanska.pl). Work on connection of new consumers is underway. Geothermal heat production in 2008 was ca. 240 GJ (total ca. 320 GJ).

In the case of Zakopane, thanks to successive introduction of geothermal heating in this town from 2001, annual average concentrations of particulate matter (PM_{10}) and SO_2 have dropped by about 50% in comparison to the situation before that heating was put on-line (Fig. 6). The limitation of CO_2, increased during the project realization and in 2007 was about 31,000 tons (Fig. 7).

1994-1997: situation prior to geothermal project development - space heating was based on hard coal and other fossil fuels, 1998-2002: situation at the beginning of geothermal heating introduction, 1998-2001: *bulk of coal-based systems replaced by gas-fired Peak Load Plant, since 2001: development of geothermal heating (source: PEC Geotermia Podhalanska SA)*

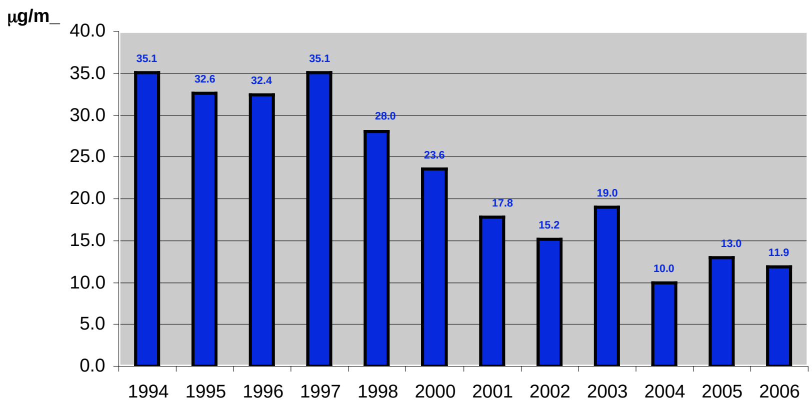

Fig. 6. Reduction of SO_2 emissions thanks to the introduction of geothermal heating system in Zakopane (source: PEC Geotermia Podhalanska SA)

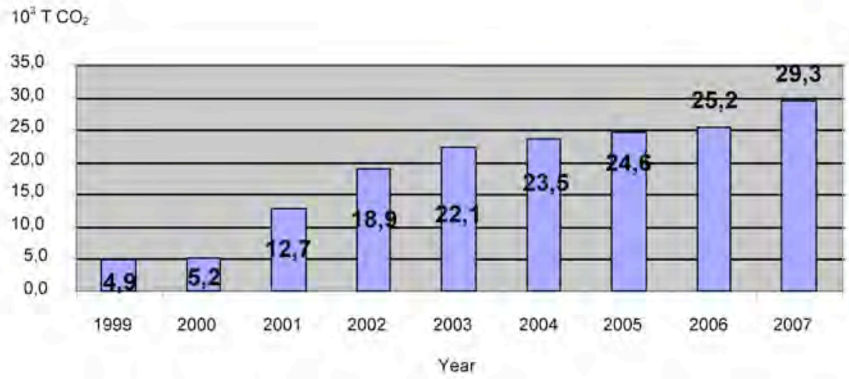

Fig. 7. Reduction of CO_2 emissions thanks to geothermal heating introduction in Zakopane (source: PEC Geotermia Podhalanska SA)

1994-1997: situation prior to geothermal project development - space heating was based on hard coal and other fossil fuels, 1998-2002: situation at the beginning of geothermal heating introduction, 1998-2001: bulk of coal-based systems replaced by gas-fired Peak Load Plant, since 2001: development of geothermal heating (source: PEC Geotermia Podhalanska SA)

5.9 Economic and social aspects of the geothermal heating project

For common heat consumers, the most important are the economic aspects of the geothermal type of heating. The current price of geothermal heat is slightly lower than gas heat, and higher than coal heat. If the labour costs are included, the price for geothermal is almost equal as coal. The cost of producing 1 GJ of heat loco the Geothermal Base Load Plant in Banska Nizna – Szaflary is around 10 PLN (2.5 USD). In the cost structure of producing 1 GJ of heat, the costs of electricity and natural gas amount 25% only. Some percentage of the expenses is connected with the obligatory taxes and payments. The VAT included into heat price is 22% (as for all fossil fuels) despite the fact that this is environment-friendly "green energy". Geothermal heat prices will be more and more competitive because of the observed and expected growth of traditional heat carriers' prices (coal, gas, oil), introducing incentives for RES producers and consumers, limitation of many taxes and fees (some activities in that field were initiated).

The project has been accompanied by information and education campaign. The most important was to convict consumers to reliability of the geothermal source of heat, its prices comparing to traditional source of heat, and environmental benefits rising the tourist value of the region. The project had to get social agreement for required technical changes and related costs. The geothermal heat consumers appreciate its benefits and advantages, mostly:

- Considerable comfort of operating the heating facilities,
- Greater possibility of regulation of temperature inside rooms,
- Possibility of observation of energy consumption, which may influence its saving,
- Limitation of air pollution in the close vicinity.

5.10 History and current state of the project

As already described, the initial stage of geothermal heating network in the Podhale region (1989–1994*)* comprised the construction of the Experimental Geothermal Plant and the connection of the first consumers. It was followed by the construction of the district heating network supplying about 200 buildings in Banska Nizna village. This stage tested the validity of the assumption and operation efficiency of the system.

The main elements of the geothermal project realized in 1995 - 2009 were as follows (Kepinska, 2004):

- Drilling of two new wells: Banska PGP-1 (production) and Bialy Dunajec PGP-2 (injection).
- Well tests and inflow-stimulation treatments in five geothermal wells previously drilled.
- Construction of the Geothermal Base Load Plant in Banska Nizna – Szaflary.
- Construction of the Peak Load Plant in Zakopane.
- Construction of the Banska – Zakopane DN 500 main transmission network, total length 14 km (the network transmits geothermal energy from the Geothermal Base Load Plant to the Central Peak Load Plant in Zakopane through several villages).
- Growth of distribution networks in Zakopane and some villages between Base Load Plant and Zakopane.
- Conversion of individual and large heat consumers in Zakopane and other localities.
- Rebuilding of the heating and distribution networks in Zakopane and several villages.
- Conversion of coal and coke boiler houses into heat exchanger units.
- 3-Dseismic survey for selected sector of the Podhale system aimed at proper location of new exploitation wells and acquiring detailed knowledge on tectonic structure of the geothermal aquifer and flow directions.

5.11 Development plans

Further planned work includes drilling of a next geothermal well in 2009 – 2010. Possible activities involve also connecting a part of Nowy Targ town (which would require construction of the main pipeline, 8 km long, to this town, construction of the distribution network in the villages situated on the way to Nowy Targ, extension of Geothermal Base Load Plant Banska Nizna – Szaflary). The long – term strategy of PEC Geotermia Podhalanska SA assumes the market development for low-parameter energy of the return water from the heating network and cooled geothermal water (greenhousing, recreation centres, floor heating systems, etc.). The strategy partly started to be realized while the recreation centre “Termy Podhalanskie” was constructed and started to use such kind of water since 2008. Some other investors are interested in similar recreation centres based on water from heat exchangers.

6 MULTIPURPOSE GEOTHERMAL USES

Along with the geothermal heating project, the PAS MEERI Geothermal Laboratory has conducted the R&D work on cascaded geothermal uses in a wide temperature range. The system is composed of the following elements: space heating and domestic warm water supply to the Laboratory buildings, wood-drying, greenhouse, stenothermal fish farming, foil tunnels for growing vegetables on a heated soil. The types of geothermal uses are those recommended both in the Podhale region and in other parts of Poland because of climatic conditions, types of agriculture and market demand (Bujakowski, 2000). the Laboratory serves also for dissemination and education being the only one of such a character in the country.

7 RECREATION AND BALNEOTHERAPY – A PROSPECTIVE LINE OF GEOTHERMAL DEVELOPMENT IN TOURISM AND LOCAL ECONOMICS

In the Podhale region, apart from the district heating – essential for the environmental reasons, another prospective geothermal line of uses is recreation and balneotherapy, especially in the region known as one of the main tourist destinations in Poland and Central Europe. Owing to the chemical composition (i.e. H_2S, sulphides, silica, fluoride), the Podhale geothermal waters have curative properties suitable in several diseases (e.g. dermatological and rheumatic ones). However, one had to wait many years for the development of this sector, in spite of the fact that initiators of the geothermal heating project for almost 20 years have been encouraging potential investors and pointing out various benefits of such a use of the described waters. The development started a few years ago when first new facilities were put into operation in 2006-2008. Some decades earlier (1960s) a small pools in Jaszczurowka (near Zakopane) using a warm spring was shut down and until 2001 only one geothermal bathing pool operated in Zakopane. Eventually, the region gained a new attractive tourist offer based on local natural resource which will support local economy and improve the quality of repose both for tourists and local inhabitants.

For the Podhale region, geothermal balneotherapy and bathing appear to boost a very important chance for sustainable development of tourism and economy.

7.1 Chemical composition of the Podhale geothermal water

Chemical composition of the Podhale geothermal water is controlled by the lithology of reservoir rocks, redox conditions, pressure, temperature and microorganisms' activity (Chowaniec et al. 1997). The waters are characterized by low TDS in the range of 0.1- 3 g/dm^3 while pH ranges from 6.7 to 7.3 (slightly acid to slightly alkaline). Hydrochemical water types change from Ca-Mg (Na)-HCO_3 in the southern part of the system, through intermediate types, to Na-Ca-SO_4-Cl in its northern part. Together with receding from the recharge area, the TDS increase (Kepinska 2003).

From the balneotherapeutical point of view, H_2S (as sulphides and hydrogen sulphide) is the most valuable chemical specific element of the described waters (Tables 2, 3). The highest H_2S content was found in water from well Poronin PAN-1 (about 28 mg/dm^3). High amounts were also found in water from wells Furmanowa PIG-1 (about 12.5 mg/dm^3) and Banska PGP-1 (to 13.4 mg/dm^3). The lowest content was in the case of Zakopane IG-1 well (2 mg/dm^3; Tab. 3). The content of dissolved silica (as H_2SiO_3) ranges from about 40 mg/dm^3 (well Furmanowa PIG-1) to 95 mg/dm^3 (well Banska PGP-1). In some cases the waters are characterized also by increased content of fluoride (to 1.5-4.0 mg/dm^3; Tab. 3) (Chowaniec et al. 1997; Barbacki et al. 1998).

7.2 Balneotherapeutical properties connected with chemical influence and temperature of waters

The Podhale geothermal waters can be successfully used both for recreation and balneotherapy. Their relatively low TDS belongs to the range of values acceptable for such applications (as defined for waters suitable for healing baths less than 50 g/dm^3 and for waters used in recreation less than 35 g/dm^3, according to the requirements for waters for recreational and healing purposes, in: Paczynski & Plochniewski 1996).

Hydrogen sulphide, silica and fluoride occur in waters discharged by some of the mentioned wells in concentrations which allow to consider them as potentially healing ones according to the Polish legal regulations (Decree of Council of Ministers, 2006; Table 2). Furthermore, these waters can be considered as potentially healing with regard to their increased temperature (at least 20^{o}C; Decree of Minister of Health , 2006).

TABLE 2. Contents of specific elements and equivalent names of healing waters (after Polish legal regulations: Decree of Council of Ministers, 14th February 2006)

Contents of elements in 1 dm^3 of water, at least	Water name
TDS 1,000 mg/dm^3	mineral water
10,0 mg Fe^{2+}	ferruginous water
2,0 mg F^-	water containing fluoride
1 mg J^-	water containing

	iodide
1 mg S^{2-}	sulphurous water
70 mg H_2SiO_3	water containing silica
1000 mg CO_2 (not dissolved)	carbonated water
$2x10^{-9}$ Ci (2 nCi, 74 Bq)	radioactive water

TABLE 3. Physical and chemical parameters determining healing features of geothermal waters from selected wells in the Podhale region (after Chowaniec et al. 1997; Kepinska 2006)

Well	**Approve d water flow rate [m³/h]**	**Parameters implying curative properties of waters**			**Water name**
		Outflow temperatur e T [ºC]	**TDS [mg/dm³]**	**Specific elements [mg/dm³]**	
Zakopane IG-1	50	37	0.3639	H_2S = 2	*sulphurous, thermal water*
Zakopane-2	90	26	0.3260	H_2S = 0.5-2	*sulphurous, thermal water*
Furmanowa PIG-1	60	60.5	0.5830	H_2S = 12.53	*sulphurous, thermal water*
Chocholow PIG-1	190	82	1.244	H_2SiO_3 = 77.4-78.1 H_2S = 7.64 (F^-) = 1.17-2.2	*containing silica, sulphurous, (containing fluoride), thermal water*
Poronin PAN-1	90	63	1.137	H_2S = 28.13	*sulphurous, thermal water*
Banska IG-1	120	82	2.690	H_2SiO_3 = 94.37-95.02 H_2S = 2.0-3.4 F^-= 2.17-4	*containing silica, sulphurous, containing fluoride, thermal water*
Banska PGP-1	550	86	3.122	H_2SiO_3 = 94.4-95.0 H_2S = 9.1-13.4	*containing silica, sulphurous, thermal water*
Bialy Dunajec PAN-1	270	86	2.500-2.830	H_2SiO_3 = 68.5-81.24 H_2S = 4.6-5.1 (F^-) = 0.66-5.89	*containing silica, sulphurous (containing fluoride), thermal water*
Bialy Dunajec PGP-2	175	86	2.784	H_2SiO_3 = 80.7-82.54	*containing silica, thermal water*

Curative properties of the Podhale geothermal waters can be described by comparison with other healing waters of similar chemical composition on a basis of long-lasting medical experience with healing waters used in balneotherapy for example by Polish spas. From the balneotherapeutical point of view (Table 2, 3), sulphides and Hydrogen sulphide are the most valuable elements of the Podhale waters. Affections cured with waters containing sulphides and hydrogen sulphide are diseases of the motion organ (bone system, joints), trouble of blood circulation, hypertension, diseases of the reproductive system, dermatological diseases, poisoning by heavy metals, neurosis. Among contraindications of using waters of such chemical composition one should mention hypotonia (low blood-pressure) and hypersensitivity to sulphur compounds (Kochanski 2002).

Silicon controls the processes of bone mineralization and hardening of connective tissue; to some degree it plays a role in construction of hair and skin structure (Kabata-Pendias & Pendias 1993).

Fluoride administered in drinking therapy supports treatment of osteoporosis. It is used in preventive treatment of teeth caries, after infections, especially infections of the urinary system (Kochanski 2002).

The temperature is the main physical factor of the Podhale geothermal waters which appeals for their use both for heating and balneotherapy or recreation, in addition to their chemical features. By means of kinesiotherapy in geothermal waters many affections connected with defects of motion organs are being cured in case of adults as well as children, for example with infantile cerebral palsy (Karski et al. 2000). However, some contraindications of healing bath in geothermal waters exist. These are e.g. acute inflammatory diseases, leukemia, high blood-pressure, tuberculosis infections, affections of the nervous system, contagious diseases, heart failure and circulatory failure, hemophilia, pregnancy, fever (Ponikowska 1996).

7.3 Geothermal recreation centres in the Podhale region – state-of-the-art

As already mentioned, the Podhale geothermal waters have been known since the 19^{th} century thanks to the warm spring (20^oC) in Jaszczurowka (near Zakopane). It was used in a small bathing pool till the 1960's. The spring played a great role in recognition of geothermal conditions, being a premise to conduct long-term research and activities aimed at practical applications of geothermal water and energy in this region. Since the 1970s to 2001, 26-36^oC geothermal waters were used in a small bathing centre in Zakopane in an outdoor pool, a paddling pool and a cascade. The centre used waters from two wells: Zakopane IG-1 and Zakopane-2. In view of temperature, sulphides and hydrogen sulphide content of the waters were formally approved as suitable for balneotherapeutical, bathing and recreational purposes. In 2001-2006, in the place of that small bathing centre, a big recreation centre „Aqua Park Zakopane" was built. The object is heated up by the geothermal heating system of Geotermia Pod=halanska SA, but geothermal water from the two above-mentioned wells supplies an outdoor pool.

Apart from the „Aqua Park", another geothermal bathing centre in Zakopane - Polana Szymoszkowa has been underway. Since summer 2007, a seasonal outdoor pool filled with geothermal water (ca. 30ºC, TDS<1 g/dm^3) has been operating. Water is produced by newly drilled well Szymoszkowa GT-1. The pool attracts numerous visitors thanks both to geothermal water and a very unique location with a beautiful view of the Tatra Mts. (Fig. 8).

In 2008 two other recreation centres were opened in the Podhale region: in Szaflary (near Geothermal Base Heating Plant Banska Nizna - Szaflary) and in Bukowina Tatrzanska. The first one called "Termy Podhalanskie" is based on water which passed through heat exchangers of the Geotermia Podhalanska SA system. The centre can serve about 250 visitors/hour. The latter – "Terma Bukowina Tatrzanska" is a large bathing facility supplied with water discharged by a deep well (3780 m) Bukowina Tatrzanska PIG/PNiG-1 drilled in 1992. The wellhead water temperature is around 65 C while the TDS are around 1.5 g/dm^3. "Terma Bukowina Tatrzanska" is built at the elevation ca. 1000 m a.s.l. with a marvellous view of the Tatra Mts. It serves about 1000 visitors/hour.

Since the beginning of the Podhale geothermal heating project's realization, tourism and balneotherapy has been indicated as an equal line of geothermal uses, next to the heating sector. However, not before recent years activities and investments have started in this field. Thus it can be stated that a new, long-awaited stage in tourism and balneotherapy has begun. A new tourist offer connected with possibilities given by geothermal waters has been added to mountain hiking and skiing. At present (May, 2009) another new centre in Bialka Tatrzanska is underway. It will use geothermal water from the new well Bialka Tatrzanska GT-1 specially drilled for this purpose. The centre will be located in the nearest vicinity of a very popular ski station.

It should be noticed that all the mentioned bathing centres are being realized by private investors and according to commercial rules. They are often situated near ski stations, which increases their attractiveness, considerably extends the tourist offer of a particular locality, and extends the duration of the tourist season. Until recently in the Tatra Mts. area it was possible to enjoy geothermal bathing on the Slovakian side only. At present, owing to investment in the Podhale region, also Poland can offer this natural resource for recreation on a larger scale. Figure 9 shows locations of geothermal bathing centres surrounding the Tatra Mts., situated both on the territory of Poland and Slovakia.

7.4 Prospects of using geothermal waters from existing wells in recreation and balneotherapy

There are some further prospects of geothermal bathing development within the Podhale region. With regard to high costs of new drillings, potential investors should give their attention, first of all, to already existing but unused geothermal wells. They form a good basis for new undertakings, similarly to those used as water producers for recreation centres mentioned in this paper. Some existing but unused geothermal wells, like Poronin PAN-1, Chocholow PIG-1, Furmanowa PIG-1 (Fig. 2), can successfully become a basis for next recreation and healing centres, and for heating and other applications (Table 3).

8 CLOSING REMARKS

The Podhale region belongs to the most geothermally-prospective in Europe. If offers very good reservoir and exploitation conditions – a basis for a large-scale geothermal heating network and other uses in recreation and balneotherapy. The geothermal heating project which is still being underway has already resulted in significant environmental results expressed by reduction of emissions generated so far by huge amount of coal burnt for heating purposes. Such effects would not be possible to achieve in a way different from introduction of the geothermal system.

Along with the geothermal heating there are great opportunities to develop geothermal recreation and balneotherapeutical centres in this region. They are indispensable factors to increase the tourist offer, to improve the quality of rest and recreation in this main tourist area of Poland, popular also in Europe. The long-awaited investments in this sector started during last several years. Currently (2009) four centres are already operating.

The up-to-date results have proven the purposefulness and reliability of using geothermal energy in the Podhale region and Zakopane as a really environmentally benign solution for a tourist centre.

One should point out that geothermal development and its benefits achieved in such extremely popular tourist region as Podhale and Zakopane itself are very important show cases for dissemination and popularization of geothermal energy among wide circles of people coming to these destinations from many localities in the country and from abroad. They shall come back homes with a positive message on geothermal. The same refers to other tourist regions possessing geothermal resources, including that on the Slovakian side of the Tatras. The efforts to undertake relevant popularization activities both at the country and the regional levels should be increased.

The Central European countries, including the Visegrád Group, have a very favourable conditions to initiate such common actions.

Fig. 8. Zakopane, Polana Szymoszkowa – the bathing centre using geothermal water opened in 2007 (*photo P. Milaniak, DORADO Ltd.*)

Fig. 9. Location of Polish and Slovakian geothermal bathing centres surrounding Tatra Mts. (map from http://maps.google.pl)

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