



1. THE PODHALE GEOTHERMAL SYSTEM AND HEATING PROJECT – AN OVERVIEW

Beata Kepinska

Polish Academy of Sciences, Mineral and Energy Economy Research Institute
Wybickiego 7 Str., 31- 261 Krakow, Poland

Abstract

The Podhale region is regarded as a cradle for geothermal energy use for heating purposes in Poland. Since the end of 1980s the research works and activities oriented to geothermal space heating and other uses have been carried out there. There, the first in Poland, Experimental Geothermal Plant was put into operation and successively a great regional heating system has been developed.

More than ten 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. The paper introduces main geological and reservoir characteristics of the Podhale geothermal system, project's assumptions, technological, ecological, economical and some other aspects and circumstances. The most recent information concerning the project realization will be presented during the IGD 2004 Field Trip.

1 THE PODHALE REGION – GENERALS

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.) and Gerlach (2655 m a.s.l.). The central part of the region is occupied by the Podhale Basin – the structure, which contains geothermal reservoirs.

Podhale is known as a very popular tourist, sport and recreational destination, visited by over four million tourists annually. It belongs to one of the most valuable regions in Europe due to the following features:

- Variety of landscape and geological structure;
- Unique flora and fauna (four Polish national parks, including the Tatra National Park being joined to the Worldwide Man and Biosphere Reservation System, M&B);

- Climatic and tourist value (the centre of winter sport and alpinism, with a number of boarding houses and hotels, a venue of many winter sports competitions);
- A vital, rich folk culture and tradition cultivated by local highlanders;
- Large resources of geothermal waters characterizing by favourable parameters.

On the other hand, Podhale has been affected by intensive anthropopression, especially extensive 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 regional geothermal heating network having been realised since the end of 1980s is of essential significance to stop further degradation of Podhale ecosystem, and to conduct sustainable management of the environment.

2 GEOLOGICAL SETTING AND EVOLUTION

In the Podhale region the two main parts of the Carpathian orogen exist - the Inner and the Outer Carpathians. They are fragments of the mountain chains that were folded during the alpine orogeny (Cretaceous-Tertiary). Within them, the following geological units have been distinguished (Fig. 1; Fig. 2):

- The Inner Carpathians: the Tatra Mountains, the Podhale Basin, and the Pieniny Klippen Belt. They are the constituents of the Podhale geothermal system and each of them plays its own specific role within it;
- The Outer Flysch Carpathians: these structures extend North of the Pieniny Klippen Belt and have no direct connection with the Podhale geothermal system.

The Tatra Mountains are built of Palaeozoic crystalline core and sedimentary rocks. The latter form a number of overthrust tectonic units (Lower Triassic-Middle Cretaceous) and act as a

cover of Palaeozoic core. These units consist mainly of limestones, dolomites, sandstones, marls and clays. They continue to the North, creating the basement of Palaeogene formations that fill the Podhale Basin. They form also the reservoir rocks for geothermal water. The Tatra Mts. act as the main recharge area for the Podhale geothermal aquifers.

The Pieniny Klippen Belt is built of Mesozoic and Palaeogene sediments forming complex tectonic units. Regional dislocations separate this structure, usually not exceeding several hundred metres in wideness, from the surrounding units: the Podhale Basin and the Outer Carpathians. The Pieniny Klippen Belt is a relict of the subduction zone of the African and North-European plates being active during the alpine orogenesis. At present, this extremely complex structure is a very long but narrow belt. It stretches almost 800 km from Vienna meters up to 3-5 km in wideness within the area of Poland.

The Pieniny Klippen Belt forms the northern impermeable boundary of the Podhale geothermal system.

The Podhale Basin is the Polish part of the extensive Inner Carpathian Palaeogene basins loca-

ted mostly within Slovakian territory (where numerous geothermal systems are found, some of them being exploited for bathing or heating purposes; Fendek and Franko, 2000). Its area within Poland amounts to about 475 km². The Basin was formed in the Palaeogene as an effect of irregular, block uplift of the Tatra Mts. and the Pieniny Klippen Belt. Its basement is composed of Mesozoic formations (that contain geothermal aquifers) outcropping on the surface mostly in the Tatra Mountains. The profile of the Palaeogene formations that fill the basin includes conglomerates and nummulitic limestone (Middle Eocene) of variable thickness (0-350 m), and the Podhale flysch (Upper Eocene-Oligocene) composed of shales, mudstones and intercalations of sandstones (reaching the maximum thickness of 2.5-3 km).

The Podhale geothermal aquifers occur within the Podhale Basin. In the South, it borders the Tatra Mts. - its main recharge area, while from the North it is limited by the Pieniny Klippen Belt acting as an impermeable barrier.

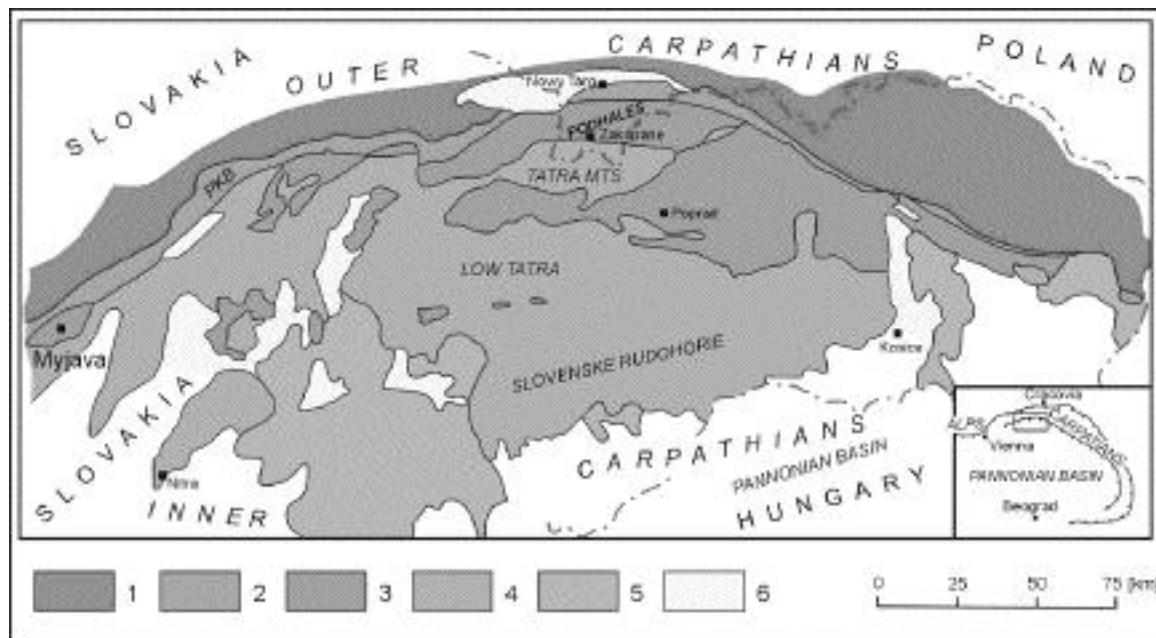


FIGURE 1. Location of the Podhale region within the Carpathians

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 intramontane depressions

3 MAIN FEATURES OF THE PODHALE GEOTHERMAL SYSTEM

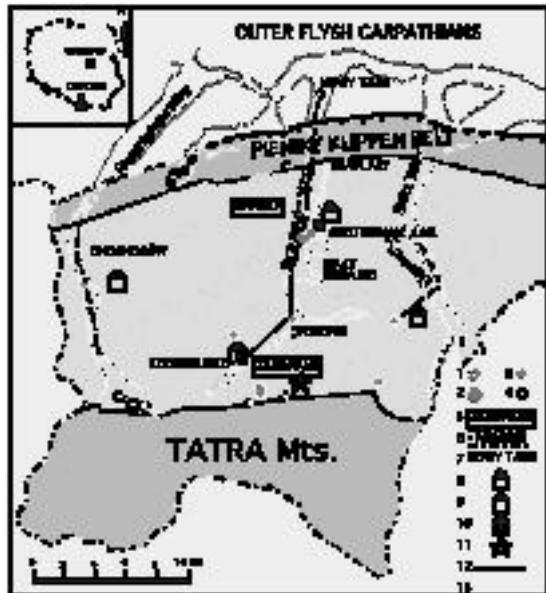
3.1 Generals

The Podhale geothermal system is built of two basic units: Mesozoic (Triassic-Cretaceous) and Tertiary (Palaeogene) formations (Figs. 2, 3). Older formations (Palaeozoic) are expected to underlie the Mesozoic series. The Mesozoic rocks have a typical alpine structure. They form numerous

nappes and scales overthrust and folded during the Upper Cretaceous-Palaeocene orogenic period. Tertiary carbonate transgressive series (0-350 m in thickness) and a thick flysch formation (2.5-3.2 km) were deposited *in situ* on the basement of the overthrust Mesozoic units. At present, they form a structural depression (through).

The rocks, which built the Podhale system, underwent long and complex geological evolution.

The Middle Triassic rocks are ca. 235 Ma, while the sedimentation of the Middle Eocene carbonates started ca. 50 Ma ago, and the Podhale flysch - 45



Ma ago. Their common history as a geothermal system begun after the flysch had been deposited, ca. 22 Ma ago.

FIGURE 2. Geological sketch of the Podhale region, location of geothermal wells and heating network under construction

1—3: geothermal wells; 1 – production, 2 – injection, 3 – not in use; 4 - other wells; 5. locality with geothermal heating system on-line (2003); 6. localities under connection to geothermal heating network; 7. localities planned to be geothermally heated; 8. Geothermal Base Load Plant; 9. geothermal heating plants planned; 10. Central Peak Load Plant; 11. warm spring (existing until 1960s); 12. main transmission pipeline; 13. transmission pipelines planned

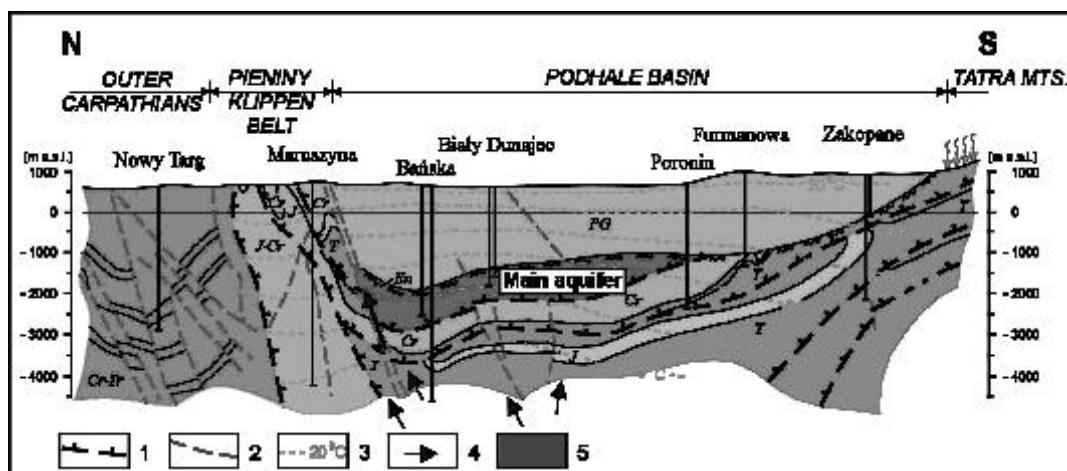


FIGURE 3. Geological – thermal cross-section through the Podhale region
(geology based on Sokolowski, 1993)

3.2 Reservoir rocks

Several geothermal aquifers have been found within the Mesozoic basement of the Podhale Basin. Reservoir rocks are mainly Triassic carbonates, and sometimes Jurassic sandstones and carbonates (Fig. 3). The particular aquifers are separated from the top and bottom by semi-permeable Jurassic and Cretaceous series (mudstones, siltstones, shales).

The most favourable and prospective geothermal aquifer (being exploited for heating purposes since the 1990-s) occurs within the Middle Triassic limestone-dolomites and in overlying Middle Eocene Nummulitic limestones and carbonate conglomerates. 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, while the effective thickness is equal to 100 m. The water circulation and high flowrates are primarily conditioned by the secondary fractured porosity and permeability. The Triassic reservoir rocks are fractured and brecciated due to the long tectonic transportation, vertical movements, weathering, karstification, and secondary dolomitisation processes. Moreover, these features make the carbonaceous rocks supple to the inflow stimulation treatments by acidizing. In such conditions, the flowrate from individual wells may increase several times, occasionally even 20 times.

3.3 Caprock of geothermal aquifers

The caprock of geothermal aquifers is formed by thick (up to 2.5-3.2 km) Palaeogene flysch

formation characterising by good insulation properties. It consists of shales, mudstones and sandstones. The presence of geothermal aquifers and heat convection manifests within the flysch as a distinct thermal blanket effect, recorded by the temperature logs. Due to the heating up, the caprock temperature is up to 10°C higher than that resulted from the geothermal gradient only.

3.4 Tectonics

The Podhale system has complex tectonic structure. Beside the nappes and overthrusts there exists a network of deep faults of regional range (some of them continue tens of kilometres, reaching out far beyond the Podhale area). Consequently, the Mesozoic units have a block structure (weaker evidenced in the Palaeogene flysch more liable to the discontinuous deformations). The faults and fractures control the water and heat circulation and their upflow from the deeper parts of the system. The spatial orientation of dislocations locally modifies the directions of waters flow. The presence of these displacements and discontinuities needs to be taken into account for proper field development planning and siting of wells, directional ones in particular. Recently, detailed recognition of the deep structure of the exploited sector of the Podhale system was done using the 3D seismic profiling. It is interesting to mention that the dislocation zones also currently manifest some tectonic activity (at 30-40 year intervals). The last movements were recorded in 1996 and with the magnitude of ca. 4.5 in Richter-scale they were the strongest among observed so far.

3.5 Thermal features

The terrestrial heat flow amounts to 55-60 mW/m² (Plewa, 1994). The average geothermal gradient varies between 1.9 and 2.3°C/100 m. In some parts of the main aquifer – including the area of Bialy Dunajec PAN-1 and Bialy Dunajec PGP-2 injection wells - positive thermal anomalies were detected: the temperature at the depth of 2-3 km amounts to 80-100°C (Fig. 3) i.e. higher than that resulted from the geothermal gradient. Apart from heat convection within the aquifer, this effect can be explained by increased upflow of heat and/or hotter fluids from the deeper part of the system along the planes of discontinuities (Kepinska, 1994; Kepinska et al., in print). In particular, it refers to the northern part of the system bordering with the Pieniny Klippen Belt - former subduction zone. The role of this zone in creating thermal conditions of the Podhale system is certainly important, but so far, learned insufficiently. The results of geophysical exploration have shown that the zero induction anomaly is ascribed to it. This suggests the occurrence of hot fluids at great depth (6-16 km) and increased upflow of heat and hot fluids (Jankowski et al., 1982), as well as their inflow into the geo-

thermal aquifers. This supposition has been supported by the surface thermal anomalies on the tectonic contact of the Podhale Basin and the Pieniny Klippen Belt recorded by 2-3°C higher than the average background values (Pomianowski, 1988). Besides, other surface researches on the zones of regional dislocations within Podhale have shown them being privileged paths of increased heat transfer (Kepinska, 1997; Kepinska, 2000). Since some of them are still tectonically active, they can play important role in the discussed heat transfer, too.

The Podhale geothermal system and the neighbouring systems in Slovakia (i.e. the Skorusina and the Poprad systems, respectively on the West and the East of it, and the Liptov system on the South of the Tatras recharge area) are similar in thermal properties. Higher values of the heat flow and geothermal gradient as well as the increased thermal activity appear in the most southern area of the Inner Carpathians, where the Neogene volcanic rocks are present (Koszyce region and Panonian Basin). The heat flow may reach a value from 80 to 100 mW/m² there. That greater geothermal effect is produced by the Neogene volcanism, while the increased heat upflow from the upper mantle of the Earth is of minor importance.

3.6 Hydrogeology

3.6.1 Conditions of water recharge and circulation

The main recharge area of geothermal aquifers is situated in the Tatras Mts. Generally, the water flows in the NW and NE-directions, and such a distribution is conditioned by the impermeable northern barrier of the Pieniny Klippen Belt (locally the directions of water flows are modified by the system of faults and fractures). The structure of the basin makes the system to be in the artesian conditions (Fig. 3). The flowrate of groundwater and intensity of its exchange decrease to the north up to the Klippen Belt border. Presumably, the flowrate in the southern part of the system amounts to several tens of meters/year while in the North close to the Pieniny only to some meters/year.

It is worth noticing that the Tatras Mts. act as a recharge area for geothermal aquifers occurring both in the North (the Podhale system) and in the South (the Slovakian systems) of them. 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. The southern area of the Tatras Mts. recharging the Slovakian aquifers is almost entirely built of granitoids and metamorphic formations while the northern area recharging the Podhale system is also built of sedimentary series (limestones, dolomites, sandstones, clays).

3.6.2 Origin and chemistry of geothermal waters

The Podhale geothermal waters are predo-

minantly of meteoric origin. Geologically, they are young waters, the age of which is from 10 years to 10 – 20 thousands of years (Quaternary, Holocene). The TDS is low, in the range of 0.1-3 g/l. The water type is Ca-Mg-SO₄-Cl or Ca-Mg- HCO₃, with a small admixture of H₂S and hydrocarbons.

Throughout the geological history, waters of different origin, age and chemical composition appeared within the Podhale system. Older waters (marine or meteoric) were gradually replaced by younger ones (Kepinska, 2000).

The water composition reveals the features typical of washing of the formations saturated with saline water in the most recent geological time. Values of the hydro-geochemical ratio rNa/rCl based on the ion exchange suggest the final stage of sweetening of the exploited water (Fig. 4).

3.6.3 Main reservoir and exploitation parameters

In the case of the main geothermal aquifer, the artesian flowrate from individual wells varies from several to 550 m³/h. If the inflow-stimulation acidizing treatment of carbonate reservoir rocks is performed, the flowrate increases markedly from 10-20s m³/h up to 90-270 m³/h and even up to 550 m³/h. The latter is amongst the highest values obtained in the terms of geothermal self-outflow in Europe.

The secondary fractured porosity of 10-20% and intrinsic permeability up to 1000 mD supported by the presence of fractures and voids of karst origin if 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.

Taking into account its inhomogeneity the permeability of main geothermal aquifer may be accepted to be of the order of 10-3 m²/s. As previously-mentioned, the thickness of the main reservoir rocks is considerable (although variable) and equals from 100 to 700 m, while the effective thickness amounts to 100 m. The greatest thickness was found in the northern exploited sector of the system.

The wellhead static pressure amounts to 26-27 atm. The reservoir temperatures within the deepest parts of the main aquifer (depths of 2-3.2 km) are as high as 80-100°C, while the wellhead temperatures reach up to 86-93°C. Within the deeper parts of the system, the measured formation temperatures reach 120-130°C (depths of 4.5-4.8 km).

4. HISTORY OF GEOTHERMAL RECOGNITION AND ITS USE

A warm spring in a suburb of Zakopane has been known since the 19th century. The water of approx. 20°C 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 river water. The spring was an important surface manifestation of geothermal system occurring in the Podhale area. Just before 1939, it induced arising of first geothermal theories and the first well design project.

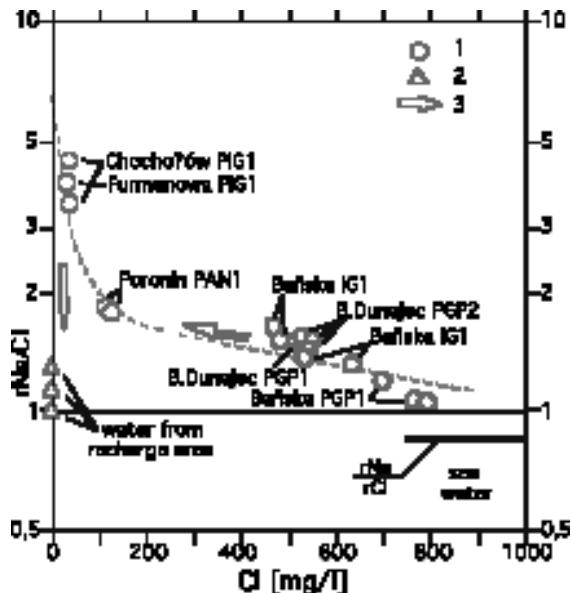


Figure 4. Change in rNa/Cl factor as assumed result of decreasing the mineralization of water from the main geothermal aquifer by meteoric water (Kepinska, 2001)

1. geothermal wells; 2. average values for the Tatra Mts. massif water; 3. direction of water mineralization decrease

In 1963 the first deep exploration well, Zakopane IG-1 (3073 m) was drilled (Sokolowski, 1973). It recognised several geothermal aquifers. The main ones belong to the Eocene carbonates and the Jurassic marls and limestones. The latter, most productive (1540–1620 m), was put into exploitation. Its main parameters were as follows: artesian outflow 50 m³/h (14 l/s), wellhead temperature 36°C, TDS 0.3 g/l. In 1973 the second well, Zakopane-2, was drilled there. High artesian water flowrate of 80 m³/h (22 l/s) from the Eocene limestones (a depth of 990-1113 m) was obtained while a wellhead temperature was 26.6°C and the TDS ca. 0.3 g/l (Malecka, 1981). Till 2001, water at temperatures of 26°C and 36°C, produced by these two wells was used for bathing pools. Since mid-2001, the construction of a large geothermal balneo-therapeutic and recreational centre has been underway there.

Between the 1970s and 1980s, several wells were drilled along the southern boundary of the Podhale system, close to the Tatra Mts. They were oriented mostly for geological exploration and potable water intake. In some cases, artesian outflows of water up to 20°C were obtained.

In 1979 – 1981, a breakthrough step in the development of geothermal energy use for heating purposes was taken when the Banska IG-1 well (total depth 5263 m) was drilled. It confirmed the existence of geothermal aquifers with advantageous reservoir parameters. The main aquifer was found in the Middle Triassic limestones – dolomites and in overlying Eocene carbonates. It was situated directly beneath the Palaeogene Flysch formation, and its main parameters were as follows: water outflow (artesian) - 60 m³/h wellhead temperature 72°C, TDS 3 g/l, wellhead static pressure 27 bars (Sokolowski, 1993).

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

The preliminary estimation of geothermal potential was carried out. The obtained results induced the intense exploration activities. In particular, a detailed investigation project to evaluate the geothermal water reserves was carried out in 1987 - 1995. Several scientific institutions participated in the project, namely: the State Geological Institute, the University of Mining and Metallurgy in Krakow, Polish Oil and Gas Company and Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (Sokolowski, 1993).

The project comprised desk studies of the numerous past surface and underground investigations from the point of view of geothermal prospects and new works including drilling five deep wells (2394 – 3572 m) in the central and north part of the Podhale basin over the years 1988-1992. The logging and well tests confirmed the occurrence of geothermal reservoirs within the entire Podhale system. They provided more detailed data testifying favourable reservoir properties of the main geothermal aquifer in the Middle Triassic and Eocene carbonates. It gave the solid basis and minimised the risk of the further works for the introduction of geothermal space heating.

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

In 1994, upon completion of the pilot stage, to conduct all the work concerning the construction of the regional geothermal heating network, the joint stock company "Geotermia Podhalanska S.A." was founded. The shareholders were the Podhale region communities being interested in, the Polish Academy of Sciences, the National Found for Envi-

ronmental Protection and Water Management, Hydrotrest S.A., and other smaller ones. In June 1998, the "Geotermia Podhalanska S.A. District Heating Company" was established as a result of fusion with municipal District Heating Company in Zakopane. It took over the project development. In 1995, the Geothermal Laboratory of the PAS MEERI superseded the Experimental Geothermal Plant to continue the further research and implementation works.

Since 1994 geothermal activities in the Podhale region has been carried out on two basic paths:

- Construction of the regional geothermal space heating system – by PEC Geotermia Podhalanska S.A. (more in Chapter 7),
- Basic research, R&D works on cascaded uses, education and promotion - by the PAS MEERI Geothermal Laboratory (more in Chapter 8).

5 GEOTHERMAL WATER EXPLOITATION AND HEAT EXTRACTION – METHOD STATEMENT

From its beginning, the Podhale project assumed a closed system of geothermal reservoir exploitation, heat extraction and distribution to the receivers. It was decided to extract the heat from geothermal water through heat exchangers while cooled geothermal water had to be injected back to the same reservoir. Such a method would assure long-term sustainable water and heat production from the field.

Since the end of 2001, 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 m³/h of 87°C water. The TDS are low, ca. 2.5 g/l, while the static artesian pressure is equal to 27 bars. The maximum self-outflow from Banska IG-1 well amounts to 120 m³/h of 82°C water (after acid treatment performance). The TDS are ca. 2.6 g/l, and the static artesian pressure - 26 bar.

In the exploited sector of the Podhale system, geothermal aquifer is situated at a depth ranging from 2048 - 2113 m (top) to 2394 – 3340 m (bottom). The effective aquifer thickness was estimated for 100 m, while in total it reaches about 700 m.

Geothermal water is transported to the plate heat exchangers in the Base Load Plant in Banska Nizna - Szaflary. In 2004, its installed capacity was 38 MW_t. Heated to 70-83°C, the network water is supplied through transmission and distribution pipelines to the receivers who have individual node heat exchangers to consume heat from the main pipeline. Cooled geothermal water of a current temperature drop not exceeding 25-30°C is sent through a pipeline to the pumping station and injected back to the reservoir by two injection wells: Bialy Dunajec PAN-1 and Bialy Dunajec PGP-2 (the maximum injection pressure amounts 55 - 60 bars). The maximum amounts of water injected

through the Bialy Dunajec PGP-2 well and the Bialy Dunajec PAN-1 well are 400 m³/h and 200 m³/h, respectively. The distance between produc-

tion and injection wells is 1.2 –1.7 km. Main data on geothermal wells are summarised in Table 1.

TABLE 1. The Podhale region – main data on geothermal wells exploited for space heating

Well	Banska IG-1	Banska PGP-1	Bialy Dunajec PAN-1	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		2113-2394 m	2048-2450 m
Lithology	Carbonate conglomerates, limestones, dolomites (Middle Eocene- MiddleTriassic)			
Production casing	Casing 6 5/8", perforated interval 2588-2683m	Casing 6 7x75/8", perforated interval 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 m ³ /h	550 m ³ /h		
Maximum wellhead temperature	82°C	87°C		
Wellhead pressure	26 bar (static)	27 bar (static)	55-60 bar (injection)	55-60 bar (injection)
TDS	2.5 g/dm ³	2.7 g/dm ³		
Maximum injection capacity			200 m ³ /h	400 m ³ /h

In 1992 – 2001, i.e. in the pilot stage of the Podhale geothermal project and at the beginning of its main stage, the exploitation system operated on one well doublet: Banska IG-1 (production) and Bialy Dunajec PAN-1 (injection). The production amounted 30–60 m³/h of 70–80°C water. Geothermal heat was transmitted to the district heating through two plate heat exchangers. Their installed capacity was 4 MW_t, the real one during the heating season was up to 2 MW_t.

This doublet served the heating network in almost 200 individual dwellings (about 1000 inhabitants), school, church, and PAS MEERI cascaded use installations. Maximum geothermal heat production was ca. 30 TJ/y for space heating in Banska Nizna village. The sketch of geothermal doublet working in 1992 – 2001 is given on Fig. 5.

In October 2001, the existing network was joined in the extended exploitation system that was put into operation thanks to two new wells: Banska PGP-1 (production) and Bialy Dunajec PGP-2 (injection). The wells were drilled in 1997-1998 and their owner is the PEC Geotermia Podhalanska S.A.

6. THE PODHALE GEOTHERMAL HEATING PROJECT

6.1 Main objectives

As mentioned before, the project to construct a geothermal space heating network within the

Podhale region was initiated by the Polish Academy of Sciences, Mineral and Energy Economy Research Centre (Ney and Sokolowski, 1987). In the period 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 S.A. has been conducted the full scope of activities related to construction of regional geothermal heating network within the Podhale region.

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

6.2 Background

The Podhale region may be divided into three areas occupied by the valleys of the three main rivers, flowing from the Tatra Mts. towards the north (Fig. 2). These valleys can be considered as

three natural, separate district heating systems: West, Central and East. The biggest is the Central Valley, i.e. the Bialy Dunajec River Valley system - the most densely populated area, where two main cities of this region, Zakopane and Nowy Targ, are located. Two other are the West Valley - Czarny Dunajec River and the East Valley - Bialka River systems.

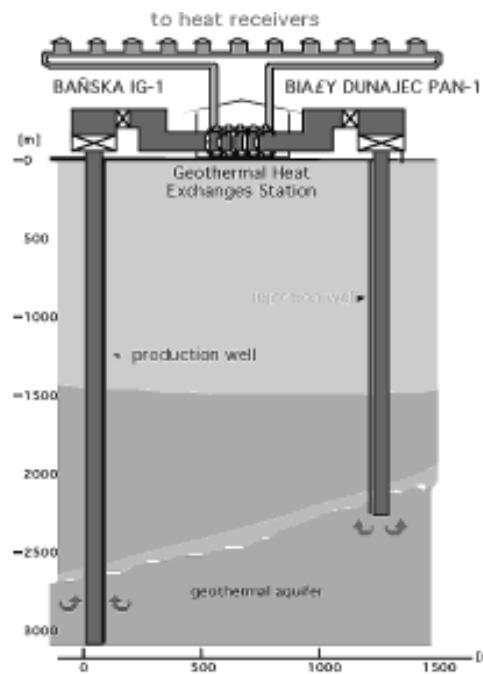


Figure 5. The sketch of the geothermal doublet working in 1992 – 2001, PAS MEERI Geothermal Laboratory

In 1993, the scientists from the PAS Mineral and Energy Economy Research Centre and experts from House & Olsen Thisted Ltd., Denmark elaborated the feasibility study for geothermal

TABLE 2. The Podhale geothermal project – specification of geothermal heat consumers and calculated heat demand according to the project assumptions from 2003 (Dlugosz, 2003)*

Category – number of users	Calculated annual heat consumption, TJ/y	Percentage of total consumption, %
Households – 1500	150	25
Large and medium consumers – 260	320	53
Nowy Targ – sale for municipal heating plant	130	22
TOTAL	600	100

- Works on correction the figures given in Table were in progress while paper preparation (May – June 2004)

The technical diagram of the geothermal heating system under construction in the Podhale region is shown on Figure 6

6.3 Energy sources

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

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

heating in the Podhale region. It was assumed that 60–70% consumers in small villages would be connected to the network, while 70–80% in larger villages and 100% in towns (Sokolowski, 1993). The above percentage was successively corrected in the course of the project realisation according to the current circumstances.

The state of reservoir exploration, the number of existing wells, and the most dense population was that caused the first steps towards geothermal heating to be taken just in the Central Valley - in Banská Nizna village in 1993 when the Experimental Geothermal Plant was launched. The next step started to be developed in the town of Zakopane, where the heat consumption is the greatest.

The part of a second main town of the region, Nowy Targ, is expecting to be partly connected to the geothermal network in the coming years.

Initially, the installed thermal power for the Central Valley System – a priority of the project - has been estimated at 150 MW_t (including about 78 MW_t from gas peak boilers). In the 1994– 2004 period, further detailed studies and optimisation work were carried out. On the base of the results of 2003, it was assumed that the thermal capacity of the geothermal system in this Valley will amount to 80 MW_t and the heat output will reach a level of 600 TJ/year. It was to be achieved due to connecting of about 2 000 receivers to the geothermal network by the end of 2005 (Dlugosz, 2003). The anticipated heat sales upon project completion for different consumers' categories is given in Table 2. It should be added that since the second half of 2003 the works are being conducted in order to definite the final target capacity and heat sales upon geothermal project completion, which can be reached in economic plausible way.

After connecting the buildings in Nowy Targ, a gas or oil plant in that town will work as a peak load and a third heat source in the system.

The role of above sources in the constructed system can be briefly characterised as follows:

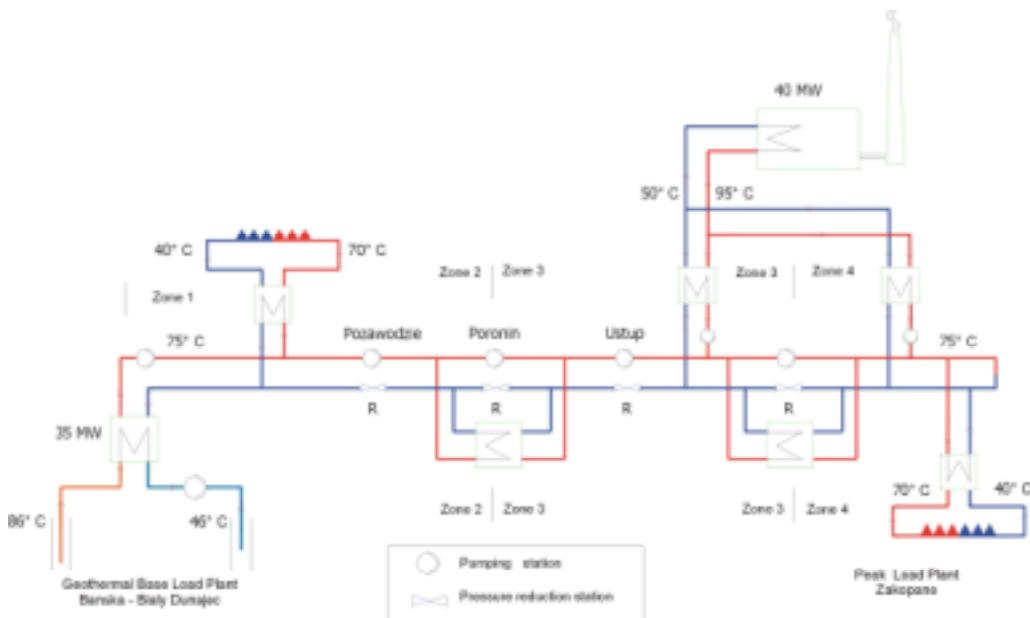


Figure 6. The technical diagram of the geothermal heating system under construction in the Podhale region

Geothermal Base Load Plant, Banská Nizna - Szaflary .

The current geothermal capacity of installed plate heat exchangers is 38 MW_t. The plant is based on two production wells PGP-1 and IG-1, capable to totally discharge 670 m³/h of 82 - 87°C water (Table 1).

Geothermal heat is transmitted to the district heating water through plate heat exchangers (about 7 MW_t each, 25-30°C cooling of geothermal water).

After passing heat exchangers, the cooled geothermal water is injected back (via pumping station) to the reservoir through two injection wells situated 1.2 – 1.7 km from the production ones. In the plant other technological facilities are installed, i.e. the circulation water treatment system with a capacity of ca. 50 m³/h, the expansion system protecting particular pressure zones, and the circulation pumps of a capacity of 3 x 470 m³/h pumping network water towards Zakopane.

Central Peak Load Plant, Zakopane.

The Central Peak Load 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) (Fig. 6).

In 1998 – 2001, i.e. until the geothermal heat has been delivered to Zakopane by the main

transmission pipeline from Geothermal Base Load Plant in Banská Nizna - Szaflary, the plant was working as a basic gas heat source.

Since 2001, i.e. after connecting the heating system in Zakopane to the Base Load Plant, the plant has two basis functions:

- Peak heat source;
- Reserve heat source (for consumers located between the Poronin pressure separation station and Zakopane).

6.4 History and current state of the project

As already described, the construction of a geothermal heating network in the Podhale region (Bialy Dunajec River Valley) was planned to carry out by stages during 1989–2002, but real date of completion is expected in 2005. The beginning stage (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 195 buildings in the village of Banská Nizna. This stage served as a control testing the validity of the assumption and operation efficiency of the system.

The main items of geothermal project realised in 1995-2004 can be summarised as follows:

- Drilling of two new wells: Banská 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 Banská Nizna - Szaflary.
- Construction of the Peak Load Plant in Zakopane.

- Construction of the Banská – Zakopane DN 500 main transmission network, total length of 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 the distribution networks in Zakopane and some villages located between the base load 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 on heat exchanger units.
- 3D-seismic survey for selected sector of the Podhale system aimed at proper siting new exploitation wells and get detailed knowledge on tectonic structure of geothermal aquifer and flow directions.

Further possible works to be completed by 2005 include drilling of geothermal well for the heating needs of the Nowy Targ, construction of the main pipeline to this town, construction of the distribution network in the villages situated on the way to Nowy Targ, extension of Geothermal Base Load Plant in Banská Nizna - Szaflary due to the needs of Nowy Targ, and construction of ca. 25 MW_t Peak Load Plant in Nowy Targ.

The long – term strategy of PEC Geotermia Podhalanska S.A. assumes the market development for low-parameter energy of the return water from the heating network and cooled geothermal water sent to the injection wells. It will make possible to develop investments in such sectors as greenhousing, recreation centres, floor heating systems, etc.

Some photographs of the main facilities of the Podhale geothermal space heating network are shown on Figures 7 – 10.

6.5 Heating networks

Prior to the geothermal project, only the part of the town of Zakopane was provided with a heating network. Therefore, most of dwellings both in Zakopane and Podhale's villages were heated by their individual heat source. Due to the great area of the developed project, the construction of the heating networks involved a major amount of expenditures (Dlugosz, 2003). A 90/50°C heating network between energy sources and consumers has been built practically from scratch. The main pipeline towards the town of Zakopane is built of pre-insulated pipes with small heat losses. The temperature drop is not higher than 2°C on a distance of 14 km. Because the temperature of network water after passage 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



Figure 7. Geothermal Base Load Plant, Banská Nizna – Szaflary - general view (photo T. Kliszcz)

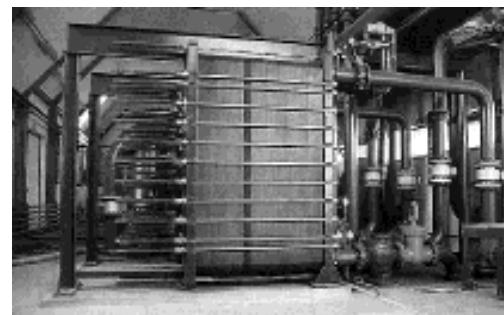


Figure 8. Geothermal Base Load Plant, Banská Nizna – Szaflary - plate heat exchangers (photo T. Kliszcz)



Figure 9. Central Peak Load Plant, Zakopane - inside view (photo T. Kliszcz)

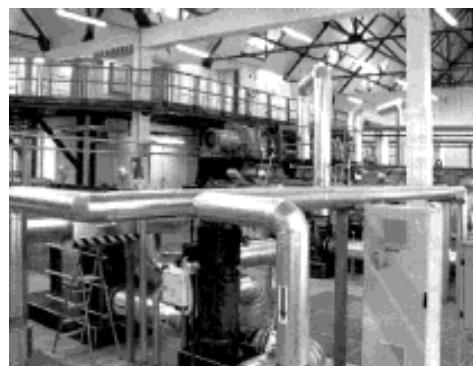


Figure 10. Central Peak Load Plant, Zakopane - general view (photo T. Kliszcz)

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 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. 6).

6.6 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. They are equipped with compact heat exchangers. They are dual-function plate heat exchangers (warm-water production for the central heating and domestic water, in a flow system without a hot-water bunker);
- Medium consumers (boarding houses, offices, schools, public buildings, etc.) and large consumers (buildings heated formerly by small local coal-based boilers). They are equipped with compact dual-function plate heat exchangers, and additionally with an automatic weather-sensitive system, with the possibility of programming many functions such as night drop, wind impact, etc. All heat exchangers are equipped with heat meters.

6.7 Outlays of investment and sources of financing

The outlay for the project of the greatest range of investment was planned for about 90 million USD. It presumed the greatest geographical range, and the greatest sale of heat, which would result in the greatest positive impact on environmental protection due to connecting to the network the greatest numbers of receivers. Due to the project optimisation with time and limiting its scope, the total costs will be lower (the total heat sales will be lower, too).

The investment is financed from the Polish and foreign sources including share capital, grants, loans, and credits (Table 3). They are as follows:

- Polish sources: the capital of the company PEC Geotermia Podhalanska S.A.; Ekofund, the National Fund of Environmental Protection and Water Management, Bank PKO;
- Foreign sources: the World Bank, PHARE EU, Large-Scale Infrastructure Projects EU, the Global Environment Facility (GEF); credits: the Bank of Environmental Protection, the Danish Environmental Protection Agency (DEPA).

The capital expenditures over the period of 1994 – 2002 totalled about 212 million zl (about 53 million USD; Dlugosz 2003). It should be mentioned that a part of means comes from Ekofund. This fund was established on the basis of the Polish foreign dept extinguished for ecological purposes. The great benefit for Podhale is a high percentage of grants (near 50%) in the financing.

TABLE 3. The Podhale geothermal project – capital expenditures 1995-2002 (Dlugosz, 2003)

Source of finance	Million USD	%
Share capital	9 900	18.8
Grants	26 175	49.7
PHARE	17 700	
NFEPWM	2 650	
Ekofund	1050	
GEF	2 500	
USAID	1 750	
DEPA	525	
Credits	16 625	31.5
World Bank	10 525	
Bank PKO	6 100	
TOTAL	52 700	100.0

* 1 PLN = about 0.25 USD (2003)

PHARE – Poland - Hungary Aid for Reconstruction, NFEPWM – National Fund for Environmental Protection and Water Management, GEF – Global Environmental Facility, USAID – the United States Agency for International Development, DEPA – Danish Environmental Protection Agency

6.8 Ecological results

Ecological benefits were the main and the strongest arguments for introducing the geothermal space heating within the Podhale region. The realisation of the project will bring measurable results in the elimination of considerable part of coal and coke burnt per year that will result in decrease in related emissions.

By the end of 2003, over 400 individual (small) consumers, 110 large-scale receivers and 25 local coal-fired space heating plants that supplied over 100 blocks of flats have been connected to geothermal network. Works on connection new consumers are underway. Geothermal heat production in 2003 was ca. 180 GJ (total ca. 240 GJ).

The project has been monitored as far as the limitation of emissions, such as CO, SO₂, and dust are concerned. In the case of Zakopane, thanks to the successive introduction of geothermal heating in this town in 1998-2002, annual average concentrations of particulate matter (PM₁₀) and SO₂ have dropped by about 50% in comparison to the situation before the geothermal heating was put on-line. Moreover, during winter heating season of

2001/2002 the SO₂ concentration dropped down by 67% as compared to the situation in 1994-1998 prior to geothermal heating initiation in Zakopane.

Figure 11 shows ecological effect expressed as limitation in SO₂ emissions generated so far mostly by coal-fired heating systems.

1994-1997- situation prior to geothermal project development when space heating in that town was based on hard coal and other fossil fuels, 1998-2002-situation at the beginning of geothermal heating system introduction in the town: 1998-2001 – bulk of coal-based systems replaced by gas-fired Peak Load Plant, since 2001 – development of geothermal space heating system. Data according to Dlugosz (2003) and unpublished files, courtesy P. Dlugosz, PEC Geotermia Podhalanska SA.

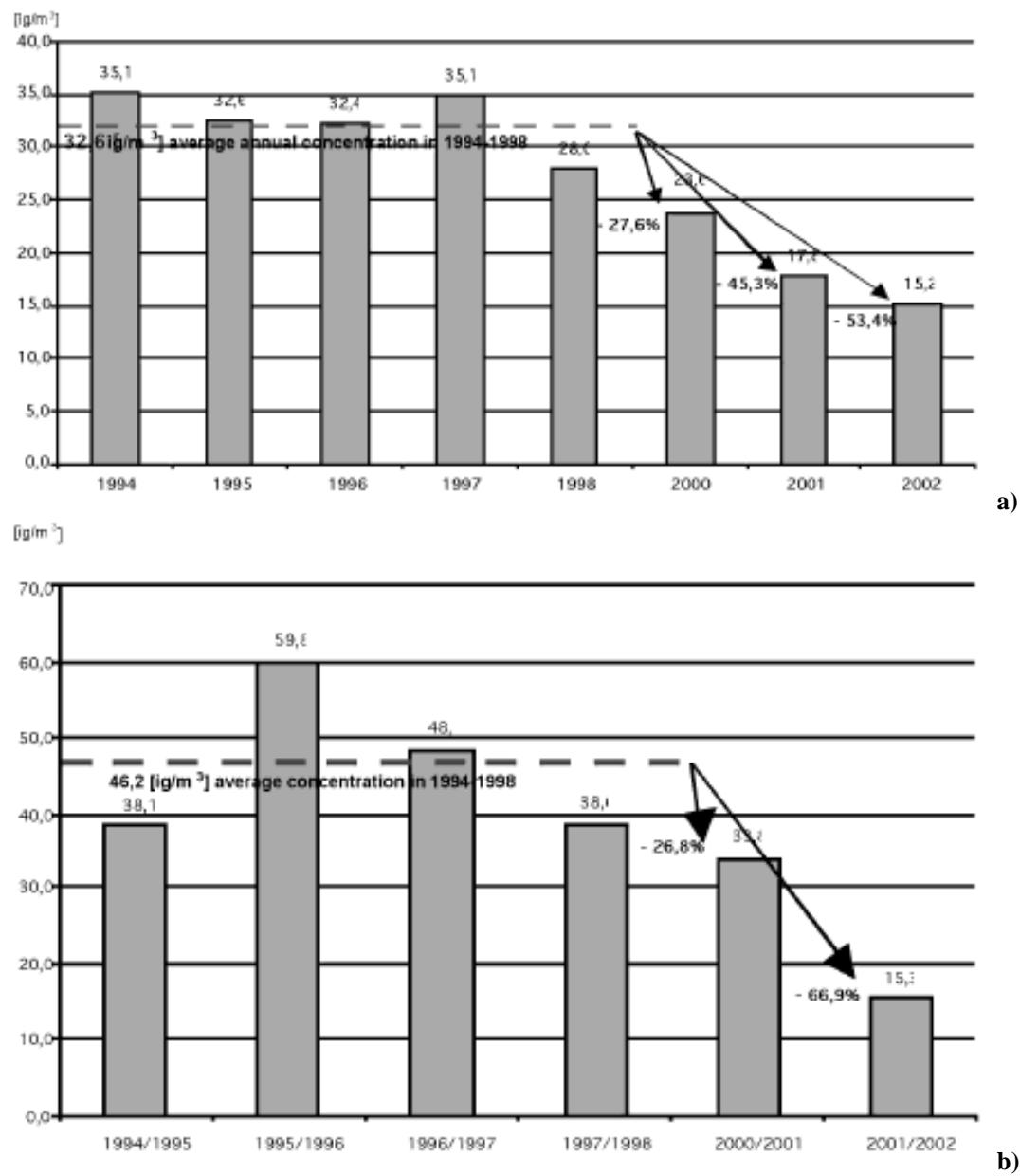


Figure 11. Limitation of main emissions thanks to the introduction of geothermal space heating system in Zakopane
 a. Average annual SO₂ concentrations, b. Average SO₂ concentrations during heating seasons

7 CASCADED GEOTHERMAL USES

Along with the geothermal space-heating project in the Podhale region, the PAS MEERI Geothermal Laboratory has conducted the R&D works on cascaded geothermal uses in a wide temperature range. It continues research, experimental and semi-technical work initiated by the Experimental Geothermal Plant. Many of the projects either have been completed or are underway thanks to the financial support from the State Committee for Scientific Research. 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 conducts monitoring of geothermal reservoir and

system in the conditions of long-term exploitation.

This place serves also for demonstration and education purposes being the only one of such a character in a country.

The operating cascaded system is composed of the following (Fig. 12):

- Space heating and domestic warm water supply to the buildings of the PAS MEERI Geothermal Laboratory;
- Wood-drying;
- Greenhouse,
- Stenothermal fish farming,
- Foil tunnels for growing vegetables in heated soil.

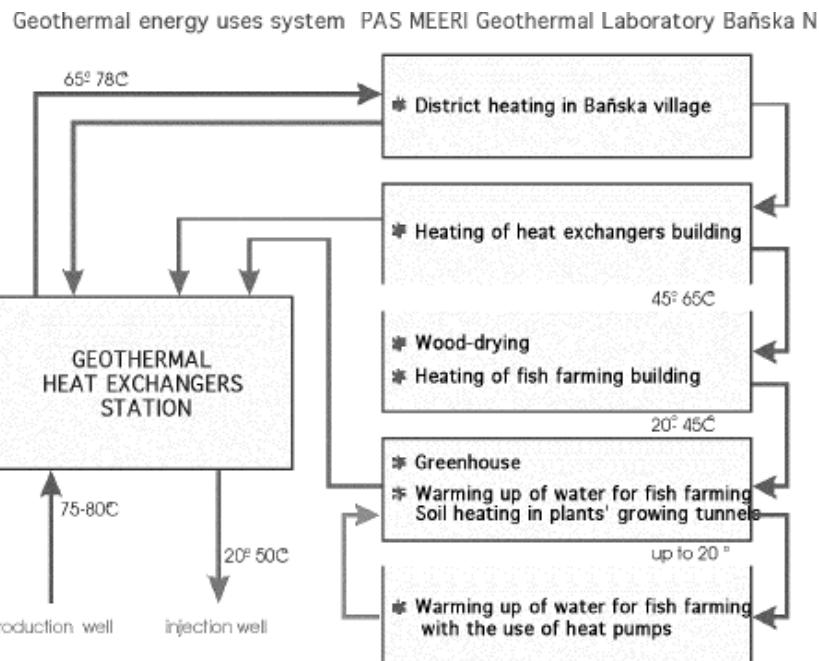


FIGURE 12. A sketch of cascaded uses system, PAS MEERI Geothermal Laboratory

The uses of special interest for the region and other parts of the country are:

Wood-drying.

This is a typical wood-drying chamber, manufactured in serial production as a steel structure. It is heated by a Favier heater and its heat requirement depends on the degree to which the chamber is filled with wood for drying, fluctuating within the range of 21 to 120 kW. The inside temperature is 40°C, while of the supplied heating water - 65/45°C. Depending on the humidity and the type of wood, the drying cycle usually takes 2 to 3 weeks, while in natural conditions on the average of 2 to 3 years is required for wood to acquire the parameters qualifying it for construction or other purposes.

Stenothermal fish farming.

The building, 21.2 x 12.25m in dimension, was made using the energy-efficient Thermomur technology. Heat savings are considerable because the building uses approx 60% of the energy needed for a traditional structure of the same size. The used technology is of particular significance because it ensures the required warm (28-33°C) inside simultaneously protecting the building elements against condensation of the humidity coming from water evaporating from eight breeding tanks. The geothermal farming makes possible to breed attractive stenothermal fish species such as African catfish or tilapia and to achieve high weight-increase rates. The fish reach their commercial weight of 1-1.5 kg over a period of 6 months, while traditional breeding of two common fish species (carp and trout) in open cold tanks takes 2 years in the climate typical in Poland.

Foil tunnels for growing vegetables in heated soil.

The foil tunnels have a heating installation in the soil. These are polyethylene pipes (DN = 32 mm and DN = 25.2 mm) laid at the depth of 30 cm under the soil surface at the intervals of 25-30 cm.

This solution resembles floor-heating systems used in buildings. The temperature of water in pipes amounts to 40 - 45°C heating the soil to 25-28°C. When leaving the tunnels, the water temperature is 38-43°C.

Due to the necessity of ensuring well-balanced distribution of temperatures in the top layer of the soil, the temperature drop along the heating pipe-layout is very small (by approx. 2°C). Consequently, the heating capacity can be controlled solely by changing the stream of water flowing through the pipes.

8 MONITORING AND PRODUCTION HISTORY OF THE PODHALE GEOTHERMAL SYSTEM

Since its putting into operation in 1990, when the exploitation through one doublet of wells Banská IG-1 - Bialy Dunajec PAN-1 started, the Podhale geothermal system has been a subject of monitoring of its main hydrodynamic, physical and chemical parameters. Both the PAS MEERI Geothermal Laboratory and PEC Geotermia Podhalanska S.A. commonly managing the production carry out the observations. In the case of latter company, the SCADA-system has been used serving both for geothermal and surface technical parts of the heating network.

From 1990 to 2001 during the exploitation of one doublet, water flowrate varied from 8 - 16 l/s while the wellhead temperature was 76 - 80°C. The maximum capacity reached 1,8 MW_t, and about 30 TJ/y was delivered to space heating network in Banská village.

Till 2001, before two new wells started the flowrate and temperature of water produced in the doublet Banská IG-1 - Bialy Dunajec PAN-1 was observed being stabilised. However, some slight pressure drop at production well and pressure increase at the injection well was recorded. Among others, the reason for this may be the slight decrease of permeability of the reservoir rocks, due to precipitation of secondary minerals and introducing products of corrosion of the transmission pipeline into the reservoir. The monitoring showed also some decrease in TDS of the produced water - from 2.9 to 2.5 g/dm³, while the water type did not change. In general, the stability of the basic parameters of the exploited system was observed in 1990 - 2001. The recovery features of the reservoir were maintained. The results of the monitoring have proven the applied exploitation method to be

correct, as it makes possible to maintain the renewable features of the reservoir.

As already mentioned, in late 2001 the exploitation system was extended by two new wells Banská PGP-1 and Bialy Dunajec PGP-2. The amount of produced and injected water considerably increased, from a level of 30-60 m³/h to 100-500 m³/h. Sustainable long-term field management requires recording the reservoir response for increased production, prediction its long-term behaviour and keeping stable level of the parameters.

The corrosive properties of geothermal water and its scaling tendency are also the subject of investigation since these effects are very significant to the reliability and uninterrupted operation of the system as well as to the durability of both surface and downhole installations.

9 ECONOMIC ASPECTS OF GEOTHERMAL HEATING

For common consumers, the most important are the economic aspects of geothermal type of heating. In the beginning of the project, the price of heat offered to the consumers in Banská Nizna, was reduced. Then the VAT value was also low, 7% against 22% at present. The current price of geothermal heat is slightly higher than coal heat and lower than gas 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 Banská 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. A high percentage of the expenses (10%) is connected with the new property tax (charged on built structures) introduced in 2002.

10 SOCIAL ASPECTS OF GEOTHERMAL ENERGY INTRODUCTION

The Podhale geothermal project has been accompanied by information and education campaign. The authors of the project and contractors organised many meetings with habitants of administrative localities being planned to join to the geothermal heating network. Some local authorities support those efforts. The most important was to convict consumers to reliability of the geothermal source of heat, its competitive prices comparing to traditional source of heat, and ecological benefits rising the tourist value of the region. The project had to get social agreement for required technical changes and related costs. Common consumers of geothermal heat 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

11 FURTHER PROSPECTS OF GEOTHERMAL USES

Apart from the district heating – essential for the ecological reasons, the other geothermal uses awaiting for realisation are balneotherapy and recreation. Due to chemical composition (i.e. H₂S, sulphides, bromium, iodium, potassium, silica) the Podhale geothermal waters have curative properties suitable in the dermatological, rheumatic, endocrinological and contagious diseases. Till 2001 only one geothermal bathing pool operated in Zakopane. There are exceptionally great opportunities to build healing and recreation centres in this region. One of them is being realised in Zakopane at the site of the existing pool. It includes the construction of the full range healing and recreation complex. This is a long expected project, indispensable to increase the tourist offer and to improve the quality of recreation in this important tourist centre. For the Podhale region, geothermal balneotherapy and bathing appear to be very important chance for sustainable development of tourism and economics.

12 CLOSING REMARKS

The Podhale geothermal system represents an interesting and complex geological structure. Regarding the implementation of its low-enthalpy resources, it belongs to one of the most prospective in Europe. If offers very good reservoir and exploitation conditions – a basis for a large-scale geothermal space heating network, and other multipurpose uses.

Geothermal space heating project which is still being underway, has already resulted in considerable ecological results expressed by significant reduction of emissions generated so far by huge amount of coal burnt for heating purposes. Such limitation of gas and dust emissions would not be possible to achieve in the way different than introduction of geothermal system.

The works aimed at definition of final project extension and heat sales are underway. The up-to-date exploitation, technical and ecological results have already proven the purposefulness, and reliability of using geothermal energy in the Podhale region and many parts of Poland, which possess geothermal aquifers connected with sedimentary systems.

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