CONDITION AND PERSPECTIVES OF UTILIZATION OF GEOTHERMAL ENERGY IN POLAND

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ABSTRACT

Up to the end of the 80-ties of the last century, geothermal energy was applied in Poland mostly in balneology. Its practical application in the power industry, and most of all in heating engineering, has begun only in 1993, as the experimental geothermal installation in Bańska, near Zakopane was built. At present, there operate six geothermal heating plants in Poland, and there are plans to build and set in operation the next ones.
The aim of the present paper is to recapitulate the almost ten-years` period of efforts connected with utilizing the geothermal energy in Poland. With consideration to the above purpose, the paper will give a description of geothermal resources in Poland and it will depict the present condition and development perspectives for energetic installations that apply geothermal water for heating purposes. The paper will also present the existing geothermal heating plants: in Banska, Banska Nizna, Pyrzyce, Mszczonów, Uniejów and Slomniki. Plants in the course of building, as well as proceedings connected with the future geothermal installations will be discussed in the paper. To make the paper complete, remarks and conclusions resulting from the operation of the so far existing geothermal installations will be presented.

1. INTRODUCTION

Gradual exploration of fossil fuels with their environmentally harmful combustion products together with a growing energy demand are the most important premises for the development of renewable energy resources all around the world. In Poland, the development of renewable power sector is additionally accompanied by such factors as the necessity to obey international agreements regarding the environmental protection (Kyoto Protocol) as well as fulfilling the European Commission requirements, where Poland plans to become the member in the years to come. According to existing estimates Poland has the renewable energy potential which is sufficient to cover the entire energy demand in the country. According to Wiśniewski [9], amongst all renewable energies in Poland the most extensive ones are the geothermal energy sources. These amount to about 1520 PJ/a. Next on the list are the solar energy resources estimated at the level of 1340 PJ/a and the biomass potential of 895 PJ/a. The other remaining sources of energy have much smaller potential.
Despite such significant energy potential in geothermal waters it has only been the last decade when their wide exploitation started. Until that time geothermal waters have only been used for balneological purposes. Important centres where utilisation of geothermal waters for therapeutic treatment took place are such spas as for example: Lądek Zdrój, Cieplice, Ciechocinek. In the years 1993-2003, on the other hand, constructed and commissioned in Poland have been six

large thermal systems based on the energy of geothermal waters. At present construction of subsequent developments is planned.

Bearing that in mind, in the present survey will be presented the actual and future perspectives for utilisation and development of geothermal installations in Poland.

2. POTENTIAL OF GEOTHERMAL ENERGY IN POLAND

Geological conditions as well as the regions of existence of geothermal water resources in Poland have been specified by Sokołowski, Górecki and Ney [1,2,5]. The total potential of Polish geothermal waters has been estimated to be at the level of about 6600 km^3 [5]. The temperature of geothermal waters ranges from 25 to 150°C, which makes it adequate for direct utilisation for heating purposes, preparation of utility hot water, as well as technological and therapeutic purposes. The resources are more or less evenly distributed across the significant part of Poland in specified geothermal basins and sub-basins, which belong to the specific geothermal provinces and regions (Fig. 1). The most favourable geothermal conditions can be found on the Polish Lowland, Podhale and Sudety. The specific analysis of the geothermal energy potential has been given in [2], and the operational resources on that energy are estimated at the level of 2.3 – 3.8 mtoe per annum.

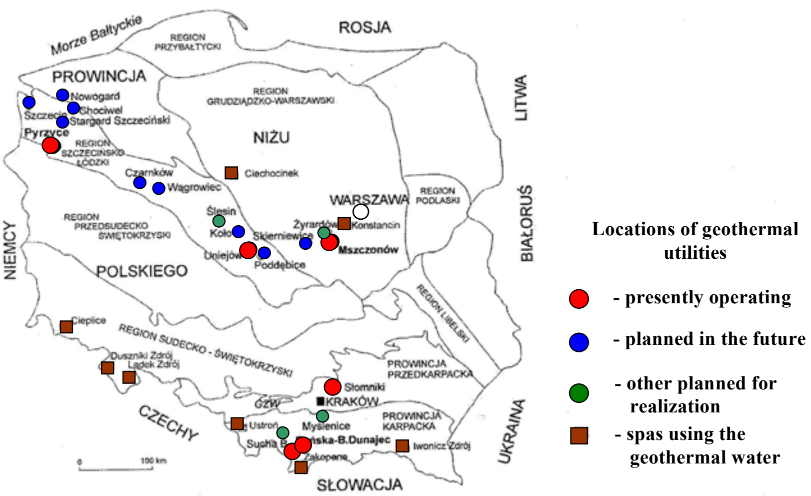

Figure 1. Map of regions and sub-basins in Poland after J. Sokołowski [9] together with existing and planned locations of geothermal utilities

It results from the hydrogeological data that over 90% of subterranean water resources can be found in the region of Polish Lowland, in the Polish part of a Central European geothermal province. Taking into account, that the geothermal resources in that region exist in the subterranean waters of various stratigraphic layers, the economic justification points at favourable conditions of utilisation, in the first turn, of two water-bearing formations, i.e. early Cretaceous and early Jurassic systems. Classified and calculated by Górecki [3] values of energy resources in geothermal waters in the Polish Lowland, in the form of temperature ranges of resource waters, have been presented in Table 1.

The more significant quantities characterising 16 major geothermal sub-basins in the Polish Lowland have been shown in Fig. 2. These quantities are:

- Potential resources of geothermal waters in Poland, V [km^3],
- Potential resources of energy contained in geothermal water, Q [mtoe.],
- Mineralisation of water in the deposit, d [g/dm^3],

- Typical water temperature at outlet, $\bar{t}$ [°C],
- Average depth of water-bearing rocks, $\overline{m}$ [m],
- Depth of the water-bearing well, H [km],
- Average roof depth in a given sub-basin, $\overline{H}$ [km].

Presented data enable fast comparison of the energy potential of particular sub-basins as well as preliminary selection of optimal regions for localisation of geothermal power stations. It must however be borne in mind that the knowledge on the localisation of geothermal water resource and contained there energy are not a sufficient criteria for taking up the decision about starting the geothermal development. A subsequent important criterion is the cost of the underground labour enabling extraction of geothermal water to the surface in order to be able to remove its enthalpy. For the conditions existing at the Polish Lowland the share of geological labour, dependent on the amount and depth of extraction and filling wells, ranges from 60 to 80% of the total cost of construction of the geothermal power plant and hence it is a major item of the investment list. From the economical point of view selection of the geothermal sub-basin, which is to be a competitive source of heat with respect to the sources utilising the conventional fuels, is a crucial issue.

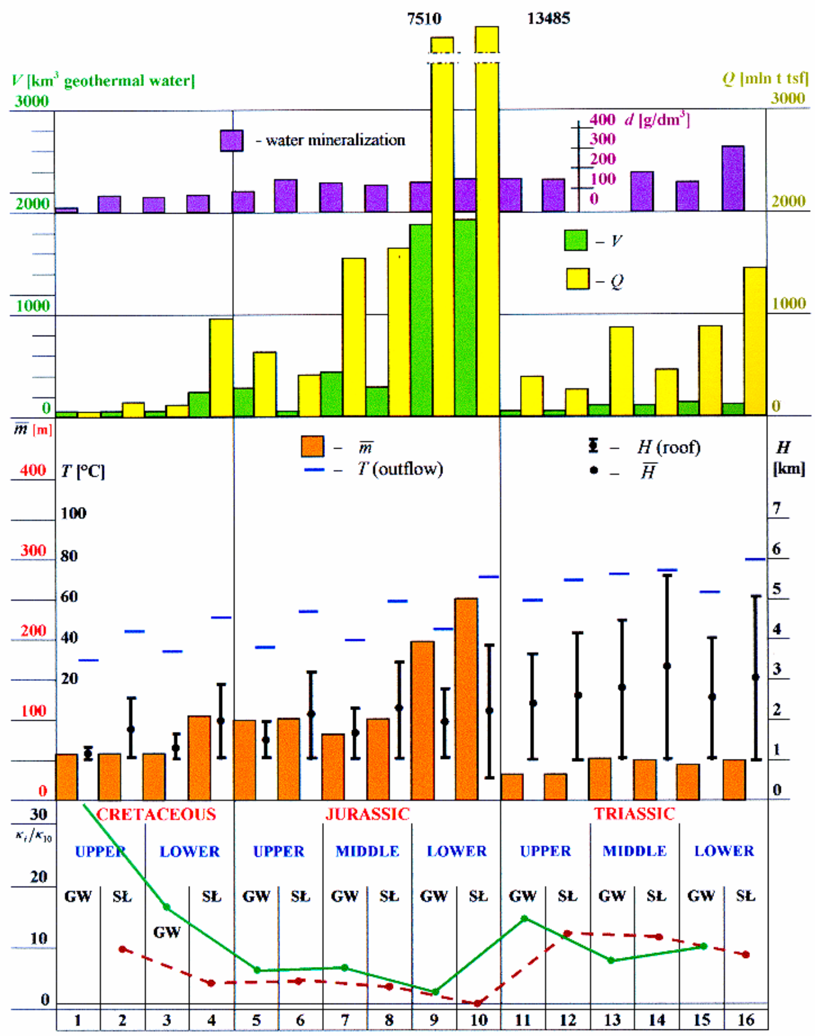

Fig. 2. Characteristics of 16 major geothermal sub-basins in the Polish Depression [6]. (GW – Grudziadz-Warsaw region, SL – Szczecin-Lodz region)

A preliminary measure of the effectiveness of the geothermal development may be the value of the cost indicator κ, which expresses the ratio of the underground labour to the nominal thermal power in the extracted water. For simplification of calculations omitted has been a cost of installation construction for obtaining of the geothermal heat. The function *f(H,t,m)* is a predominant factor, which determines variation of the *κ* indicator. The geothermal deposit, where value of the function reaches minimum ensures economical exploitation of the geothermal well.

Table 1. Geothermal energy resources in the Polish Lowland

Formation	Deposit water temperature	Static extractable resources	Disposable resources	
	[°C]	[J]	[J/a]	[toe/a]
Early Cretaceous deposit	< 40	$1{,}66 \cdot 10^{19}$	$0{,}96 \cdot 10^{17}$	$2{,}18 \cdot 10^{6}$
	40 – 60	$1{,}46 \cdot 10^{19}$	$1{,}44 \cdot 10^{17}$	$3{,}27 \cdot 10^{6}$
	60 – 80	$1{,}19 \cdot 10^{19}$	$1{,}23 \cdot 10^{17}$	$2{,}80 \cdot 10^{6}$
	80 – 100	$0{,}24 \cdot 10^{19}$	$0{,}19 \cdot 10^{17}$	$0{,}43 \cdot 10^{6}$
	Total	$4{,}55 \cdot 10^{19}$	$3{,}82 \cdot 10^{17}$	$8{,}68 \cdot 10^{6}$
Early Jurassic deposit	do 40	$0{,}51 \cdot 10^{20}$	$1{,}69 \cdot 10^{17}$	$3{,}84 \cdot 10^{6}$
	40 – 60	$1{,}66 \cdot 10^{20}$	$6{,}20 \cdot 10^{17}$	$14{,}09 \cdot 10^{6}$
	60 – 80	$1{,}55 \cdot 10^{20}$	$5{,}48 \cdot 10^{17}$	$12{,}45 \cdot 10^{6}$
	80 – 100	$0{,}44 \cdot 10^{20}$	$2{,}52 \cdot 10^{17}$	$5{,}73 \cdot 10^{6}$
	> 100	$0{,}20 \cdot 10^{20}$	$1{,}42 \cdot 10^{17}$	$3{,}23 \cdot 10^{6}$
	Total	$4{,}36 \cdot 10^{20}$	$17{,}31 \cdot 10^{17}$	$39{,}34 \cdot 10^{6}$

Based on presented mean data calculated have been values of the cost indicators for 16 sub-basins in the Polish Lowland. In Fig. 2 presented is a distribution of relative values of the cost indicator for the sub-basins of the Grudziadz-Warsaw region (solid line) and the Szczecin-Lodz region (broken line). In both cases value of the indicator κ for a given basin has been referred to the indicator for the Lias Szczecin-Lodz sub-basin, for which has the lowest value of the cost indicator [6].

That figure enables to assess the particular sub-basins with the view to the extent of the investment cost on drilling the wells for the geothermal power plant of specified power. The lowest cost of performing the drilling works referred to the unit of installed thermal power of a geothermal development is found for both regions in the case of sub-basins of the earlier Jurassic.

These are the most capable resources of geothermal waters in Poland, which ensure economically vital extraction of water to the surface. This, however, does not mean that in the individual cases exploration of geothermal energy accumulated in other geothermal deposits should be ceased. The final decision depends on the results of technical and economical analysis for a given case.

3. EXISTING GEOTHERMAL POWER PLANTS

The first geothermal power plant has been commissioned in 1994, where utilised has been a geological well Bańska IG-1, which has the efficiency of 120 m^3/h (Fig. 3). That well functions as an extraction well and co-operates with the filling well Biały Dunajec PAN-1. The geothermal water is taken from the depth of 2000–3000m, from the limestone and Eozoic conglomerates, dolomites and Jurassic sandstones. These rocks form an artesian well, where from the geothermal water is self-ejected. The company "Geotermia Podhalańska" uses that installation for heating of a complex of about 200 houses, a church and a school in the town of Bańska Niżna (Fig. 4). In such installation, the geothermal water feeds also the experimental cascade system of a "Geothermal Laboratory of Polish Academy of Sciences" consisting of a wood dryer, greenhouse, foil tunnel (Fig. 5), fish breeding house (Fig. 6) and a swimming-pool. That experimental part of installation enables to conduct investigations on effective utilisation of geothermal energy. The thermal power of operated power plant is about 9 MW_t [5].

Figure 3. Geothermal intake (extraction well) in geothermal plant in Banska

Figure 4. Geothermal heat exchanger in geothermal plant in Banska

Figure 5. Foil tunnel in experimental cascade system of Geothermal Laboratory of PAS

Figure 6. Fish farming in experimental cascade system of Geothermal Laboratory of PAS

In the second half of 90-ties started has been in the Podhale in Bańska Niżna a construction of another thermal system (Fig. 7), where the fundamental source of energy is a new geothermal power plant (Fig. 8, Fig. 9). The task of the system is to fulfil the thermal energy demand of the towns: Zakopane and Nowy Targ, as well as few other smaller villages. The thermal power station co-operates with the extracting well Bańska PGP-1 with the efficiency of 550 m^3/h and the filling well Biały Dunajec PGP-2. Temperature of extracted geothermal water is about 76-

80°C, and its static pressure is equal to 2.7 MPa. At the same time, in 1998 in Zakopane, commissioned has been a modern gas thermal power plant equipped with two water boilers of 10 MW_t power each. These boilers have the economisers of 1 MW_t power each. In the years to come, that power plant will play a role of a peak-time boiler co-operating with the system of a geothermal power plant. At present there are final works underway to connect the geothermal well in Bańska Niżna and a central boiler-house in Zakopane. Constructed transmission district heating is a pioneering task due to a fact that the level difference between the heat source and the recipients placed above is about 260 m. In parallel with these construction works there also are being works conducted on the development of a heat distribution network in Biały Dunajec and Zakopane as well as connection of recipients to that network in both towns. In a further perspective planned are subsequent wellbores as well as further extension of the heat distribution network in the direction of Nowy Targ. In Nowy Targ planned is also construction of a second peak-load thermal power plant. After completion, the installation will be the biggest Polish geothermal installation of total power of 125 MW_t.

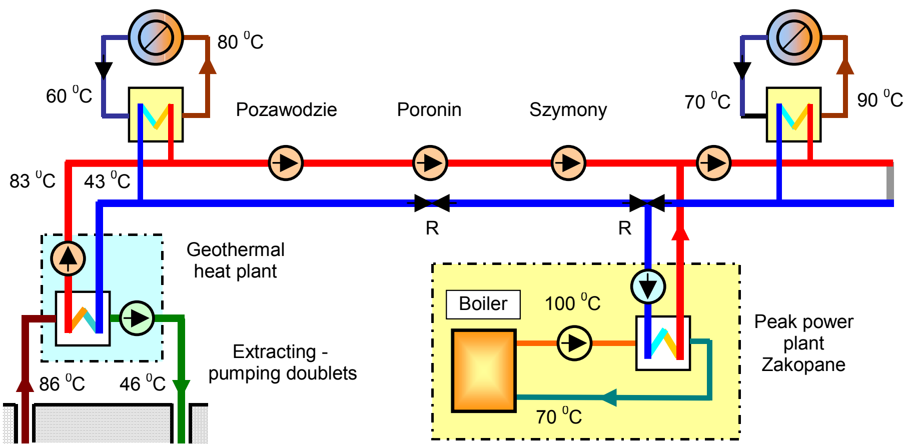

Figure 7. Schematic of Banska Nizna-Zakopane geothermal heating system

Fig. 8. Main building of geothermal heat plant in Banska Nizna

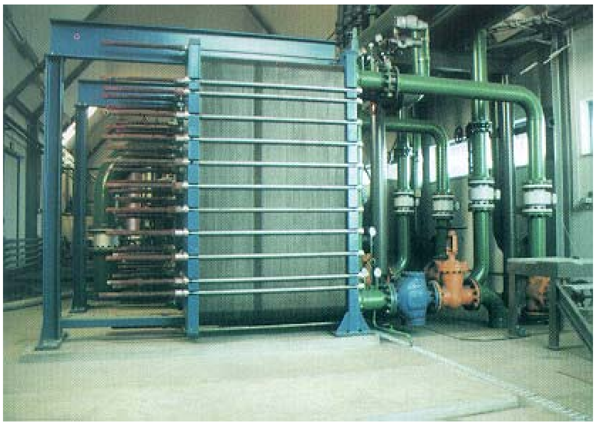

Fig. 9. Geothermal heat exchangers in geothermal heat plant in Banska Nizna

Another, and at the same time the biggest geothermal power plant was built in 1996 in Pyrzyce near Szczecin [6,7]. That investment has been realised in the years 1993-1996 and consisted of a construction of a new source of energy as well as the new heat distribution network and gas feeder main. The total power of that modern gas-geothermal power plant is 50MW_t. It uses one geothermal wellbore for the production of thermal energy with the maximum installed power of

13 MW_t together with peak-load boilers (Fig. 10). For the more effective utilisation of geothermal energy in the system implemented are two absorption heat pumps (Fig. 11). These pumps are fed by a thermal energy from the high-temperature boilers (Fig. 12). Geothermal water is extracted from the depth of about 1500-1650 m, from the rock deposits of earlier Jurassic by means of two doublets. The efficiency of a single wellbore is 170 m^3/h. The fundamental thermal parameters of extracted water are following: temperature 61°C, salinity 120 g/l, density 1,062 kg/m^3 and the heat capacity ~3.7 kJ/kgK at 20°C.

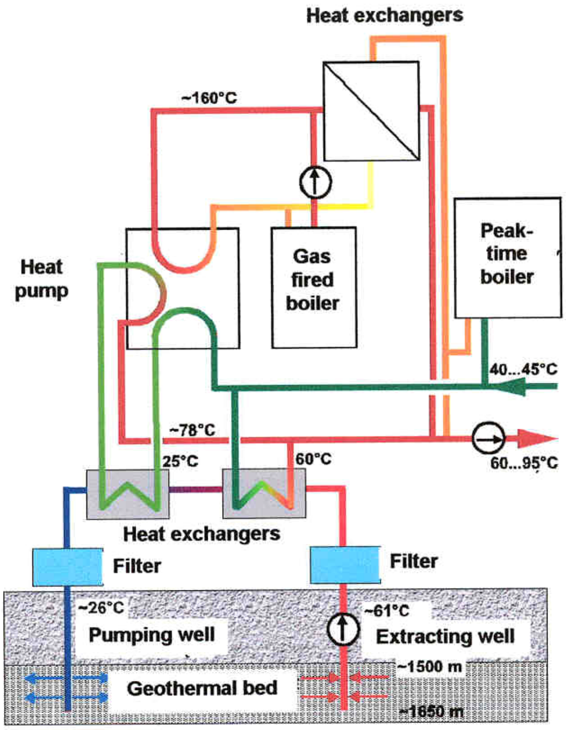

Figure 10. Simplified schematic of Pyrzyce geothermal power plant [6]

Fig. 11. Absorption heat pumps in geothermal heat plant in Pyrzyce

Fig. 12. High and low-temperature gas boilers in geothermal heat plant in Pyrzyce

Geothermal water extracted by means of the borehole pump from the deposit flows through a set of filters and finally reaches geothermal water heat exchangers. In a basic geothermal heat exchanger thermal energy of water is transferred to the municipal water heating it up from 40°C (winter) or 45°C (summer) to 60°C. Preliminarily cooled geothermal water is directed to the

second geothermal heat exchanger, where it is chilled to the temperature of 26°C, and then after flowing through a set of filters it is fed back to the Earth. In the second geothermal heat exchanger, only a part of return municipal water is being heated. That part of return water undergoes chilling first in the evaporators of absorption heat pumps to reach 25°C, and then is heated in the second geothermal heat exchanger to the temperature of 41°C. On the other hand, the stream of municipal water leaving the basic geothermal heat exchanger is joined by the streams of hot water heated in absorbers and condensers of heat pumps, flue gas coolers of high-temperature boilers, flue gas coolers of peak-load boilers. The total flux of heated municipal water flows to the peak-load boilers, where it is further heated to achieve temperature required by the heat recipients. An important element of the thermal power plant installation is the water circuit feeding the desorbers of heat pumps. That water circulates in a closed loop encompassing absorption heat pumps, high-temperature boilers and, if needed, additional heat exchanger.
The third of geothermal power plants has been commissioned in May 2000 in Mszczonów, Mazovia (Fig. 13). Geothermal water with temperature of about 40°C is extracted from the borewell with efficiency of about 60 m^3/h, from the deposit from the level of earlier Cretaceous period (~1600-1700m). Such water is characterised by a very small mineralisation degree of about 0,5 g/l, which enables its utilisation as a drinking water.

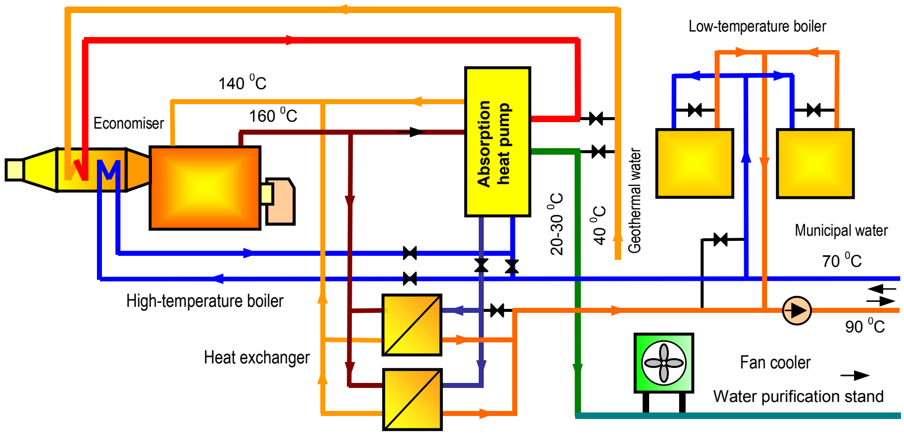

Figure 13. Simplified schematic of Mszczonow geothermal power plant

Figure 14. Geothermal intake (extraction well) in geothermal plant in Mszczonow

Figure 15. Absorption heat pump in geothermal plant in Mszczonow

That is the second in Europe thermal power plant, where the geothermal water is also a drinking water. Water from the geothermal wellbore (Fig. 14) is extracted by a multi-stage borehole pump and pumped to the power plant in the centre of Mszczonów. In the power plant water flows first through the economiser of a high-temperature boiler, where it is heated to the temperature of about 44°C, and then through an absorption heat pump (Fig. 15), where it is chilled to the temperature of about 20–30°C. Cooled in this way geothermal water is directed to the ventilator cooler and then to the nearby water treatment plant. In the water treatment plant, after passing through automatic filters it is mixed with water from the Quaternary period deposit and after subsequent treatment it feeds the municipal network. In order to cover the peak thermal demand in the power plant installed are two gas boilers. The peak power of the entire installation is 12 MW_t.
The next of Polish geothermal power plants has been commissioned in 2001 in Uniejow near Lodz. The plant uses three borewells with the depth of over 2000 metres each (Fig. 16). From the bores water is extracted with the temperature 67-70°C and pressure 0,4 MPa. That water with the mineralisation degree of 6,8-8,8 g/m^3 has interesting therapeutic features.

Figure 16. Geothermal intake (extraction well) in geothermal plant in Uniejow

Figure 17. Pipeline with geothermal water, filters and injection pumps

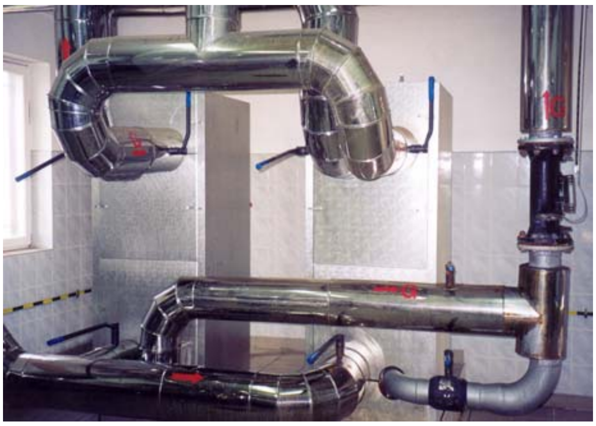

Figure 18. Geothermal heat exchangers in geothermal plant in Uniejow

Figure 19. Gas peak boilers in geothermal plant in Uniejow

A different design of the geothermal power plant operates at Słomniki near Krakow (2002). In that case utilised are low-temperature thermal waters with temperature of +17 ^{0}C, extracted from the depth of 300 metres by means of three extraction wells. Due to rather low temperatures of

extracted geothermal water the thermal plant doe not have a geothermal heat exchanger. Extracted water serves as a lower heat source for compressor heat pumps located in heated objects and the peak-time boiler house. In installation there have been installed total of 13 compressor heat pumps. The peak-time boiler is equipped with three low-temperature water boilers.
After utilisation geothermal water is dumped to the sewage system. The major objective of the installation is heating and preparation of utility hot water in co-operation with existing heat source. The process of buildings' heating in following: in the case of external temperatures above 0 ^{0}C particular objects are heated by means of heat pumps utilising energy of geothermal water. In the case of external temperatures below 0 ^{0}C switched on are peak-time boilers, which have to ensure required temperatures of municipal water supplied to the specific recipients. The thermal power of the geothermal point is estimated to the about ~ 3,5 MW.
Geothermal power plants under operation in Poland differ between themselves with the parameters of geothermal deposits and hence resulting technical solutions. Acquired during their design, construction and operation experiences will enable better and faster implementation of new installations utilising geothermal energy.

4. PLANNING AND DESIGN OF GEOTHERMAL POWER PLANTS

In the near future construction and commissioning of further geothermal power plants is planned (Fig. 1). The most advanced are works in Stargard Szczeciński, where drilling of the first couple of the extraction-feeding doublets takes place. In the previous year the water-bearing level has been attained in the first borehole (Fig. 20). Expected temperatures of geothermal water are estimated at the level of 95-100 °C, with water mineralisation rate close to that of Pyrzyce. According to schedule the entire investment should be completed in December 2004.

Figure 20. Drilling of wells in new building geothermal heat plant in Stargard Szczecinski

Other towns are also interested in construction of geothermal power plants, such as: Cieplice Zdrój, Lądek Zdrój, Konstancin, Ustroń, Iwonicz, Duszniki, Żyrardów, Skierniewice, Koło, Czarnków, Poddębice, Ślesin, Szczecin, Chociwel, Nowogard, Wągrowiec, Kraków, Myślenice, Sucha Beskidzka etc.. [3]. As an example in [2] presented are the design conditions for the gas-geothermal power plant in Koło.
In [3,4,6,7,8] have been presented favourable conditions accompanying implementation of geothermal power plants in Poland.

Table 2. Data of Geothermal Power Plants in Poland

Geothermal heat plant	Year	Temperature of water	Depth of deposit	Minerali-sation	Flow rate	Tot. thermal power
	-	°C	m	g/l	m^3/h	MW_t
Banska – Bialy Dunajec	1994	86	2000-3000	3,0	120	9
Pyrzyce	1996	61	1500-1650	120	2x170	50
Mszczonow	1999	40	1600-1700	0,5	60	12
Uniejow	2001	67-70	~2000	6,8-8,8	68	4,6
Banska Nizna – Bialy Dunajec	2001	76-80	2500	3,0	550	125
Slomniki	2002	17	300	-	-	3,5

At present construction of such plants is economically vital only in towns with a large number of inhabitants and a developed industry, where the recipients guarantee high and continuous reception of thermal energy from the geothermal resources. Existing prognoses foresee that a dynamical development of geothermal power plants in Poland should take place not earlier than 2020-2050 [8].

5. OTHER APPLICATIONS OF GEOTHERMAL ENERGY

The oldest way to utilise geothermal waters was in therapy. In Poland there are seven spas and Zakopane which utilise hot sources for therapeutic purposes [3]. Uniejów plans to join that group of towns in the near future.
It ought to be expected that in the vicinity of the geothermal power plant there will appear also other objects utilising geothermal energy. These can typically be recreational facilities such as: water parks, as well as agricultural and industrial objects – greenhouses, agricultural products dryers, wood dryers, fish breeding ponds, etc. Construction of large and temperature differentiated heat recipients favours larger effectiveness of thermal power plant operation as well as more effective utilisation of geothermal water energy.
On the other hand, the low-temperature energy in the lithosphere can be used by the installations with heat pumps. In such installations the lower temperature source is the soil, where from by means of vertical probes or horizontal collectors the thermal energy is acquired [6,7]. According to Kepińska et al. [3] at the beginning of 2000 in Poland there were about 500 heat pumps under operation with the total power of 5.5 MW_t producing about 62 TJ/a of thermal energy. Presented values must be regarded as estimates due to a lack of accurate evidence of installation under operation.

6. CONCLUSIONS

The assessment of the present state and perspectives for the development of geothermal installations has been undertaken by several authors [2,3,4,5,8,10], who give consistent conclusions. All authors stress that practical utilisation of that kind of renewable energy is at present not justified on the technological, economical and ecological grounds.

- Poland has at its disposal significant resources of geothermal waters with the total volume estimated at about 6600 km^3, however, temperature of these waters is relatively low (30–150°C). Bearing that in mind, such water can only be used for heating purposes and preparation of utility hot water as well as technological and therapeutic applications.
- Results of the analysis of exploitation of hitherto constructed geothermal power plants enabled better technical and economical preparation of subsequent projects, where local conditions as well as actual and future demand for thermal energy have been included. It is recommended that a complex approach to the management of geothermal energy in systems of cascade heat reception is taken.
- In parallel with the construction of geothermal power station necessary is modernisation of existing heat distribution network, heat distribution centres as well as internal networks in buildings.
- Taking into account a large volume of documentation on the resources of geothermal waters as well as existing reports on the possibility of implementation of geothermal waters for several towns in Poland, a conclusion can be drawn that in the near future the number of geothermal power plants will increase significantly.

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