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Analysis of Possibilities for Electricity Production from Geothermal Waters in the Province of Małopolska, Poland

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ABSTRACT

Decisive influence on the efficiency of electricity production and the installed capacity of geothermal power plants are: the temperature of geothermal water and the flow rate of the production well, determined by the physical parameters of the rock formation. Following the examples of some other countries and current state of geothermal uses, the paper shows realistic perspectives to produce electricity in Małopolska province using geothermal waters.

The paper presents the way to recognize possibilities of electricity production (thermal parameters of the ground analysis, installed capacity calculation method) with the use of geothermal waters in the province of Małopolska. The total number of wells in the region (326.8 km^2) is around 6000. To identify perspective areas for electricity production, data form 320 wells with the depth over 2000 m have been taken into account and analyzed. The reason for that were geothermal water resources proved so far in Poland (including Malopolska province) with the temperatures not exceeding 90–120^{0}C at the depth over 3000 m.

The energy conversion method taken to the analysis was Organic Rankine Cycle as a basic and most suitable method for electricity production from low temperatures geothermal waters. Calculations present in the paper lead to the conclusion that there are realistic perspectives to produce, in cogeneration, heat and electricity from geothermal waters in the Malopolska province, however the install capacity of power plants will not exceed 2 MW.

1. INTRODUCTION

Małopolska province with a total area of 15 183 km^2, represents 5% of the Poland. Province is located in the southern part of Poland, bordering the provinces: Świętokrzyskie (from the north), Subcarpathian (east), Silesia (west). From the south province borders with Slovakia. The area is inhabited by approximately 3 298 000 people and urbanized at 49.3%. Kraków is the capital of the province, covering an area of 326.8 km^2 and a population of approximately 755 000 people (www.malopolska.pl).

From a geological point of view, Małopolska province covers its surface the Miechow Basin, the Carpathian Foredeep, The Silesian-Cracow Monocline, the Upper Silesian Coal Basin and the Western Carpathians (cover more than 60% of the region) (fig. 1). Topography is a highlands (over 50% of the area is located more than 500 m above sea level) which is the result of geological processes (Barbacki, 2006). In the area there are 6 national parks, 11 landscape parks, 10 protected landscape areas and 84 nature reserves. There are two catchment: the Baltic Sea (the basin of the Vistula – 90% of the area) and the Black Sea (the basin of the Danube).

Figure 1: Map of the study area including tectonic units in Poland

Approved supplies of groundwater resources in the province of Małopolska is approximately 50 000 m^3/h. The most abundant water reservoir are quaternary (Triassic, Upper Jurassic, Upper Cretaceous) and Tertiary (Miocene) (Barbacki, 2006). The most promising region due to the operating systems that use geothermal water, is the area of the Podhale.

2. RESULTS OF THE GEOLOGICAL INTERPRETATION

The total number of wells in the region (326.8 km^2) is around 6000. To identify perspective areas for electricity production, data form 320 wells with the depth over 2000 m have been taken into account and analyzed. Analysis of the thermal data obtained from boreholes located in the province of Małopolska showed that the most promising area in terms of the production of electricity using geothermal waters is Podhale. Table 1 summarizes the temperature and performance of the boreholes over the depth of 2000 m, in this area.

The analysis of the temperature distribution with depth indicates although the presence of relatively high temperature anomalies outside the Podhale region, such as Jaszczurowa (Potrójna IG-1), Łętownia (Jordanów IG-1), Podole-Górowa (Siekierczyna IG-1), Krzywaczka (Głogoczów IG-1), Łękawica (Zawada 8K), Wiśniowa (Wiśniowa 1), Machowa (Pogórska Wola 15). However, these areas require further analysis for the presence of geothermal water deposits, potential flow rate of production wells and chemical composition of geothermal waters.

Tab. 1. The parameters of geothermal waters exploited in the Podhale region

Borehole	Depth [m]	Reservoir	Temperature in the reservoir [^{0}C]	Temperature on the surface [^{0}C]	Flow rate [kg/s]	TDS [g/dm^3]
Bańska PGP-1	2731-3240	Nummulite Eocen, Triassic	89	85	130.55	3.12
Bańska IG-1	2565-2656	Nummulite Eocen	88	82	20.27	2.69
Bańska PGP-3	c.a. 3200	Nummulite Eocen, Triassic	c.a. 89	c.a. 85	c.a. 55	<3
Białka Tatrzańska GT-1	c.a. 2500	Nummulite Eocen, Triassic	82	73	10.55	1.786
Biały Dunajec PAN-1	2117-2394	Nummulite Eocen, Triassic	88	82	55.55	2.62
Biały Dunajec PGP-2	2083-2450	Nummulite Eocen, Triassic	88	85	111.11	2,7
Bukowina Tatrzańska PIG-1	2390-2605	Triassic	74	67	11.11	1.49
Chochołów PIG-1	3218-3572	Triassic	93	82	52.77	1.24
Furmanowa PIG-1	2003-2324	Jurassic	68	60.5	25	0.58

From the listed in table 1 potential wells for the electricity production, the most perspective ones are: Bańska PGP-1, Bańska IG-1, Bańska PGP-1, Biały Dunajec PAN-1, Biały Dunajec PGP-2 and Chochołów IG-1. The decisive criterion was the geothermal waters temperature at the outlet. All of these boreholes are used currently to production or injection (Biały Dunajec PAN-1, Biały Dunajec PGP-2) of geothermal waters. For further analysis took into account only production wells.

3. PERSPECTIVE AREA – PODHALE BASIN

As the most forward-looking, in terms of electricity production, structure should be considered Podhale Basin belonging to the Innner Carpathians, quite different from the Outer Carpathians representing the northern part of the province of Małopolska. Podhale Basin is an asymmetric area (width of several kilometers), being a part of the Central-Carpathian Paleogene Basin.

Podhale Basin reservoir deposits are Triassic limestones and dolomites, Jurassic sandstones and carbonate rocks and Nummulitic Eocen carbonates. The main reservoir of geothermal waters formed Middlie Traissic limestones and dolomites, Jurassic sandstones and Middle Eocene carbonates (top).

Recharge area and the southern border of the Podhale Basin are the Tatra Mountains, impermeable barrier is the Pieniny Klippen Belt which is also the northern boundary of the basin, and an insulating cover is the Podhale Flysch (fig. 2). The eastern border of the Podhale Basin is the Rużbachów Fault, and the western – the Krowiarki Fault (Kępińska, 2006).

Reservoir sealing of the Podhale Basin forms: nummulitic eocen deposits with thickness of 300-320 m, represented by conglomerates, sandstones and dolomitic limestones situated at the top, with thickness up to 30 m (Oszczypko, 2011). The most important from the point of view of the occurrence of geothermal reservoirs is the Podhale Flysch 2500–3000 m thick, occurring over Nummulitic Eocen, which consists of Oligocene layers: Szaflary Fm., Zakopane Fm., Chochołów Fm. and Late Oligocene-Early Miocen Ostrysz layer.

The temperature of the geothermal waters at the depth of 2–3.2 km is about 80-95^{0}C (temperature of geothermal waters increases with depth to the north of the infiltration area, which are the Tatra Mountains), the flow rate of production wells is 50–550 m^3/h with static wellhead artesian pressure up to 2.9 MPa. Total dissolved solids (TDS) in the area does not exceed 3 g/dm^3. In this study, the effect of TDS on the ability to produce electricity has been treated as negligible, with no impact on the operation of the system.

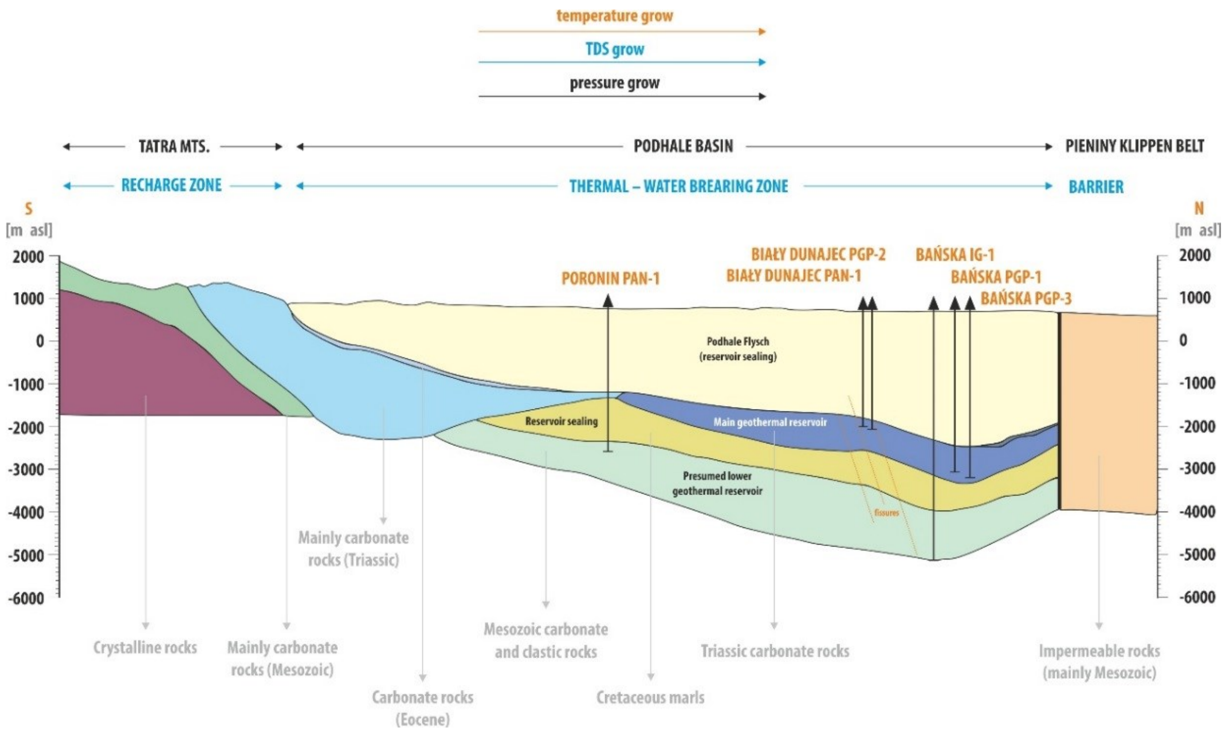

Fig. 2. A conceptual model of artesian hydrogeothermal system Tatra Mountains-Podhale (based on Wieczorek, 2011, modified)

4. THERMODYNAMICS CALCULATION ASSUPTION

The main factors affecting the efficiency of the ORC geothermal power plant are: the geothermal water temperature at the outlet, the flow rate of geothermal water and its mineralization, the choice of the organic working fluid and its condensing parameters (DiPippo, 2012). For the purposes of this paper, the thermodynamic analysis were obtained to the boreholes: Bańska PGP-1, Bańska IG -1, Bańska PGP -3 and Chochołów PGP-1. Calculations were performed for subcritical Organic Rankine Cycle with the working fluids R245fa and R600a. Alternative solution – Kalina Cycle has been rejected by the author as the use of this solution in Polish conditions (not only) is complicated because the working fluid, which is ammonia, is flammable and toxic. To be precise, the circulation in which it is used is a closed circuit, however the process of filling the system or leaks requires constant monitoring and specific security measures. Another issue that precludes discussion in this paper on the application of the Kalina Cycle, is the possession of a license to implement this type of solution by one company – Kalina Cycle®, which together with the ubiquity and ease of use of the ORC, indicating the validity of the decision. The number of geothermal power plants operating in the world in 2011, based on the Kalina Cycle – 3, and 75 geothermal power plants based on ORC, confirm that decision (Kaczmarczyk, 2011).

It was assumed that the ORC processes correspond to the Clausius-Rankine Cycle: isobaric heating in preheater (4s–5) and evaporation of the working fluid in evaporator (5–1), isentropic expansion of the refrigerant vapor in a turbine (1–2s), isobaric discharge heat which occurs during cooling (2s–2), working fluid condensation (2–3) and an isentropic condensate pumping (3–4s).

It was also assumed that:

• the temperature difference at the inlet and outlet of the evaporator is constant for all production wells and working fluids, dT = 20^{0}C

• condensing temperature is equal for all production wells and working fluids, 30^{0}C

• efficiency of the turbine is: inner efficiency η_i = 0.70, mechanical efficiency η_m = 0.98 and electrical efficiency of the generator η_g = 0.95 (Szargut, 1998)

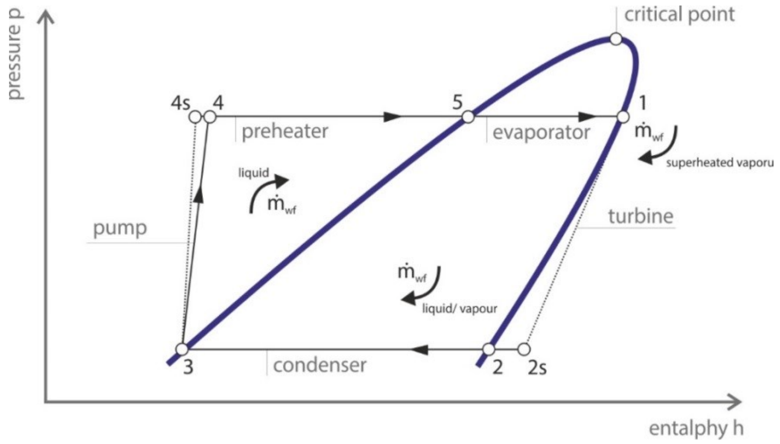

Fig. 3. Cycle of thermodynamic processes

Basic equations of the calculation scheme for the estimation of potential installed capacity of the power plant ORC are defined by the formulas:

$$\dot{W}_{net} = \dot{m}_{wf}(h_1 - h_4)\eta_{el} \quad [1]$$

The efficiency of the ORC cycle was calculated from the equations:

$$\eta_{CR} = 1 - \frac{h_2 - h_3}{h_1 - h_4} \quad [2]$$

$$\eta_{el} = \eta_{CR}\, \eta_i\, \eta_m\, \eta_g \quad [3]$$

The paper aims to present, in theoretical way, the perspectives of the use of geothermal waters of the Małopolska province to produce electricity. Designing of the potential ORC geothermal power plant in Poland needs careful analysis of the heat transfer coefficient at the experimental level, in order to minimize the risk of error in the working fluid selection.

5. THERMODYNAMICS CALCULATION RESULTS

Calculations of potential installed capacity of geothermal ORC power plant were made for the four production wells: Bańska PGP-1, Bańska IG-1, Bańska PGP-3 and Chochołów IG-1 (tab. 2). The results obtained from the calculation show the potential installed capacity for maximum possible flow rate and for the flow rates in the ranges: Bańska PGP-1 (10–120 kg /s), Bańska IG-1 (10–20 kg/s), Bańska PGP-3 (10–50 kg/s) and Chochołów IG-1 (10–50 kg/s). Distribution of installed capacity potential due to the geothermal water flow directed to the evaporator, due that all boreholes taken into account are in operation. In the case of boreholes Bańska PGP-1, Bańska IG-1, Bańska PGP-3 they are used for obtaining geothermal energy for heating purposes, while in the case of the borehole Chochołów IG-1, for recreational purposes. The aim of the paper was to perform additional calculations indicate the possibility of the production of electricity by directing a part of the geothermal water stream to the ORC power plant, without changing its original application.

Tab. 2. Calculation results

Working fluid	Flow rate [kg/s]	Potential instaled capacity [kW]			
		Bańska PGP-1	Bańska IG-1	Bańska PGP-3	Chochołów IG-1
R245fa	Maximum	130.55 [kg/s]	20.27 [kg/s]	55.55 [kg/s]	52.77 [kg/s]
		1915.59 [kW]	277.87 [kW]	815.10 [kW]	723.40 [kW]
	10	146.73	137.09	146.73	137.09
	20	293.46	274.17	293.46	274.17
	30	440.20	-	440.20	411.26
	40	586.93	-	586.93	548.34
	50	733.66	-	733.66	685.43
	60	880.39	-	-	-
	70	1027.13	-	-	-
	80	1173.86	-	-	-
	90	1320.59	-	-	-
	100	1467.32	-	-	-
	110	1614.06	-	-	-
	120	1760.79	-	-	-

R600a	Maximum	130.55 [kg/s]	20.27 [kg/s]	55.55 [kg/s]	52.77 [kg/s]
		1286.78 [kW]	190.14 [kW]	547.54 [kW]	494.99 [kW]
	10	98.57	93.80	98.57	93.80
	20	197.13	187.60	197.13	187.60
	30	295.70	-	295.70	281.41
	40	394.27	-	394.27	375.21
	50	492.83	-	492.83	469.01
	60	591.40	-	-	-
	70	689.96	-	-	-
	80	788.53	-	-	-
	90	887.10	-	-	-
	100	985.66	-	-	-
	110	1084.23	-	-	-
	120	1182.80	-	-	-

The results indicate that the greatest potential to produce electricity has a geothermal well Bańska PGP-1 (1915.59 kW). The reason is the high flow rate of a production well, which directly affects the size of the installed capacity. Understandably, the lowest values were obtained for the Bańska IG-1, due to the smallest flow rate 20.27 [kg/s] and the temperature of geothermal water at the outlet 82^{0}C.

Significantly higher values were obtained using the working fluid R245fa, for which a potential installed capacity for the maximum flow rate of geothermal water is 628.81 [kW] for the Bańska PGP -1, 87.73 [kW] for the Bańska IG-1, 267.56 [kW] for the Bańska PGP-1 and 228.41 for the Chochołów IG-1.

Interesting from the point of utilization of geothermal energy for electricity production can be two cases. First, in the case of Bańska PGP-1, the use of e.g. 30 [kg/s] of geothermal water to produce electricity will result in 440.2 [kW] of installed capacity. The second case – Chochołów IG-1 is interesting because of the use of geothermal water only for recreational purposes, where required geothermal water temperature at heat exchanger may be equal or lower than 62^{0}C (assumed temperature of geothermal water after the ORC evaporator) without negative impact on recreational use. Installed capacity achievable in Chochołów can be 723.4 [kW].

6. CONCLUSIONS

The energy conversion method taken to the analysis was Organic Rankine Cycle as a basic and most suitable method for electricity production from low temperatures geothermal waters. Calculations presented in the paper lead to the conclusion that there are realistic perspectives to produce, in cogeneration, heat and electricity from geothermal waters in the Małopolska province, however the install capacity of power plants will not exceed 2 MW. The most perspective area in Małopolska province is Podhale Basin with production wells in operation: Bańska PGP-1, Bańska IG-1, Bańska PGP-3 with potential of installed capacity respectively: 1915,59,81 [kW], 277,87 [kW], and 815,10 [kW]. It's important that the paper aims to present, in theoretical way, the perspective of the use of geothermal waters of the Małopolska province to produce electricity. Designing of the potential ORC geothermal power plant in Poland needs careful analysis of the heat transfer coefficient at the experimental level, in order to minimize the risk of error in the working fluid selection.

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