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The Polish Experience in Utilization of Abandoned Oil and Gas Wells for Geothermal Purposes

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ABSTRACT

Geothermal energy, as an ecological and sustainable source of energy, is an excellent alternative to fossil fuels in the context of generation of heat and electricity. In Poland, geothermal resources have been used since the 90s of the last century. So far, six geothermal heating plants, a few recreation and balneological centers have been operated. Generally, the utilization of geothermal energy is possible mainly due to the deep boreholes, either brand-new ones dedicated for geothermal extraction or old, petroleum wells adapted to geothermal purposes. However, Polish geothermal energy sector is based primarily on new geothermal wells, there is also the Mszczonów IG-1 well that underwent the successful revitalization process and for around 20 years has been working for geoDistrict Heating Plant. It is worth mentioning that tremendous but unexploited potential resides in the possibility of utilization of petroleum boreholes located within oilfields such as the Carpathian Foredeep Province and others. Currently, the positive changes in the domestic legislation and opportunity of obtaining a financial support for a geothermal investment bring the intensified investments in drilling of new geothermal boreholes. Nonetheless, there is a prospect for the future development of utilization of old petroleum wells, as it might become economically and ecologically justified under Polish circumstances. Thus, the paper presents Polish experience in utilization of abandoned oil and gas wells for geothermal energy extraction with a special emphasis on technical aspects.

1. INTRODUCTION

Geothermal energy is a renewable source of energy endowed with considerable energetic potential considering both its availability fairly all over the globe as well as low impact on the natural environment. It can be harnessed to provide thermal energy and to generate electricity, thus it finds applications in several economic sectors including district heating, agriculture, recreation and healing purposes (Lund and Boyd 2016, Bertani 2016). Exploitation of geothermal resources is possible due to the deep hole drilling or utilization of Heat Pump technology (shallow geothermic). Obviously, drilling brand new geothermal wells requires extensive designing phase and entails high investment cost. That is why the adaptation of existing wells after the exploitation of hydrocarbons for geothermal purposes remains a highly desirable solution, worldwide. As evidenced by several studies, the re-adaptation of abandoned petroleum wells and negative exploratory wells not only diminishes investments costs (Bu et al. 2012) rendering a geothermal project economically justified but also limits possible environmental hazards (Thiessen and Achari 2016). So far, due to the depletion or limitation of oil and gas resources many petroleum boreholes have been abandoned and/or liquidated. Its number all around the globe have reached 30 million (Caulk and Tomac 2017, Nian and Cheng 2018a). What is more, a few of them are located within the areas characterized by favorable geothermal parameters, such as geothermal gradient, heat flux and have been transformed (or are to be) into geothermal wells. In many countries, projects aimed at the re-adaptation of petroleum boreholes in order to obtain geothermal energy (hydrothermal resources) in open-loop systems have been completed or are currently in progress. One can list among others: Albania, China, Croatia, Israel, New Zealand, Poland, Hungary or even United States (Templeton et al. 2014). What is more, the subject of re-utilization of old petroleum wells is still an outstanding trend in the international researchers. Scientists have considered various concepts for obtaining thermal energy (Bu et al. 2012, Templeton et al. 2014, Nian and Cheng 2018b) and electricity generation (Davis and Michaelides 2009, Cheng et al. 2013, Wight and Bennett 2015), depending on the regional thermal parameters. They focuses primarily on the idea of implementation Borehole Heat Exchangers (BHEs) in variable configurations.

Since, the topic of re-use of oil and gas boreholes is extremely important and constitutes an alternative solution for the coal-based energy sector, the current state and Polish perspectives regarding the implementation of this technology were analyzed. Therefore, this paper focuses on the experience on the utilization of abandoned petroleum boreholes and old exploratory wells gained in Poland in recent years.

2. GEOTHERMAL FIELDS IN POLAND

Geothermal energy resources in Poland are related to the underground waters of various stratigraphic layers (thereby various depths), within geological units – main geothermal provinces, namely, the Polish Lowlands, the Carpathians, the Carpathian Foredeep and the Sudetes (Fig.1). They are natural sedimentary-structural basins filled with geothermal waters with relatively high temperature range, namely, from 20°C to even 100°C (low-temperature hydrothermal resources) (Kępińska 2018). Generally, the water flowrates (from a single well) vary from several to around 150 dm^3/s, whereas the total dissolved solids (TDS) of thermal waters differ from 0.4 g/dm^3 to as many as 300 g/dm^3, depending on the province. As geological conditions of geothermal resources in Poland have been analyzed since the 80s of last century, geothermal waters have already found applications mainly in heating (six geoDistricts Heating Plants), balneotherapy and recreation sectors, as well as agriculture, aquaculture and various industrial applications (Figure 1) (Górecki et al. 2015, Miecznik et al. 2015, Bujakowski et al. 2016, Sowiżdżał and Kaczmarczyk 2016). Nevertheless, the recognition of geological structures either for direct or indirect applications of the geothermal energy is still an important direction of proceeded geological researches (Wójciki et al. 2013, Bujakowski and Tomaszewska 2014, Kaczmarczyk 2017, Kępińska 2018).

Figure 1: Geothermal provinces and installations in Poland in 2018; modified after (Sowiżdżał, 2018).

The most prospective regions for a geothermal energy development in Poland are connected with areas characterized by a high value of heat flux and appropriate hydrogeological parameters, and are ascribed to the Polish Lowlands and the Podhale region, i.e. the Carpathian Geothermal Province (Sowiżdżał, 2018). The Polish Lowlands (Figure 1) is the largest geothermal field in the country (about 87%) and it is characterized by the geothermal gradient varying from 2-3°C/100m. The highest capacity for a single well is 300 m^3/h, whereas the TDS of thermal waters amounts even to 300 g/dm^3.The principal resources of geothermal waters within the relevant field are accumulated in the Mesozoic groundwater horizons. They are accumulated predominantly in the Lower Jurassic and Lower Cretaceous formations but also significant resources are assembled in the Upper Jurassic, Middle Jurassic, Upper Triassic and Lower Triassic formations (Górecki et al., 2015). The second out of geothermal areas in Poland is the Podhale region (Figure 1). There, the geothermal waters' resources are connected to the Mesozoic sedimentary formations. mostly within the Middle Triassic limestones and dolomites, as well as in overlying Eocene carbonates (Sowiżdżał, 2018). The boreholes are from 2 to 3.2 km deep with maximum temperatures of reservoir between 90-95°C, and the (artesian) flow rates varies from several to even 500 m^3/h for a single well. The TDSs of thermal waters are measured as 0.1-3.2 g/dm^3. Then, the Fore-Carpathian Geothermal Province (Figure 1) is characterized by low discharges (only several m^3/h) of single wells in vast majority of aquifers, except from the Cenomanian reservoir (sandstones). In this case, the water capacity is expected to reach even 250 m^3/h and the temperature of geothermal waters between 30 and 100°C (Sowiżdżał, 2018). The TDS rises from the East to the West of the province, presenting values from 1-150 g/dm^3. Thereby, the Fore-Carpathian Geothermal Province is less prospective in the context of possible utilization in district heating but might find successful applications in recreation and/or balneotherapy. Last but not least – the Sudetes Geothermal Province (Figure 1) differs from the aforementioned fields, as geothermal waters occur only within the crystalline formations. The temperature of geothermal waters varies between 20 and 87°C, whereas, the average well capacity is about 10 m^3/h. Thus, this geothermal field is rather insignificant for a space heating sector, but has an important application in curing and therapeutic issues (Kępińska 2016, 2018).

3. OIL AND GAS PROVINCES IN POLAND

Poland has a long established history of petroleum industry dating back to the Middle Ages (the 16th century), when the bitumen permeates occurring on the slopes of the Flysch Carpathians were quite extensively exploited. Nevertheless, the first commercially organized modern oil well was drilled in 1854 in Bóbrka Village (Carpathian Petroleum Province). Nowadays, one can distinguish five petroleum provinces that are subsequently (PGI-NRI 2019): the Carpathians, Wielkopolska, Lublin, Pomerania and Gdańsk, as well as Lower Paleozoic Shale Gas and Oil Belt (Figure 2).

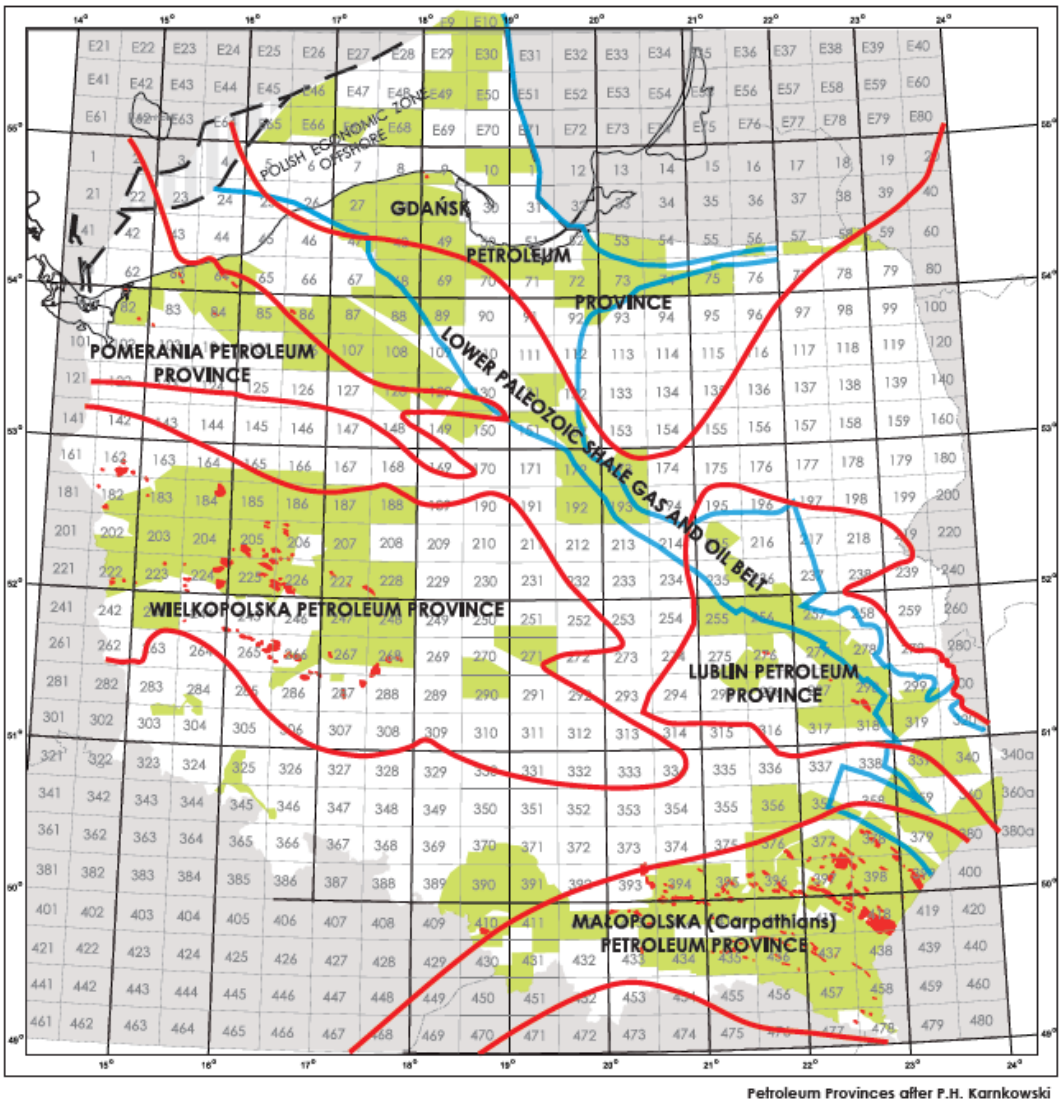

Figure 2: Petroleum provinces in Poland (PGI-NRI 2019).

Geologically, the Carpathian (known also as Maloplska) Petroleum Province occupies the area filled with sediments left from several sedimentary basins: Paleozoic, Mesozoic, Carpathian (the Carpathain Mountains), Fore-Carpathian (the Miocene of the Carpathian Foredeep) (PGI-NRI 2019). In turn, the Wielkopolska Petroleum Province covers mainly the southern part of the Permian Polish basin with two exploratory levels – the Rotliegend and the Zechstein. The Lublin Oil Province is the remnant of the Devonian-Carboniferous sedimentary basin in the Lublin region. Then, the Pomeranian Petroleum Province occupies part of the Devonian-Carbonate sedimentary basin and the Permian Basin (the Rotliegend and the Zechstein). In turn, the Gdańsk Oil Province is the residue of the central part of the early Paleozoic Baltic Basin. In this case, the greatest research successes so far are ascribed to the Baltic shelf in the Polish Economic Zone (Petrobaltic). In the land part of this province, there is no deposits of an economic value (PGI-NRI 2019).

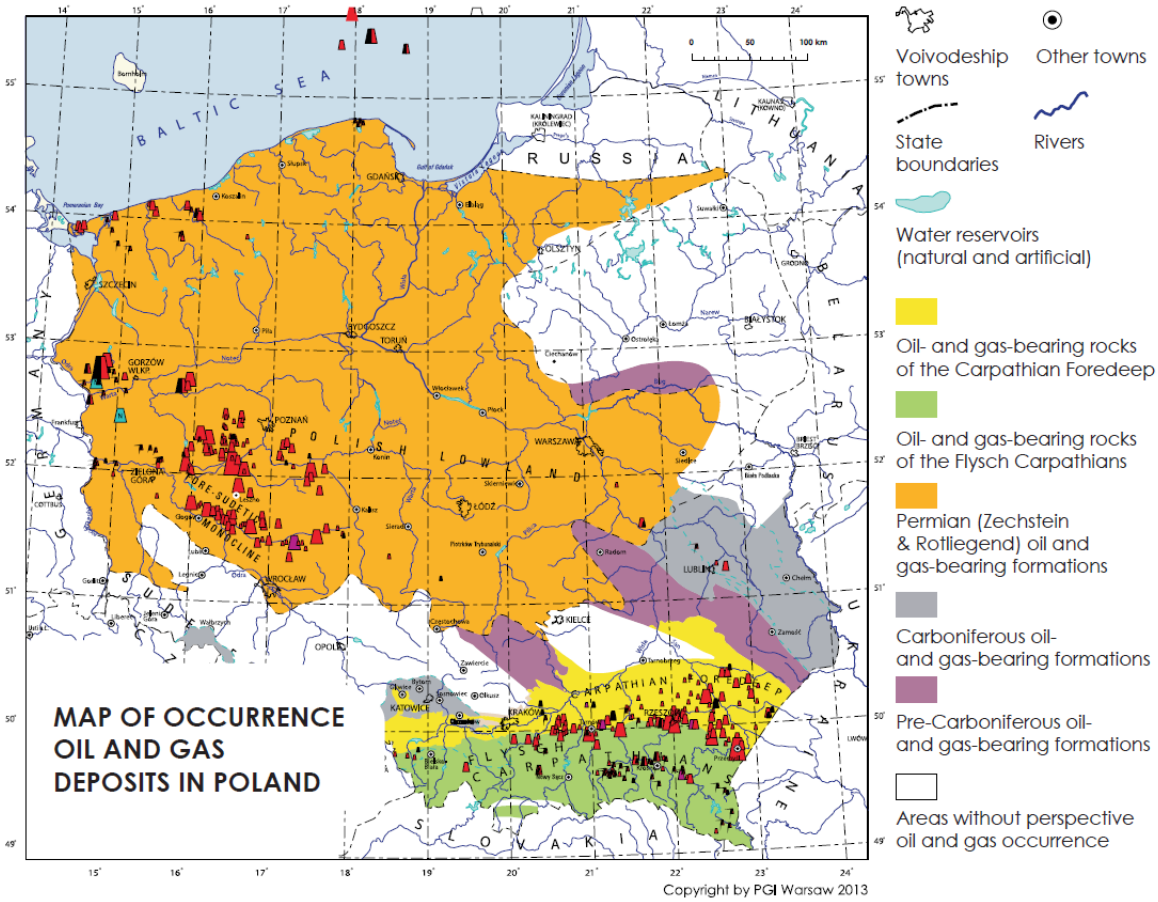

Figure 3: The occurrence of oil and gas deposits in Poland (PGI-NRI 2019).

Within these areas, summarily more than 8,000 boreholes deeper than 1,000 meters and more than 150,000 wells up to 500 meters deep exist (Figure 3), either operating, abandoned (or liquidated) or negative exploratory (PGI-NRI 2019). Moreover, the vast majority of oil&gas wells are located within two petroleum provinces, namely, the Carpathians and the Wielkopolska. It can be easily noted that these aforementioned regions correspond with relevant geothermal provinces that are: the Carpathians and the Carpathian Foredeep as well as the Polish Lowlands, respectively (Figure 1). Hence, those petroleum wells are located within areas characterized by a more or less prospective geothermal parameters and are possible to be used for various geothermal applications.

4. PETROLEUM WELLS IN THE GEOTHERMAL ENERGY SECTOR

Currently, six geothermal district heating plants are operating in Poland: Podhale region (Bańska) and municipalities of Pyrzyce, Mszczonów, Poddębice, Uniejów and Stargard Szczeciński (Kępińska 2016, 2018). Heating plants acquire geothermal water using deep wells – five of them work on the basis of production-injection systems (geothermal doublets) and one, Mszczonów, uses single-well production system. Moreover, 17 recreation centers are located within the country, where geothermal water is used both for swimming pools and other facilities as well as for preparation of hot domestic water. Geothermal water is also utilized in 12 health resorts for curing and rehabilitation purposes (Kępińska 2018). In total, it gives over thirty operating geothermal boreholes (CBDG 2019a). The vast majority of aforementioned wells was done directly for geothermal purposes, nevertheless, two of them are re-adapted exploratory/petroleum wells – the Mszczonów IG-1 and Poręba Wielka IG-1

4.1 The Mszczonów IG-1 Well

The Mszczonów IG-1 well was drilled in 1976/1977 to the depth of 4,119 m, for leading geostructural research in Mszczonów (Bielec and Balcer 2015). The town of Mszczonów is located in central Poland, in the Masovian Voivodeship, within geological structure of the Polish Lowlands (Figure 1). The well was operated by the Polish Geological Institute (formerly the Institute of Geology), and after the planned tests were carried , it was liquidated to a state that preclude the visual localization (Bujakowski (Ed.) 2000, Bujakowski 2015). After the total reconstruction that took place in the period from 1996 to 2000, the well was designed to produce thermal waters for the geoDistrict Heating Plant in Mszczonów. It was the first total reconstruction of old, liquidated well aimed at the well's adaptation for geothermal purposes in Poland (Bujakowski 2015). In terms of reconstruction, technical works as well as field tests were completed. The technical work included drilling, well protection issues, access to the reservoir, installations and operating equipment, whereas, tests concerned pumping (scrubbing, metering, pre-exploitative), hydrodynamic, geophysical, mineralogical-petrographic, physico-chemical and isotopic studies (Bujakowski (Ed.) 2000). The drilling contributed due to reconstruction of the Mszczonów IG-1 well (Figure 5) had the following course (Bujakowski 2015): (1) drilling of cement plugs throughout the interval 0-1,612 m bgl (i.e. below ground level); (2) milling in the interval 59.6-60.3 m bgl; (3) well rinsing throughout the interval 0-1,793 m bgl; (4) replacement of drilling mud into water; (5) running the casing-collar locator (CCL) to the depth of 200 m; (6) replenishment of piping ø 9 5/8" (interval 0-23.6 m bgl). This completed work allowed the use of the Mszczonów IG-1 well

for the exploration of geothermal waters. Through the perforation of casing pipes ø 9 5/8" at two intervals (1,602.5-1,645.5 m bgl and 1,663.5-1,714.0 m bgl), the Lower Cretaceous (sandstones) level of thermal waters was made available (Bujakowski (Ed.) 2000).

Since 2000, the Mszczonów IG-1 well works incessantly and failure-free in the single-well operation system. Exploited thermal water is being used for space heating (temperature 42°C) and drinking (type HCO_3-Cl-Na-Ca; mineralization <0.5 g/dm^3) purposes (Bujakowski 2015) . The formation pressure is approximate to the hydrostatic and amounts to 10^3 hPa (CBDG 2019b). Due to the subartesian conditions, the exploitation is possible only with using downhole pump. The concession for the exploitation of thermal waters is held by the Geotermia Mazowiecka SA, for the period from 2003 to 2028 (Felter et al. 2017). Moreover, the continuous monitoring of reservoir (i.e. exploitive parameters, a technical condition of the well, etc.) is being held (Bielec and Balcer 2015).

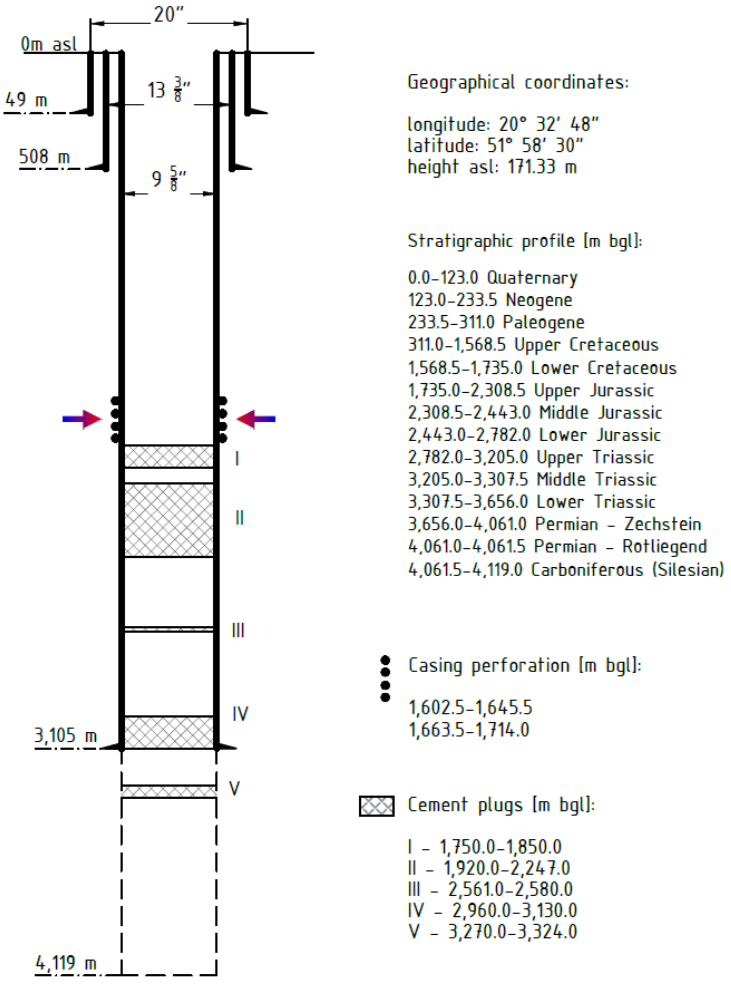

Figure 5: The schematic design of Mszczonów IG-1 well; based on (Bujakowski, 2015).

4.2 The Poręba Wielka IG-1 Well

The exploratory well Poręba Wielka IG-1 (Figure 6) was drilled in 1975 in the village Poręba Wielka, in Niedźwiedź borough, in Lesserpoland Voivodship (Outer Carpathians) (Figure 1). It is 2,002 m deep (CBDG 2019b). During the drilling work, at the depth of 1,798 m bgl (i.e. Paleocene Sandstones), geothermal waters with a temperature of 42°C (type Cl-HCO_3-Na+I) were discovered. The measured capacity was set as 12.1 m^3/h and the mineralization of water was equaled to 24 g/dm^3 (Felter et al., 2017). Nevertheless, due to the planned utilization of the well for geothermal purposes (probably recreation), the hydrogeological research was carried out once again, then exploitation resources were determined at 16.1 m^3/h (Felter et al. 2017). The concession for the exploitation of thermal waters is held by the company Gorczańskie Wody Termalne, for the period from 2013 to 2035. Nonetheless, the well has not been operated yet (Felter et al., 2017).

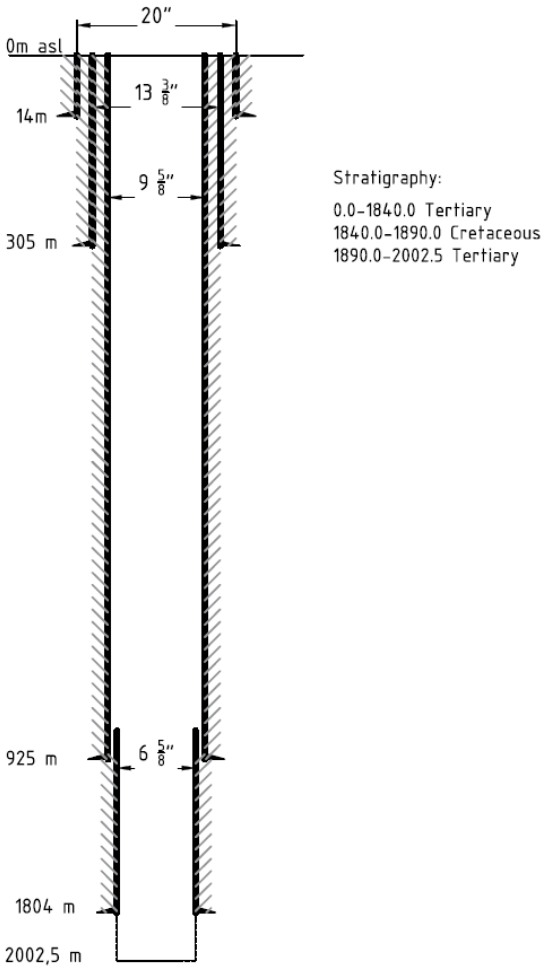

Figure 6: The schematic design of Poręba Wielka IG-1 well; based on (CBDG 2019b).

CONCLUSION

As a renewable source of energy, geothermal energy is endowed with considerable energetic potential. Due to the low impact on the natural environment and ability to be extracted from fairly all over the globe it is consider as a prospective and reliable source of energy. The most common way to access and extract geothermal resources is to drill deep boreholes that is either expensive and demanding an extensive planning. However there is a possibility to use existing petroleum wells - research, exploratory and/or exploitative ones. Currently, this is one out of the main directions for the development of the global geothermal energy sector. The conducted research is concentrated on the implementation of technology that might enable efficient and economically justified acquisition of electricity and heat, in a manner consistent with strict environmental requirements and energy policy.

In Poland, geothermal resources have been used since the 90s of the last century. Several geothermal district heating plants, recreation and balneological centers have been operated mainly in the central Poland (the Polish Lowlands) and the Podhale region (the Carpathians). The vast majority of geothermal systems in Poland constitutes boreholes dedicated directly for geothermal purposes. Nevertheless, there is one geoDistrict Heating Plant, namely Mszczonów, that is based on the old research well. The failure-free operation of the aforementioned geoDH Plant (and Mszczonów IG-1 well) for nearly 20 years indicates that the re-use of petroleum wells is not only possible, but with appropriate thermal conditions also effective in terms of energy, economy and environment. The Poręba Wielka IG-1 is the second well that has gone through the successful reconstruction process, nonetheless, it has not been operated yet.

Currently, financial support programs for geothermal energy in Poland are aimed at drilling new boreholes dedicated for geothermal purposes. It is therefore the most popular and dynamically developing area of the geothermal energy sector. Nevertheless, as the greatest financial burden (around 70%) of any geothermal project is the cost associated with the drilling stage, the re-use of existing petroleum wellbores can significantly reduce investment costs (even up to 50%), making it economically viable. What is more, in Poland, summarily more than 8,000 boreholes deeper than 1,000 meters and about 150,000 wells up to 500 meters deep exist. They are either operating, abandoned/liquidated or negative exploratory wells that are often placed within the areas of prospective geothermal parameters (i.e. within the main geothermal fields). This fact enables them to be re-used for different geothermal purposes, which may vary depending on the location of selected petroleum boreholes within given geothermal provinces.

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