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Use of Oil Boreholes in the Carpathians in Geoenergetic Systems: Historical and Conceptual Review

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ABSTRACT

Past, present and possible future uses of oil boreholes in the Carpathians in Poland are examined from the perspective of geoenergetic systems. To start, a brief historical review is presented of oil wells in the Carpathians, which was one of the first areas in the world where oil extraction began. Numerous boreholes were drilled and many are now located in urban areas. Oil and gas resources are no longer extracted and the wells need to be closed according to Polish law. This need has led to considerations of converting the wells into borehole heat exchangers. This idea would allow the old Carpathian wells to be used for heating or cooling with the assistance of heat pumps, contributing a new option for solving present energy and environmental problems.

Key words: Abandoned well, borehole heat exchanger, oil well, Carpathians, orphan borehole, geoenergetic

INTRODUCTION

Oil has been used since ancient times. It was collected from natural seepages and used for lighting, tarring ships and building roads. Oil mining rapidly started to develop in the second half of the 19th century, with the first oil well drilled in 1859 in the state of Pennsylvania, USA. A few years later, oil fields in Russia, Canada and Romania started to be exploited. The oil industry in Poland dates back to 1853, when Ignacy £ukasiewicz successfully distilled crude oil for the first time and when on 31 July of that year the hospital in Lviv was lit with an oil lamp (Wolwowicz, 1994).

Oil fields in the Carpathians, the second-longest mountain range in Europe, are to a great extent depleted and the old wells are being closed in line with mining and geological laws and regulations. However, owing to their location, they can be used for other purposes. Recently dynamic developments have been observed of low-temperature geoenergetic applications in many developed countries around the world, with significant attention to Borehole Heat Exchangers (BHEs) integrated with heat pumps, which provide heat and/or cold to customers. A number of boreholes in the Carpathians could be used as borehole heat exchangers for heating and heating/cooling purposes. Instead of being shut down, such wells could be converted to borehole heat exchangers. Such a conversion involves cutting off the water-bearing horizons with cement or mechanical plugs and equipping the borehole with a heat carrier circulation system. These can be U-tubes in shallow (maximum 150 m depth) boreholes or co-axial systems in deeper ones.

In this study, an idea for extending the use of old oil wells by directing them to a new application is described and examined. The aim is to consider alternative options to the problem of shutting and decommissioning old oil wells, by considering heating and cooling applications. Boreholes are often used in geothermal heating and cooling systems (Sanner, 2001), where the Borehole Heat Exchangers (BHEs) are drilled to depths normally not exceeding 200 m. But drilling is very expensive. Nonetheless, research is ongoing into deep BHEs in some countries (e.g., Germany, Switzerland, Japan). For instance, a well has been drilled to a depth of 2500 m in Aachen, Germany. In Poland there has also been research on adapting deep directional wells into BHEs (Sliwa and Kotyza, 2000).

In the Carpathians and many others places, old oil wells can be used for extracting geothermal energy for heating as well as cooling (Gonet *et al.*, 2010). Areas where oil/gas reservoirs were in the past exploited contain many old wells, which can be attractive for industrial buildings. Furthermore, the costs of shutting old oil wells are high, increasing the attractiveness of adapting them for BHE applications. In fact, Sliwa (2002) showed that the adaptation of the oil wells to BHEs for use in conjunction with heat pumps for heating and cooling nearby buildings, can be less expensive than cost of liquidation of the wells.

DRILLING INDUSTRY DEVELOPMENT IN THE CARPATHIANS

The first reference to rock oil in Poland appeared in the 13th century (Wolwowicz, 1994). Initially oil was collected from seepages, but this method quickly turned out to be inadequate and oil wells began to be dug, to depths of even 200 m. Construction was performed by people operating at the bottom of such wells, which was dangerous and technically difficult. To reduce the safety risks and improve quality, human power was substituted by technology, e.g., drills. The shafts dug by drilling are termed boreholes. The first boreholes were pole hand-drilled in Borislav (now in Ukraine) in 1861 and in Bobrka, Poland in 1862. At that stage of development, rock at the bottom of the borehole was impacted by the drill and crushed. The up-and-down movement of the drill was powered by a walking beam located on the surface and put in motion by people. The drill was connected with the walking beam through the use of wooden poles forming a so-called string. A significant problem associated with drilling using the new technique was the lack of qualified technical personnel. To address this problem, £ukasiewicz invited German drillers to teach Polish workers and the best of them became then instructors. A subsequent modification was the use of Fabian drilling jars, which protected the poles against the negative impact of the hits. Another advance, implemented around 1866, was the use of a steam machine for driving the walking beam. This made the work easier but also created a hazard due to the potential ignition of natural gas released from the boreholes by sparks emitted with the waste gas from the nearby traction engine.

In 1867 a German engineer Albert Fauck drilled a borehole 250 m deep in Klêczany, Poland using a cable as a string. Polish drillers were interested in string drilling, but this method was not popular because of the lack of specialist machines and skills. Groundwater appearing in boreholes created considerable problems, as casing techniques were not known at that time. At the end of the 1870's, therefore, string drilling was abandoned.

ACTIVITY OF CANADIAN ENGINEERS (DRILLER-ENTREPRENEURS) IN THE CARPATHIANS

In the 1880's, drilling techniques were still being developed and improved. Stanisław Szczepanowski, the discoverer of oil fields in Sloboda Rungurska (now in Ukraine), stated that the

Fig. 1: William Henry MacGarvey

techniques applied at that time did not bring about satisfactory technical results for deep wells. In 1882, Szczepanowski together with outstanding entrepreneur from Canada, William Henry MacGarvey (Fig. 1) and an Austrian financier John Bergheim, opened a company “MacGarvey and Bergheim.”

The drilling operations performed with the “Canadian system” spurre the oil industry. The Canadian system of pole drilling nearly completely substituted the manual drilling method. The rigs were driven by steam machines, located at a distance from the borehole to reduce the risk of spontaneous ignition of gas. The Canadian system became more and more popular, quickly contributing to the development of numerous mines in south-east Poland.

In 1883, MacGarvey and Bergheim built a drilling tools factory and an oil refinery plant in Glinik Mariampolski, Poland. The company rapidly developed and soon became the biggest oil enterprise in Europe before the First World War. Undoubtedly the big industrial complex in Glinik Mariampolski contributed to the intense economic development of Gorlice (Pabis, 2001), Poland (present population about 30,000). The drilling tool factory still exists and is operational and now is a holding of five companies under the name of Machines Factory Glinik S.A.

William Henry MacGarvey was highly esteemed both by entrepreneurs and oil workers. He knew the oil industry of his time and was a teacher of the best directors of mines and in 1903 was appointed to the position of Vice President of the National Oil Association. MacGarvey was also an inventor of drilling tools, e.g., an eccentric drill bit which was used for drilling to a depth of 1000 m.

After drilling a number of boreholes, the original Canadian rig observed to have some shortcomings when used in the Carpathian geological conditions and at increasing depths. Over time the rig was modified so many times that it eventually became known across the world as the Polish-Canadian rig.

However, some were not satisfied with the output of the modified rig. Attempts were made to improve drilling, e.g., by acquiring more skilled drillers. In 1885 engineer. Szczepanowski invited Perkins and Groby drillers, entrepreneurs from Canada, to join him. As with MacGarvey, they kept their system of work secret, not even allowing Polish technicians to enter the drilling utilities. Despite those obstacles, two Polish engineers, Stanisaw Jurski and Ludwik Zdanowicz, managed to undertake work as regular workers. They quickly learned the operations and the details of the rig. After some time the Poles made a Canadian rig with a mast. The actions undertaken to improve the Polish-Canadian rig led in 1895 to the wooden poles being substituted with steel ones. The abaca cables were also substituted with steel ones. The tools were improved by using higher quality steel and new shapes and designs. More and more novel ideas appeared at that time, e.g., the use of drilling mud for carrying out cuttings and equipping rigs with a hydraulic motor. In 1905-1906 the new Pennsylvania cable drilling system tested in Poland at Kryg and Kobylanka. The original Pennsylvania rigs and drillers were brought from the United States, but the low level of operation techniques at that time did not yield the expected results.

Moreover, skepticism of conservative enthusiasts of the Canadian system who did not believe in the success of cable drilling had to be countered. In 1911 MacGarvey tried the rotary drilling method for the first time. In the same year, the quick-pole drilling method of Lapp and Alliance was tested in Borislav (in the Ukraine after the Second World War). These attempts to shorten drilling time were not successful technically and economically.

Regardless, further ways of accelerating drilling operations were sought. In 1914 Stein patented a ball drilling system, which gave very good results in hard rock conditions. At the outbreak of World War I in 1914, efforts to improve drilling technology ceased and only resumed in 1922. Probably after contacts among the world's drilling centers and reviewing newest achievements, the decision was made by drilling engineers in Carpathians to restart systematic cable drilling with the original Pennsylvania rig. The results of the first drillings were promising, leading to the application of that system on a wider scale. Investigations were conducted on increasing efficiency, improving the technical results considerably in terms of the number of drilled meters per unit of time. Before the outbreak of the World War II the rotary drilling technology was receiving much attention. As with other drilling techniques, the first attempts did not yield the expected results, mainly due to primitive technology and a lack of experience of Polish drillers with this method. During the German occupation, the development of the drilling industry stopped as the crews and directors did not desire to bring about good results.

After World War II, drilling activity resumed, first with pole drilling and then with the rotary method. In the second half of the 1950's the distance drilled with the pole method was so small compared to that with total drilling that it was gradually abandoned. It was only locally applied at a marginal scale. Those years roughly represent the closing years of percussion (impulse) drilling in Poland. But this development did not avert new trends and directions in drilling. Percussion drilling is still sometimes used in hydrogeological drilling.

PRESENT STATE OF BOREHOLES

At present there are many boreholes in Poland which were previously used for oil and natural gas production. According to the relevant regulations, such wells should be closed (Fig. 2) so that they do not create environmental hazards. The closing operation involves filling open intervals with a sealing slurry and performing a cement plug above the perforation. A pipe is positioned at a certain depth and slurry is then injected through that pipe. The volume of the sealing slurry should

Fig. 2: Closing of a borehole

Fig. 3: Cement plinth and plate with the number of the closed borehole

not exceed the volume of the plug plus the driven pipe. Another method involves inserting special slurries into the borehole; these can be introduced below the water filling the well without mixing. After setting, the seals provided by such cements are very tight.

A cement plug is placed in the upper part of the borehole. Its fragment is visible over the terrain surface (Fig. 3). The plugging procedure is aimed at separating the remaining oil in the field from groundwater and near-surface rock mass layers.

BOREHOLE HEAT EXCHANGERS

Increasing oil prices and concerns regarding environmental degradation have motivated searches for alternative energy sources (Sliwa, 2000). Many renewable energy options allow for the harvesting of accessible thermal energy at low temperatures and have significant potential for applications. As opposed to heat sources based on underground water exploitation, low-temperature geothermal energy systems can be used in most locations (Sliwa and Kotyza, 2003). The low-temperature heat of the rock mass cannot be used directly. Heat pumps can be installed to increase the temperature of heat to that required for heating and heating/cooling systems.

Geothermal energy systems that exploit the low-temperature heat of a rock mass and operate in a closed system utilize a heat exchanger. Heat exchangers permit heat to be exchanged between the rock mass and the heat pump through a circulating fluid (Sliwa, 1996). Generally ground heat exchangers can be divided into horizontal and vertical types. Horizontal heat exchangers are placed at shallow locations in the ground and require a considerable ground surface area to perform well. With vertical borehole heat exchangers, the ground surface area covered needed by the exchanger is relatively small. Another advantage of vertical borehole heat exchangers is that the temperature of the rock mass is constant at greater depths, irrespective of daily and annual temperature oscillations on the surface. Consequently, borehole heat exchangers are commonly used as heating/cooling installations.

Designing and operating a vertical borehole heat exchanger requires a good understanding of the properties of rocks and soils, their thermal resistances and bulk heat capacities, their systems of layers and also their hydrogeological conditions. For a borehole heat exchanger operating in normal hydrogeological conditions, a typical average unit power is of 50 W/m BHE length (after VDI 4640-German standards). Two types of exchangers are used in basic applications: Single or double U-tube and concentric heat exchangers (Fig. 4).

In the first type of borehole heat exchanger in Fig. 4 (left side), a polyethylene U-tube is placed in the drilling borehole and the remaining space between the walls of the tube and the rock mass is filled with special slurry having appropriate thermal properties (especially enhanced thermal conductivities). One, two or even three connected U-tubes are usually utilized in a borehole. This type of borehole heat exchanger is most frequently applied in Europe because of its relatively low price and ease of assembly. In most cases, these are boreholes reach depths of 150-200 m.

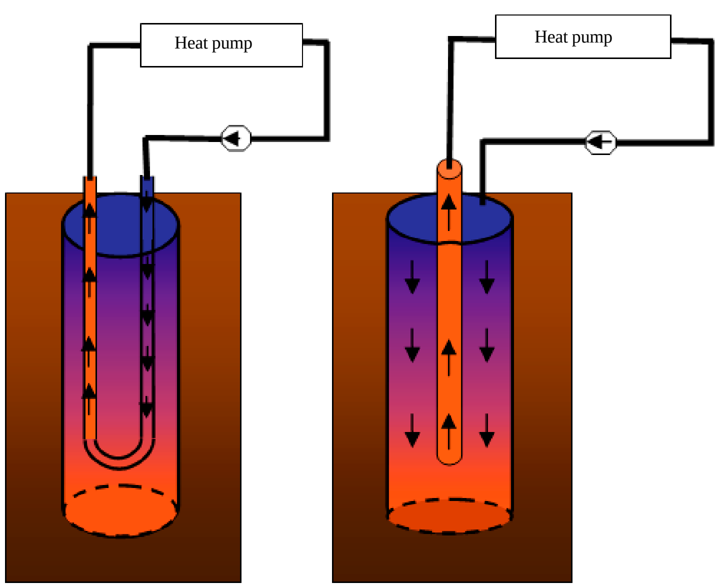

Fig. 4: U-tube borehole heat exchanger (left) and coaxial borehole heat exchanger (right)

In the case of borehole heat exchangers that exploit old, depleted wells, this construction method is also applicable, even if the borehole is leaky. Slurries can also play the role of a sealant.

The concentric borehole heat exchanger consists of at least two tubes of various diameters. The outer tube is made of high thermal conductivity material to provide good transfer of heat between the rock mass and liquid circulating in the borehole heat exchanger, whereas the inner tube typically has a high thermal resistance to reduce thermal losses resulting from the internal heat exchange.

GEOENERGETICAL ACTIVITY IN POLAND AND IN CANADA

In Poland, the low-temperature geoenergetics industry is not well developed. This is due to the high capital costs of geothermal heat pump installations. A significant part of the investment cost (frequently over 50%) is associated with the capital and operating costs of the in-ground equipment. The capital cost can be considerably lowered when an existing borehole is adapted. A number of such oil boreholes exist and they could be successfully used as borehole heat exchangers to produce inexpensive thermal energy. In the region of the Carpathians, boreholes are frequently located in the immediate neighborhood of construction projects, i.e., near potential energy consumers.

For example, the Polish village of Lipinki has over 650 boreholes that were drilled between 1854 and 1970. Their locations are illustrated in the map in Fig. 5. Many wells are located very closed the buildings (Fig. 6) and can be used as borehole heat exchangers (Sliwa *et al.*, 2006; Sliwa and Jezuit, 2007).

The region of the old oil field at Turaszowka now is a part of Krosno, a town with 50,000 inhabitants. A swimming pool complex is located close to the wells. The wells can use energy of earth for heating (Sliwa and Gonet, 2006).

The town Iwonicz Zdroj is the spa. mineral waters were obtained from part of the oil reservoir energetic system. The old oil wells (up to 1000 m deep) can be used for spa energetic purposes. The buildings of spa, for example the large sanatorium building Excelsior, are located among the oil wells (Sliwa and Gonet, 2003).

An old oil field is located in the village Czarna. Although the oil resources are exhausted, some wells can be used as BHEs for the recreation center located in this area.

In 2011 the idea was proposed to use the deep negative exploratory well in Rzeszow as a heat source. Using calculations made with a numerical simulator (Sliwa and Gonet, 2005; Sliwa *et al.*, 2010), it was determined that a heat rate (50 kW without heat pump) can be used for heating for the gas decompression system in the natural gas well. A high-pressure gas well is located 20 m from this well (having the potential deep BHE). It is necessary to heat the gas within the decompression system (Gonet *et al.*, 2011).

The areas of old oil fields with many wells can also be of interest to industries in the province of Alberta in Canada. If old wells are converted to BHEs, the value of the land around which they are located will likely increase. It is important to identify old oil wells in areas with good energetic possibilities and potential thermal energy users.

In Canada, like Poland, universities laboratories exist where research is ongoing into many aspects of the development and exploitation of BHEs. One example in Canada is geothermal installation at University of Ontario Institute of Technology (UOIT), located in Oshawa, Ontario near Toronto (Dincer and Rosen, 2011). That Borehole Thermal Energy Storage (BTES) system serves almost ten buildings (Fig. 7), which are designed to be heated and cooled using ground-source heat pumps while achieving reducing energy use, emissions and costs. The UOIT

BTES system has almost 400 boreholes each over 200 m deep. A glycol solution circulates in polyethylene tubing through the underground network. The BTES provides for both heating and cooling on a seasonal basis. The hydrogeologic setting at the site has over 40 m of unconsolidated overburden deposits overlying shale bedrock. The total cooling load of the campus buildings was anticipated to be about 7000 kW. U-tubes are placed in water-filled BHEs, instead of the North American practice of grouted BHEs. System operation began in the summer of 2004.

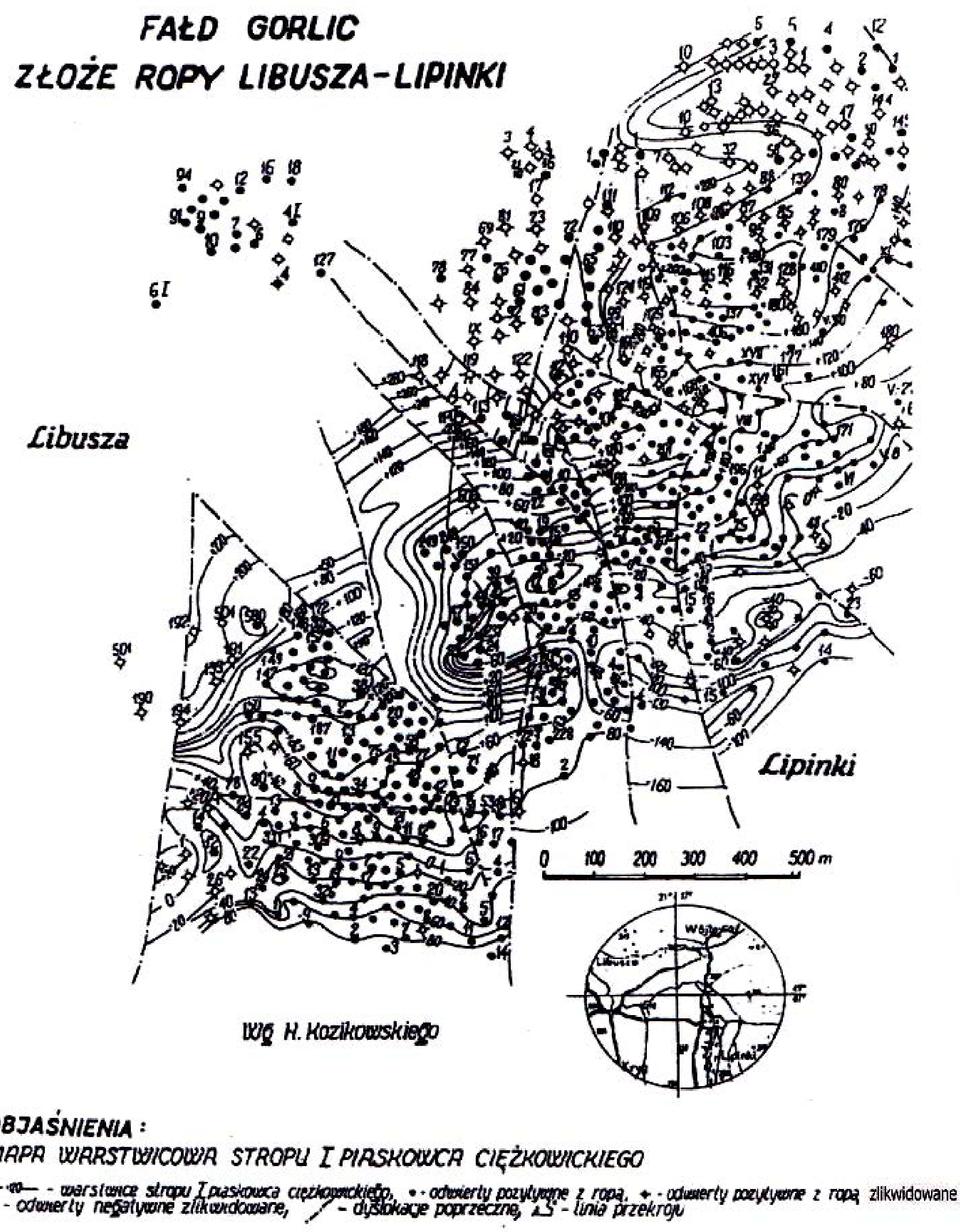

Fig. 5: Location of boreholes in the oil field at Libusza-Lipniki, Poland

Fig. 6(a-b): Boreholes near buildings in Lipinki, Poland

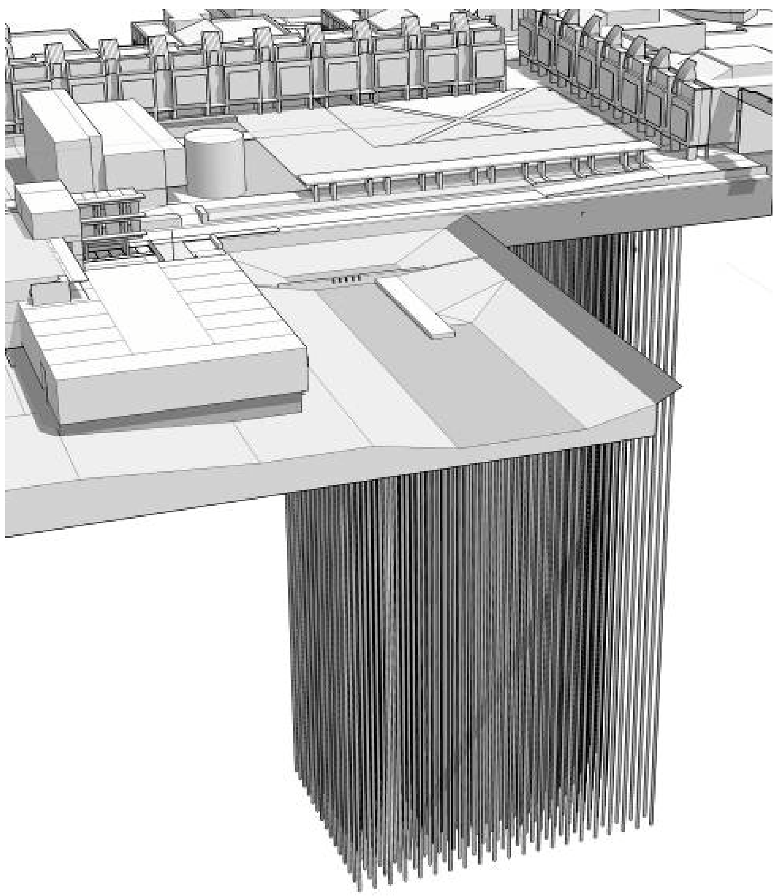

Fig. 7: Borehole thermal energy storage system below university buildings of University of Ontario Institute of Technology

The BTES system at UOIT is economically advantageous, with annual energy savings of about 40% for heating and 16% for cooling. The simple payback period for the geothermal well field was

7.5 years when the system was designed and for the high-efficiency HVAC equipment incorporated was three to 5 years. The system also reduced costs associated with the boiler plant, potable water and treatment chemicals use and rooftop cooling towers.

In Poland, new BHEs were installed in 2008 at AGH University of Science and Technology in Cracow for research and teaching purposes (Sliwa and Gonet, 2011). The system is made up of five BHEs, each 78 m in depth. Each BHE has a different construction. The research conducted using this facility includes determining how energy transfer efficiencies depend on BHE construction and technological parameters related to the exploitation of the BHE and the flow rates of the heat transfer medium and its temperatures.

In addition, Koohi-Fayegh and Rosen (2012a, b) have examined the thermal interaction among the multiple vertical ground heat exchangers that make up BHEs, for constant and variable heating strengths, using analytical and numerical approaches.

CONCLUSION

Several conclusions can be drawn from this review of the use of oil boreholes in the region of the Carpathians in geothermal energy systems:

- Low-temperature thermal energy has considerable global potential as a renewable energy resource, as it is widely accessible in most locations. Exploitation of such resources is in line with present worldwide efforts to increase energy production from renewable sources
- Installations based on vertical borehole heat exchangers are especially advantageous when the boreholes already exist and in close vicinity to energy consumers. Such geothermal installations do not impair the aesthetic value of the landscape as its main elements are hidden below the surface of the ground and have limited environmental impacts. However, not all boreholes can be used as borehole heat exchangers for technical reasons and, in some cases, their operation may also be economically unjustified
- The operation of an overall heating system that utilizes geothermal energy depends on a number of factors and determining the optimum parameter values is challenging and time consuming
- Numerous potentially adaptable old boreholes exist in the Carpathian region. It should be emphasized that the geothermal-based projects are ecologically friendly. Financial support to help offset the initial investment costs appears to be merited
- If the cost of the closing of old boreholes is accounted for in economic assessments, the actual capital costs of using oil boreholes in the Carpathians in geothermal energy systems may turn out to be comparable with the costs of traditional heating systems
- Although oil was important to the wealth of the Carpathian region some time ago, geothermal energy harvested using reconstructed boreholes has significant potential now and can contribute to regional wealth if used properly

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