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Use the wells of historic cradle of the world's oil industry for geothermal purposes

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ABSTRACT

Existing wells of past drilling activity in the area of oldest oil region in the world actually are majority not in use. Exhaustion of hydrocarbon resources requires doing away with such wells, which relates to incurring costs. According to polish mining legislative and the requirements of environmental protection the wells of depleted oil and gas fields should be closed down.

Region constitutes a historic cradle of the world's oil industry. It is more than 150 years old, i.e. it has been in existence from the moment when Ignacy Lukasiewicz invented a paraffin lamp in the area of Podkarpacie region.

In Podkarpacie Region (SE-Poland) liquidation of wells is systematic in its nature. Some of oil and gas fields are now to be located in the developed area of many towns and villages in the Podkarpacie. Therefore, an idea was conceived to adapt the existing wells for borehole heat exchangers, which will provide energy for heating purposes to the adjacent facilities. Some of them can be use as heat sources and/or heat storages in heat pumps systems. The authors describe a possibility and potential analyse of utilize the wells of used up fields. There is also described conception of use watered gas fields for both exploitation of gas and water with extraction heat from water by absorption heat pump supplied with exploited natural gas. Some potential examples of apply the idea are shown in the paper.

1. INTRODUCTION

On 2003 the Polish Oil and Gas Company celebrated the 150th anniversary of lighting the first oil lamp. This innovation by Ignacy Lukasiewicz was a milestone in the development of the world' civilisation.

Oil has been known for thousands of years all over the world, e.g. in the Middle East it was used for construction works, conservation of timber and sealing of boats. Some 2500 year ago the Persians used oil in medicine. In the 13th century Marco Polo reported on oil seepages in the area of the Caspian Sea.

In Poland, natural oil exhalations along the northern edge of the Carpathians were known and described in 13th century documents. Many centuries elapsed and in 1853 the Carpathian oil was first used for lightening a hospital and streets. Since that time a big scale industrial oil production started. In 1854 Ignacy Lukasiewicz organized the first in the world's history crude oil mine. Then there was established the first oil company, where crude oil was exploited, processed and sold.

The end of the 19th and the beginning of the 20th century was a period of an „oil rush" in the S-E Poland. Potential profits from oil discovery and its utilization, gave spur to big scale drilling works. The need for oil in the world's economy and industry started to grow rapidly. Oil prospecting at greater depths, and perfection of drilling tools and methods were a consequence of this situation. A number of oil production wells were drilled and intensive prospecting and drilling works were carried out in the Galicia region. As a result, rich oil fields were discovered (fig. 1).

Figure 1: Oil and gas fields in the eastern part of Polish Carpathians and the Pre-Carpathian Basin, a) oil fields, b) natural gas fields, c) sulphur deposits, d) border of the Carpathian thrust, e) northern range of Miocene formations (Karnkowski 1993).

By March 1896, 210 boreholes and wells had been drilled or dug in the whole Galicia area. At the end of the 19th century 156 oil mines and companies operated.

At the end of the last century, oil exploitation in this region declined rapidly. Consequently the Polish Oil and Gas Company started systematically in 1991 to close down the oil production wells. This was prompted by legal regulations. Over 100 wells are closed down each year. The total number of decommissioned wells in the successive years is given in Fig. 2.

Polish mining and geological regulations impose on an investor an obligation to do away with wells in the following cases:

a) shutting down a mine or a part of it,
b) after finishing drilling if a well is not designated for further operation,
c) once a given well stops to be exploited,
d) in the event of finding well removal ineffective.

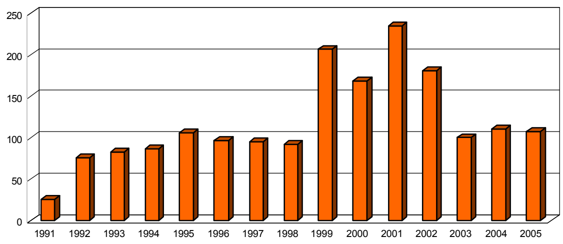

Figure 2: Number of wells closed down by the Polish Oil and Gas Company, Section in Krosno during the years 1991 to 2005 (actualised after Liput and Szmyd 2000).

The number of all wells appropriated for liquidation is about 3000 in Poland (Macuda et al., 2001). Most of them belong to the first in the world oil basin in the Carpathians.

Drilling works are the most costly element of geothermal activities. Some kind of utilization of the existing oil wells may significantly reduce the cost, especially as funds are necessary for closing the wells down. According to Sliwa (2002), the cost of decommissioning may exceed the cost of adapting the wells for heat exploitation purposes (surface heat exchange and reception systems including).

What speaks for the geothermal use of wells is the fact that a number of wells are sited in densely populated areas. Deposits and wells are often sited within towns, near developed areas, making the use of surface installations for heat management unnecessary.

Old, exploited wells can be used for geothermal heat production. This can be realized in a variety of ways. The most favourable solution lies in geothermal waters exploitation or injection. In the case of deposit hydration, water can be exploited with oil and/or gas. After separating hydrocarbons on the surface, heat can be recovered from the reservoir water. Such water can be injected on the deposit contours, thus increasing reservoir pressure.

Heat of waters discharged from hydrocarbon deposits can be recovered through the reception of heat energy enclosed in water before injection. If the temperature of reservoir water if sufficiently high, the heat can be directly exchanged between reservoir water and heat carrier in the heating system (fig. 3). After separating natural gas from reservoir water in the separator, heat is recovered.

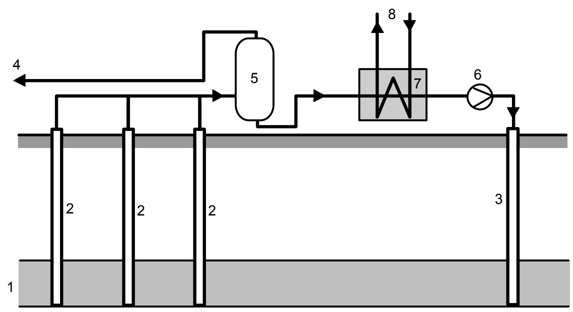

Figure 3: A scheme of heat recovery from reservoir waters at high temperatures accompanying hydrocarbon extraction in watered deposits: 1 – deposit horizon, 2 – watered production wells, 3 – injection well, 4 – natural gas transportation, 5 – separator of reservoir media, 6 – injection pump, 7 – heat exchanger (or heat pump), 8 – heat customers

If the customers need higher temperatures than provided by the existing waters, heat pumps can be applied (Sliwa et al. 2003).

Another way in which the wells can be used is for borehole heat exchangers (BHE).

In table 1 is shown a list of wells exploited and blocked on oil and natural gas fields exploited by Polish Oil and Gas Company Dpt. ZRG in Krosno which was analysed in the paper in aspect of BHE.

Table 1. A list of wells exploited and blocked on oil and natural gas fields exploited by Polish Oil and Gas Company Dpt. ZRG in Krosno which was analysed in the paper in aspect of BHE (after Walecki 2000)

Name of field	Year of discovery	Depth of deposition [m]	Percent of using up the resources		No. of wells in operation (Aug. 2000)	No. of blocked wells (Aug. 2000)
			gas	Oil		
Kryg-Libusza-Lipinki	1860	60-490	100	98,44	271	16
Iwonicz-Zdrój	1890	150-900 750-950	97,5	97,74	41	1
Turaszówka	1892	120-380	100	97,52	30	3

When adapting an oil well in operation for BHE it is necessary to do the following:

a) seal the productive level (in such a way that a well constitutes tight heading, without a hydraulic contact with the ground),
b) check effectiveness of the sealing and leaktightness of the whole well,
c) clean the borehole wall (e.g. from petroleum sediments and paraffin waxes),
d) sink of an internal circulation system (single pipes column by coaxial system or a U-tubes system),
e) hang pipes and install a circulation head,
f) fill the circulation system with a heat carrier.

Figure 4 shows diagram of a model of existing oil well designated for liquidation, liquidated well and adapted for BHE

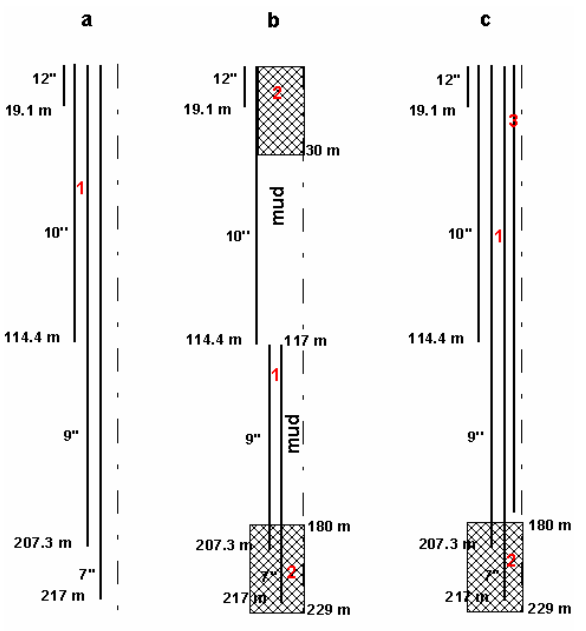

Figure 4: Diagram of a model oil well, a) designated for liquidation, b) liquidated, c) adapted for BHE in place of closing down, 1 – casing, 2 – sealing plug, 3 – pipes of the internal circulation system.

2. THE CHARACTERISTICS OF BOREHOLE HEAT EXCHANGERS

The construction and principle of BHE are described in a number of publications. The concept of adaptation of the existing boreholes to BHE is discussed in (Gonet and Sliwa 2002). There are a lot of advantages of recuperation of the heat of the earth through BHE, e.g.:

- no risk accompanying drilling and geothermal waters exploitation;
- no mass exchange (water) – no impact on mass equilibrium; the borehole constitutes a closed system, therefore no environmental hazard is expected;
- high durability, practically no replacements in the borehole are necessary;
- maintenance not needed, unless the surface equipment;
- easy and safe control of the heat source;
- high reliability;
- accessibility all year long (highly coherent source);

After completing oil extraction operations, wells are usually closed. Another option is that they may be partly closed, i.e. part of the productive interval is cut off so that the existing boreholes have no hydraulic connection with the rock mass, and BHE can be installed.

A borehole heat exchanger consists of a casing pipe of a borehole, a column of internal tubing of good thermal insulation and a tubing head. In this way a circulation system is created. This system consists of annular space in which a heat carrier will be moving towards the well bottom and coming back to the surface in the channel inside the insulation column (Sliwa et al. 2000).

The circulation liquid gets hot from the rocks during its movement downwards. After the heat is received the heat is transported to a receiver by means of a heating medium (Gonet and Sliwa, 2002). The function scheme of a borehole heat exchanger is outlined in fig. 5.

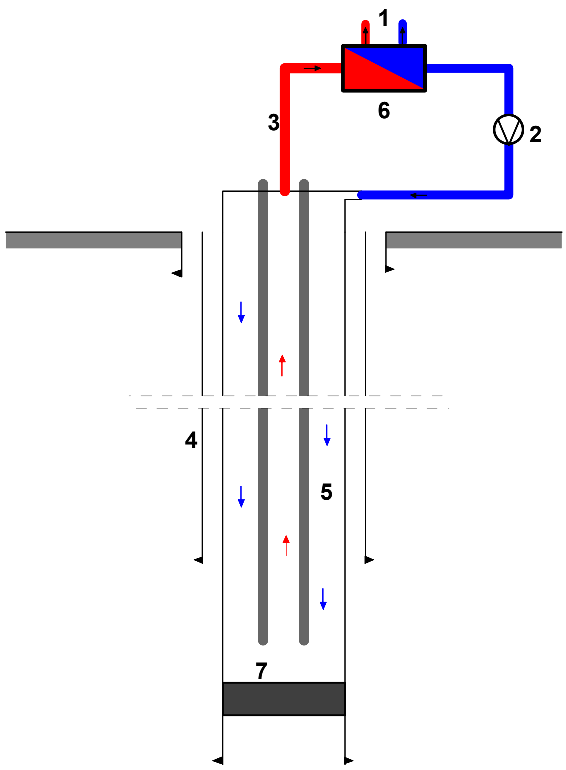

Figure 5: Schematic of a borehole heat exchanger; 1 – heating system; 2 – circulation pump; 3 – surface piping, 4 – well casing, 5 – inner isolation string; 6 – heat pump; 7 – sealing plug (Sliwa and Gonet, 2005).

The local characteristics of lithosphere and the layers drilled by the well are the geological parameters of a borehole heat exchanger. They influence its energetic effectiveness. The value of energy flux which gets to the earth surface as a result of the borehole heat exchanger exploitation depends, to a large extent, on its constructional characteristics.

The construction of borehole heat exchangers consists of the equipment made for both the original destiny of a well and the heat exploitation purposes.

The constructional characteristics can be partly formed in the design and implementation process of a borehole heat exchanger.

The exploitation parameters depend on the above mentioned geological and constructional characteristics. They play a decisive role in the profitability of using existing wells as borehole heat exchangers. The geological, exploitation and constructional characteristics are shown in the table 2 (Sliwa and Kotyza, 2003).

Table 2. Parameters influencing of efficiency of use BHE

Geological	Constructional	Operational
Geothermal gradient	the depth of insulation cork (or packer)	the average annual heat production
natural earth heat flux	the internal well diameter	long-term heating power

Thermal conductivity of the rocks	the length of the insulation casing	the maximum instantaneous heating power
anisotropy of orogenic belt thermal conductivity	the internal and external diameter of the insulation casing	the flux of heat carrier volume
a type of deposit medium filling the pore and fracture space	the distance between borehole heat exchangers in case of their greater amount	a type of a heat consumer, working time and the level of heat consumption
layer thermal capacity	heat resistance of the material of the internal column	resistance of heating medium flow
porosity and saturation of layers	centricity of the internal column	the temperature of a flowing heat carrier
rock density	the course of the drill axis	a type of a heat carrier
hydrodynamic characteristics of layers and the natural speed of deposit medium filtration	the drill construction including the number, length and diameter of casing, the quality of the material insulating the casing as well as the condition of this material	the temperature of a compressed heat carrier (the variable of carrier cooling in the receiving installation)
		the time and circularity of exploitation
		the distance of a heat consumer from a well
		the time of ground temperature restoration (the period of energy resources renewability process)
		local climatic conditions

3. KRYG-LIBUSZA-LIPINKI OIL FIELD

Adaptations should be made in wells situated close to the heat consumers, which has an economic justification. Besides, clean thermal energy can be recuperated with heat pumps from the rock mass. One of the about to depleted fields is oil field in Lipinki discovered in 1860. There are 271 operational wells, 16 are designated for closing (Walecki 2000). A number of wells are localized close to the potential heat consumers.

The field has been drilled for several years. Gradually, the new wells were completed and new resources discovered the development of drilling technologies used could be observed. Accordingly, the wells have different designs.

The analysis of heat demand in the Lipinki county reveals that there exists a number of possibilities of adapting the heating system in view of heat pump application. Unfortunately, a thorough analysis of the energy state of the county is required, especially of objects localized in the vicinity of the closing wells.

The school in Lipinki is one of potential heat customers. The school covers an area of 484.6 m^2, and its cubature 1551 m^3. The annual demand for heat for this object was assessed for 1043.8 GJ, out of which nearly 800 GJ/year shall be spent for the central heating. The remaining part is planned to be used for heating useful water. At present, the school is supplied with heat coming from the combustion of natural gas. The total yearly gas consumption in the school totals to almost 27,000 m^3 (Sliwa et al. 2006).

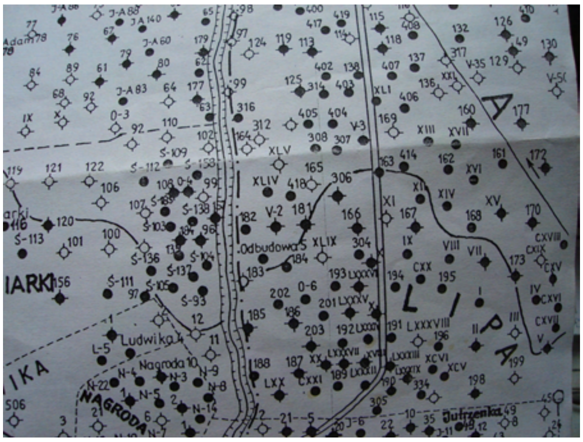

Figure 6: Localize of the wells of Kryg-Libusza-Lipinki Oil Fields in urban area

Other objects in Lipinki which could make use of the heat recuperated with BHE are the County Administration objects, kindergarten, Culture Center and Health Center. Moreover, much energy is used each year by communal objects in other towns in the county, e.g. the yearly natural gas demand of communal objects in Kryg totals to 44,000 m^3

Figure 7: Many houses and public building is located between the wells of oil field Kryg-Libusza-Lipinki

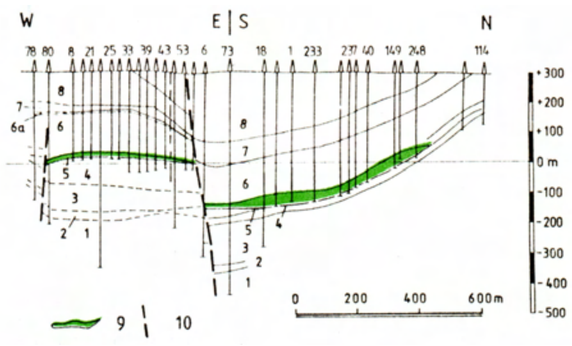

Figure 8: Cross-section of Kryg-Libusza-Lipinki Oil Field (Karnkowski 1993)

4. IWONICZ ZDRÓJ OIL FIELD

Iwonicz Zdrój oil field is located in a spa in the Carpathians. Iwonicz Zdrój, as a spa town, should be especially interested in using clean methods of acquiring heat energy.

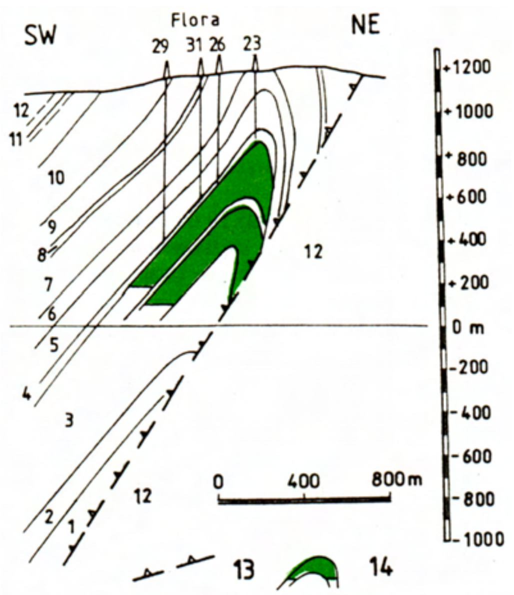

Figure 9: Cross-section of Iwonicz Oil Field (Karnkowski 1993)

Wells short distance from a large heat recipient being the Excelsior sanatorium belonging to the spa Iwonicz S.A.

In the sanatorium building there is an extended heating system characterised by a high extent of diversity.

The analysis of mean monthly temperatures for many years shows that a heating season in Iwonicz Zdrój is longer than Poland's average.

In the period from 1981 to 1990 it was noted that the average winter duration with mean daily temperatures below 0 °C was as many as 90 days, whereas summers with mean daily temperatures above 15 °C lasted only 78 days.

When analysing only two wells based on which it is possible to make borehole exchangers at the depth of 860 m and 460 m, it turns out that the amount of heat possible to be acquired annually is 2050 GJ, with the stream of exploited energy amounting to 65 kW.

5. TURASZÓWKA OIL FIELD

In the neighborhood of Turaszówka oil fields, a few potential geothermal energy users exist. The energy can be produced through the existing boreholes. It follows from the preliminary analysis that the heating system in the Complex of Upper Grammar School no. 5 in Krosno would be the best candidate.

The complex consists of 6 objects (school, dorm, indoor swimming pool and workshops) totaling to 73005 m^3. It is located in the north-east part of the field, close to the active wells of the Turaszówka wells.

Figure 10: Indoor swimming pool in Turaszówka located into area of the wells prepared for closing down (Sliwa and Gonet 2006)

Total heat demand is 2742.6 kW. Central heating load at ambient temperature 253 K is 1926.5 kW. For useful water production 584.2 kW is needed. The indoor swimming pool technological needs amount to 231.9 kW. The average annual gas consumption is ca. 500 000 m^3/a.

The yearly production of primary energy is expected to be 17500 GJ, the useful energy demand - 13125 GJ.

The analysis of heat system characteristics shows that the low-temperature heat of Turaszówka field can be best utilized for the needs of hot useful water production and heating of the indoor swimming pool (heating water for the pool and floor heating).

The total depth of active wells used in Turaszówka field is 5317.6 m. After adaptation to BHE, the total depth of the boreholes will be 4355 m. The analysis of the average yields of the operational foreign BHE and heat exchangers, whose capacity was established through mathematical modeling, the accessible heat capacity can be assessed to about 220 kW. In the case of the full load, which is possible after modernization of the existing customer's heating system, 6938 GJ of thermal energy can be produced each year.

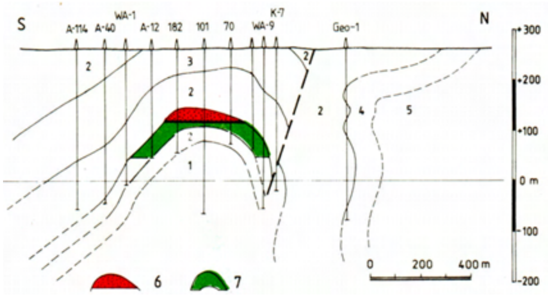

Figure 11: Cross-section of Turaszówka Oil Field (Karnkowski 1993)

A number of wells in the Turaszówka field are not operational any longer or closed. After restoring these wells to operation, the accessible capacity and quantity of produced energy can be increased. This, however, requires additional investments.

Figure 12: Oil wells of Turaszówka oil field

Adaptation of pipeline systems may be a problem. When a borehole starts operation as a BHE, additional pipe has to be disposed to each of the wells. The circulation system is a closed system, therefore each BHE has to be supplied with two pipes – supply and recuperation pipes The ground may be the preliminary source of heating for the pipes with the chilled heat carrier (disposed in the ground). Pre-heated fluid should be thermally insulated. Earth works on the pipeline network supplying the customer with heat will cause additional costs, much smaller if the distance between the well and the user is small (Sliwa and Gonet 2004).

6. TARNÓW GAS FIELD

Near the Tarnów field zone, a total of 29 wells were drilled. Watered production wells are closed down or used for injection purposes. By 2000, 18 186 Mg of reservoir water was produced (Sliwa et al. 2003). After cooling the water from 60 to 5 ^{o}C, only 4 200 GJ heat energy could be gained. One should take into account the costs of purchase, installment, servicing and driving of heat pumps, which will receive the low-temperature heat. The application of the feeding system based on the exploited natural gas should result in the reduction of these costs.

Because of the shrinking natural gas resources and the considerable increase of watered wells, one should closely look at the perspectives of the mines where the increasing share of reservoir water in the exploited media can be used for the recovery of thermal energy of waters.

Reservoir water at 61 ^{o}C in deposit can be directly used for heating industry purposes. In this situation, the system depicted in fig. 3 can be applicable.

The realization of the concept according to the scheme in fig. 3 is connected with inevitable investments, i.e.:
- making system of heat recuperation from reservoir water prior to its injection to the reservoir;
- purchase and assembly of electric energy generator fed by natural gas,
- making a system of heat transportation to the customers,
- reconstruction of wells to enable tripping of deep pumps (owing to the waterhead character of the exploitation, reservoir pressure stabilized at 16.48 MPa).

Making the system according to the elaborated concept may result in elongation of the time of gas production. In a situation, when gas constitutes a minority of the exploited reservoir medium, its production will become unprofitable at a certain point in time. If this gas is exploited on the spot for feeding a heat pump, the profitability of exploitation can be evaluated together with hear recuperation from water.

Moreover, the influence of injection of reservoir waters, having changed physico-chemical parameters, should be analysed. Particularly the influence of water temperature drop on the permeability of reservoir rocks in the absorptive zone, which can have an influence on lowered absoptivity. Lowering of temperature and products of corrosion of the surface installments may result in precipitation of dissolved mineral components, and in turn, colmatation of the near-well zone.

7. CONCLUSIONS

Most of oil wells performed in the last 150 years in the Carpathian and Fore-Carpathian region is not fit for production purposes. The reserves are depleted. According to the geological and mining law the wells should be closed.

Some of the wells can be remade for geothermal heat exchangers, one of the renewable energy sources. The solution lies in exchanging heat between the rock mass and the carrier circulating a close circuit. Part of the wells designed for closing can be locally used for clean thermal energy production and storage. Owing to the storage of heat in the rock mass, the energy can be managed more rationally in objects localized in a close vicinity of abandoned wells.

Heating systems based on heat exchangers and heat pumps are more and more frequently used in a number of places all over the World. The necessity to drill geothermal wells considerably increases the capital costs. The cost of adaptation of wells designed for closing are much lower than the new wells downhole heat exchangers. This solution makes it possible the lower the total capital cost. Economic profitability of use of abandoned wells is determined by the distance between them the potential heat consumers. Wells made in the Carpathians are frequently localized in the immediate vicinity of potential heat customers.

Energy of the rock mass recuperated through heat exchangers cannot be used directly. In the Polish conditions downhole exchangers must cooperate with heat pumps.

A special construction and technology of adaptation of abandoned wells for downhole exchangers create possibility of recuperating heat of the rock mass and/or its storing.

Modern technical and technological solutions are advantageous for recuperation of geothermal energy in an increasing number of cases, both geologically and ways of its recuperation. Hydrocarbon exploitation, especially at the final stage, deposits are usually flooded. Reservoir water extracted with oil and/or natural gas may become a source of clean energy instead of being a waste.

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