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THE CONCEPT OF A DEEP BOREHOLE HEAT EXCHANGER AT THE AGH UNIVERSITY STUDENT CAMPUS

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Abstract: The paper provides an introduction to deep borehole heat exchangers, their use and completed projects worldwide. The aim of the study is to design a deep borehole heat exchanger at the AGH University Campus, more specifically its design, casing and internal heat exchanger pipe concept with a view to minimizing temperature losses. It goes on to describe the location of the project, including the geology of the area and the solution to the design problem, i.e. the casing of the borehole and the design concepts for the deep borehole heat exchanger. In the following section, the design of a deep borehole heat exchanger is presented. During the research, the main problem was the limited availability of articles on deep borehole heat exchangers. This is due to the continuous development and testing of new engineering ideas and the high implementation costs compared to the energy effects obtained. The publication only deals with technical issues, financial issues were not considered, among other things due to the current global geopolitical situation in 2023.

Keywords: deep borehole heat exchanger, geoenergetics, geothermal, drilling, geothermal heat pumps

1. Introduction

Nowadays, there is growing interest in energy from renewable sources due to an increase in public awareness of environmental issues or ensuring energy neutrality. More recently, the construction industry has been following the idea of creating buildings that consume less energy. Regardless of this, its sources are also changing. This can be achieved using, for example, thermal energy from the Earth's interior. This can be exemplified by deep borehole heat exchangers, which can operate independently, or shallow heat exchangers cooperating with geothermal heat pumps.

The aim of this paper is to design a deep borehole heat exchanger at the AGH University Student Campus in Krakow and to adapt the parameters of the operation of the system with a geothermal heat pump to the required average power needed to meet the energy demand for central heating and domestic hot water of selected dormitories.

The introduction introduces the concept of geothermal energy, ways of utilizing and accessing thermal energy in the rock mass, explains the operational principles of deep borehole heat exchangers and supplies some examples. The operational principles of geothermal heat pumps is also described. The research problem was then defined and the location of the proposed project was outlined along with the expected geological structure. In the next section, the design of a deep borehole heat exchanger is presented.

Due to increasing energy consumption in the world, mankind is being forced to look for new, alternative sources and ways of obtaining it. The reason for this is the depletion of classical energy resources and their negative impact on the environment [1].

1.1. The concept of the deep borehole heat exchanger

There is currently considerable interest in borehole heat exchangers around the world. The vast majority of these are shallow boreholes with depths of tens to hundreds of meters. The use of deep boreholes (e.g. with depths of 2,000 to 4,000 m) for the installation of deep borehole heat exchangers makes it possible to obtain higher working fluid temperatures and also more energy [2]. In contrast to shallow installations, a deep borehole heat exchanger is only able to convert energy for heating purposes. Due to the high rock temperatures in the rock mass, it is not advisable to use such exchangers for cooling purposes. Given the high costs of drilling boreholes, existing boreholes that were drilled for other purposes, such as negative exploration boreholes or depleted oil wells, are usually considered for investment [3].

1.2. Examples of deep borehole heat exchangers worldwide

To date, deep borehole heat exchangers have already been constructed at several sites. Some of these are operational, while others are only being used for research purposes.

Switzerland

In 1993, in Weissbad, Switzerland, a borehole with a depth of 1,213 m was deepened to 1,600 m, this was to test the permeability of the rock. At a depth of 1,213.3 m, a cement plug was drilled into the borehole, then center pipes were installed to form a deep borehole heat exchanger (Fig. 1). When designing the exchanger, it was assumed that a temperature of approximately 15°C would be achieved in a continuous mining process, however, the actual temperature was 1.8°C lower [4].

At Weggis, the operation of the deep borehole heat exchanger has been monitored since 1994. The first phase of operation lasted from 1994 to 1996 and the borehole was underused. This was evidenced by the high temperatures of the outflowing heat carrier. The system at Weggis has proven to be reliable and robust, where it delivers thermal energy of 230 MWh per year. At present, with 40 kW of geothermal power, the unit efficiency is less than 20 $W \cdot m^{-1} \cdot K^{-1}$. The potential of this heat exchanger is estimated at around 180 kW of thermal power production [5]. The heating power is closely linked to the quality of the extracted heat energy. The lower the temperature of the extracted heat, the higher the heating power of the exchanger can be.

Germany

In the German town of Prenzlau, one geothermal borehole double was drilled in the early 1990s. Due to the poor permeability of the reservoir layer, no hot thermal water was extracted from it, but it was converted into a deep borehole heat exchanger with a depth of 2,786 m. Since 1994, with intermittent reconstructions, it has operated year-round in the load range up to 600 kW (with the help of a heat pump) [6].

A deep borehole heat exchanger with a central design was constructed on the premises of the RWTH University in the city center of Aachen. The purpose of the project was to heat the university building and conduct research. The borehole seal was made of two different cement grouts (Fig. 2). The lower part of the borehole was sealed with a grout with high thermal conductivity, while the upper part was sealed with a grout with low thermal conductivity. It was shown that with a heat carrier discharge temperature of 55°C, the heating capacity of the system would be approximately 100 kW [7].

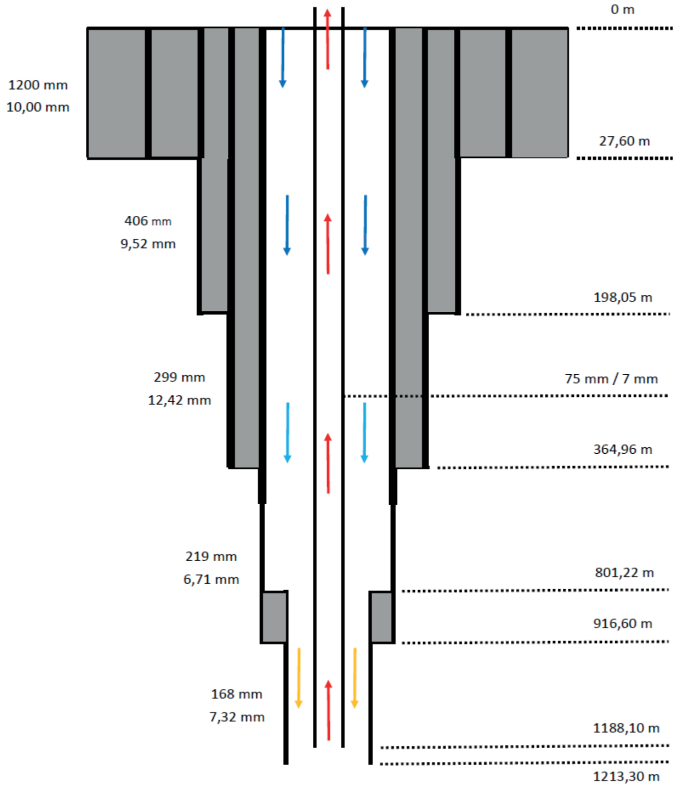

Fig. 1. Construction of a deep borehole heat exchanger with a depth of 1213 m in Weissbad, depths are given on the right, casing diameters and wall thicknesses on the left, casing – black, seal – grey (converted on the basis of [4])

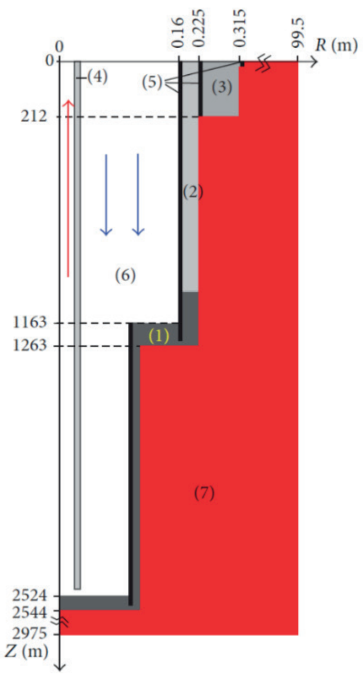

Fig. 2. Aachen heat exchanger. The 2D cylindrical grid used (radius 99.5 m and depth 2,973.5 m) with a breakdown of the different material types in the heat exchanger:
1 – high thermal conductivity cement, 2 – low thermal conductivity cement, 3 – ordinary cement, 4 – internal low thermal conductivity pipe, 5 – steel cladding pipes, 6 – water (heat carrier), 7 – surrounding rock (converted on the basis of [7])

Hungary

As part of the WeHEAT project, MS Energy Solutions Ltd. implemented Hungary's first deep borehole heat exchanger at a depth of 1800 m in the KIHA-EK-14 borehole in Kiskunhalas. A geothermal gradient of 56°C/km was calculated from the original data at the drilling of the borehole. These data were used for the first simulations, which were later made more realistic by measurements during the pilot project. Different configurations of heat carrier influent temperature to the heat exchanger (20°C, 25°C, 30°C) were tested and it was found that, with the designed borehole geometry and geological conditions, an influent temperature of 20°C was the most favorable. Simulations showed that the discharge water temperature varied between 40 and 50°C for all tested capacities. The measured and modelled temperature differences show a slight decreasing trend over time.

1.3. Geothermal heat pumps, principle of operation

A heat pump is a device that makes it possible to use distributed energy in the environment. This is only possible with the consumption of mechanical (drive) energy. The drive energy consumed by heat pumps has a higher energy utility compared to the thermal energy received in condensers [1]. Heat flow only occurs from a source that has a higher temperature to a source that has a lower temperature. If one wishes to realize the flow in the reverse direction, according to the second law of thermodynamics, drive energy must be brought in from the environment [8] (Fig. 3).

A compressor heat pump works very similarly to a refrigerator, which extracts heat from the products placed inside it and releases it outside (into the room). The unit consists of an evaporator, compressor, condenser and expansion valve (Fig. 4). The evaporator and condenser are heat exchangers [9]. In addition to this, the heat pump is equipped with various types of valves, an automation system or a working fluid reservoir.

The evaporator extracts heat from the so-called lower source, i.e. water, air, ground. Under the influence of the heat, the working medium is transformed from a liquid phase into a low-pressure, low-temperature gaseous phase. The compressor then compresses the vapor using drive energy to produce a high-temperature, high-pressure gas. In the condenser, the process of heat transfer to the heating system takes place, condensing the hot steam (transformation into a hot liquid at high pressure). The last transformation is the passage of the working medium through the expansion valve. This results in a cold liquid/steam mixture at low pressure.

In the heat pump circuit, the working medium is a fluid that receives heat from the lower source in the evaporator – at low pressure and temperature – and transfers (gives up) heat in the condenser at high temperature and pressure [3].

There are heat pumps on the market that use driving energy in the form of electricity (compressor pumps with a compressor driven by an electric motor) or high-temperature thermal energy (absorption pumps with boilers, e.g. gas-fired). Any heat pump, regardless of design, is regarded as a device that, with the help of additional energy, increases the temperature of the working medium in order to make practical use of the heat [3].

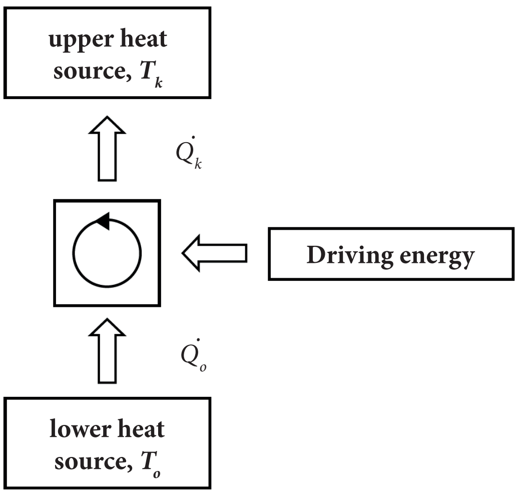

Fig. 3. Principle of energy transport in a heat pump [8]:
T_k – average flow temperature of the heat consumer, T_o – average temperature of the heat transfer medium in the evaporator, $\dot{Q}_k$ – heat flux (heating power) from the condenser to the consumer, $\dot{Q}_o$ – heat flux from the mountain to the evaporator (low-temperature heating power)

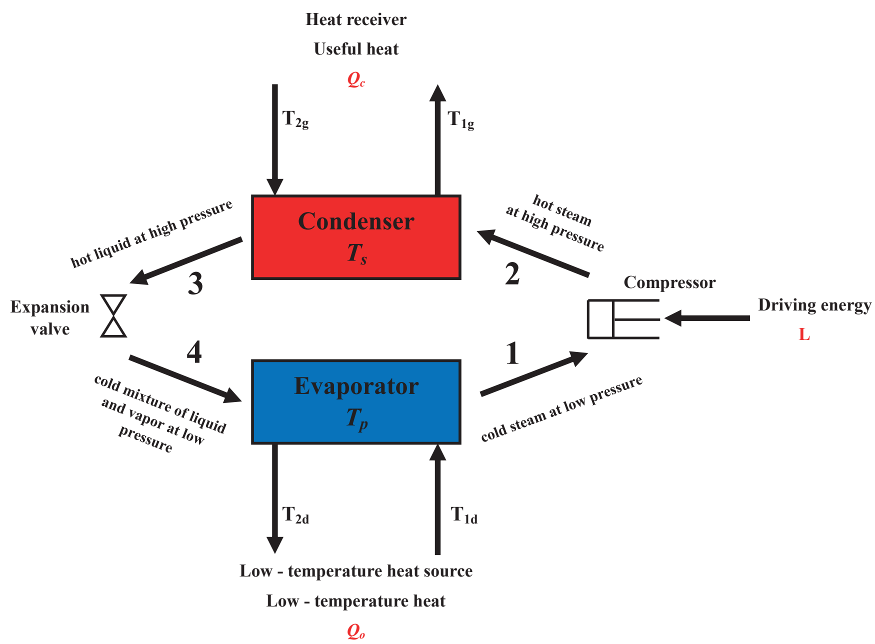

Fig. 4. Schematic diagram of the working medium circuit in a compressor heat pump [3]:
T_s – condensation temperature, T_p – evaporation temperature, Q_c – heat supplied from the condenser, Q_o – heat supplied to the evaporator, L – electrical energy to drive the compressor, $T_k = (T_{2g} + T_{1g})/2$, $T_o = (T_{2d} + T_{1d})/2$, where T_{2g} – return temperature from the consumer installation (the so-called upper source), T_{1g} – supply temperature, T_{2d} – flow temperature of the borehole exchanger (the so-called lower source), T_{1d} – flow temperature of the borehole exchanger (the so-called lower source), T_{1d} – flow temperature of the evaporator (the so-called lower source). upper source), T_{1g} – supply temperature, T_{2d} – supply temperature of the borehole exchanger (so-called lower source), T_{1d} – outlet temperature from the exchanger

2. Definition of the research problem

The concept involves the design of a 3,000 m deep vertical borehole with the construction of a deep borehole heat exchanger.

2.1. Location of the project

The site of the planned borehole for the deep borehole heat exchanger is located in Krakow, Malopolska voivodship, in the area of the AGH University Campus, at Piastowska Street (Fig. 5). The plot of land on which the borehole is planned has the number 261/1. It is located at an altitude of approx. 204 m above sea level (Fig. 5).

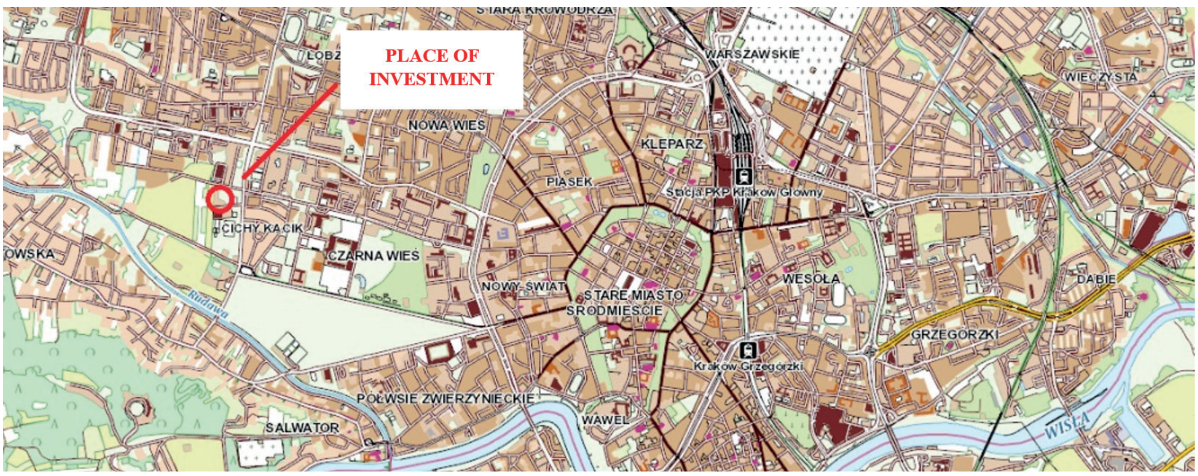

Fig. 5. Overview map No. 1 (topographic)

Source: geoportal.gov.pl

2.2. Geological structure

Krakow is located on the border of major structural units: Upper Silesian Zapadliska, Silesian-Krakow Monocline and Nida Basin, as well as the Carpathian Mountains, Pre-Carpathian Zapadliska and Carpathian Foredeep [10].

The Krakow region below ground level is built from Jurassic, Cretaceous, Miocene and Quaternary sediments (Fig. 6). As regards the Jurassic, these are shoal or rocky limestones. In the case of the Cretaceous, the marls, locally occurring on Jurassic limestones, are of low thickness. The marly clays of the Skavian strata and the clays and siltstones of the Wieliczka strata are Miocene sediments which occur almost throughout the Krakow area. The Quaternary is developed as sands and gravels with silts, water-glacial sands and loess, which occur in the north-eastern part of Krakow. The thickness of these sediments is quite variable - in places it can be up to 30 m [11]. The lithological profile with the boundary of the layers marked can be seen in Table 1 [12].

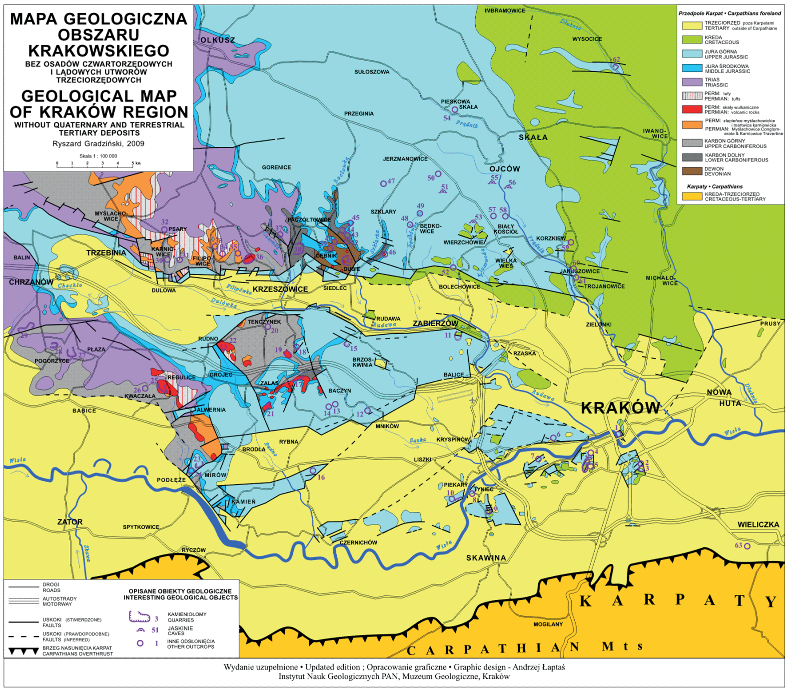

Fig. 6. Geological map of the Krakow area [13]

Table 1. Lithological profile of the analyzed borehole [12]

Layer, lithology	Top [m under surface]	Bottom [m under surface]	Thickness [m]	Density [kg/m³]	Formation type
Siltstone, shale	0	172	172	1,590	plastic
Grey altered sandstones	172	327	155	2,580	resilient
Diabase	327	423	96	2,800	resilient
Grey fine-grained sandstones	423	498	75	2,660	filtration
Shale, siltstone	498	764	266	2,260	plastic
Fine-grained sandstones	764	929	165	2,660	filtration
Dark grey shales, dark grey siltstones	929	1,160	231	2,200	plastic
Grey and dark grey limestones	1,160	1,452	292	2,620	resilient
Dolomitic limestones, dolomites 30/70	1,452	1,684	232	2,510	resilient
Beige and grey-beige dolomites	1,684	1,888	204	2,410	resilient
Grey and dark grey limestones, dolomitic limestones 10/90	1,888	2,349	461	2,509	resilient
Beige and gray-beige dolomites	2,349	3,000	651	2,410	resilient

3. Problem-solving methodology

The heat, from the deep borehole heat exchanger, will be used to cover the demand for central heating and domestic hot water. The sources must be designed as bivalent.

3.1. Design of the borehole casing

Borehole pressure and strength calculations were carried out. The pressure distribution in relation to depth (gradients) was summarized in diagram form (Fig. 7). Table 2 summarizes the values of pressures in individual lithological layers. Table 2 summarizes the values of pressure gradients in the borehole for individual layers.

Strength calculations made it possible to design the pipe columns in the borehole and, more specifically, their permissible lengths. Based on the H_{di} factor, which determines the tensile strength of the steel pipe, the lengths of the individual casing columns were selected:

– pre-column – 0–60 m;
– guidance column – 0–498 m;
– technical column I – 348–1160 m:
  - section I – 348–600 m,
  - section II – 600–900 m,
  - section III – 900–1160 m;
– technical column I – 1110–3000 m:
  - section I – 1110–1750 m,
  - section II – 1750–2350 m,
  - section III – 2350–3000 m.

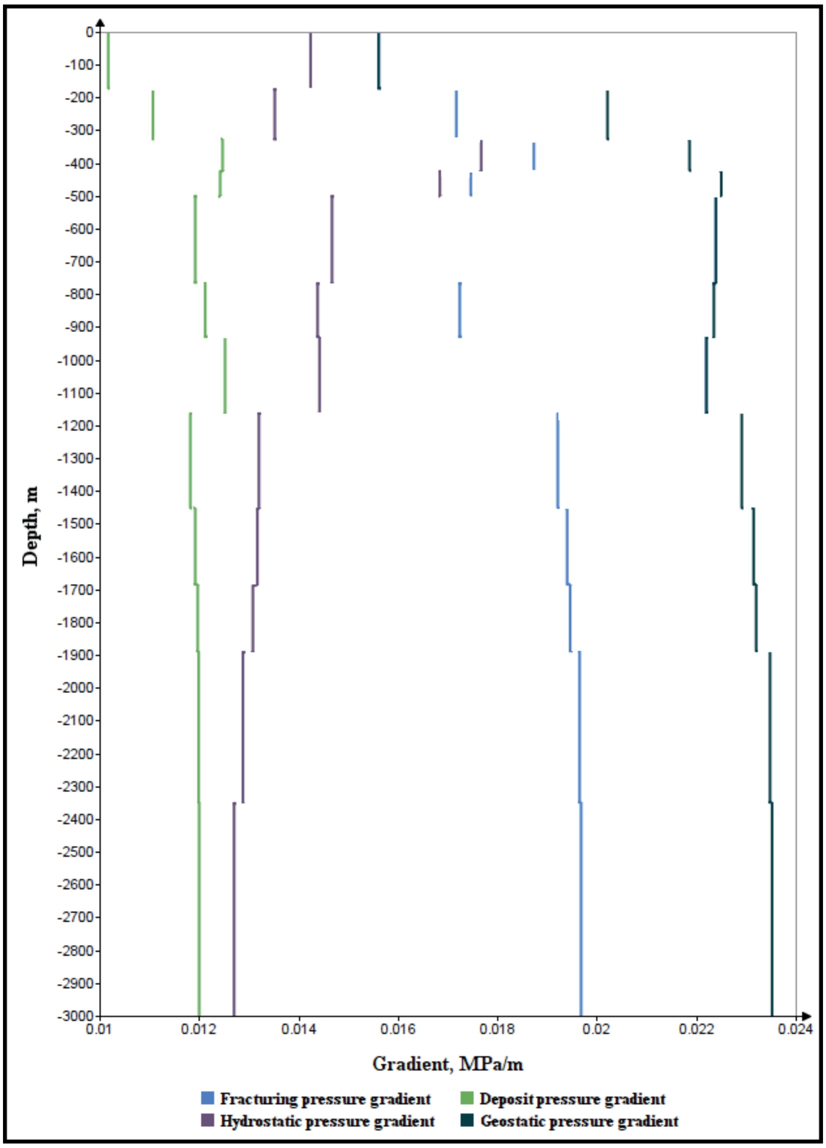

Fig. 7. Diagram of pressure gradients in a borehole

Table 2. Borehole pressures for individual layers

Layer, lithology	Top [m under surface]	Bottom [m under surface]	Thickness [m]	p_{zl} [MPa]	p_g [MPa]	p_{sz} [MPa]	p_h [MPa]
Siltstone, shale	0	172	172	1,746	2,682	2,682	2,446
Grey altered sandstones	172	327	155	3,613	3,922	5,607	4,413
Diabase	327	423	96	5,266	2,636	7,915	7,466
Grey fine-grained sandstones	423	498	75	6,175	1,956	8,686	8,375
Shale, siltstone	498	764	266	9,092	5,895	17,091	11,192
Fine-grained sandstones	764	929	165	11,241	3,657	15,995	13,341
Dark grey shales, dark grey siltstones	929	1,160	231	14,500	4,984	25,732	16,700
Grey and dark grey limestones	1,160	1,452	292	17,134	7,502	27,868	19,134
Dolomitic limestones, dolomites 30/70	1,452	1,684	232	20,040	5,711	32,643	22,140
Beige and grey-beige dolomites	1,684	1,888	204	22,562	4,821	36,698	24,662
Grey and dark grey limestones, dolomitic limestones 10/90	1,888	2,349	461	28,118	11,343	46,112	30,218
Beige and gray-beige dolomites	2,349	3,000	651	35,940	15,386	58,977	38,040

Table 3. Values of borehole pressure gradients for individual layers

Layer, lithology	$G_{zł}$ [MPa]	G_g [MPa]	G_{sz} [MPa]	G_h [MPa]
Siltstone, shale	0.01015	0.01559	0.01559	0.01422
Grey altered sandstones	0.01105	0.02019	0.01715	0.01350
Diabase	0.01245	0.02184	0.01871	0.01765
Grey fine-grained sandstones	0.01240	0.02248	0.01744	0.01682
Shale, siltstone	0.01190	0.02237	0.02237	0.01465
Fine-grained sandstones	0.01210	0.02233	0.01722	0.01436
Dark grey shales, dark grey siltstones	0.01250	0.02218	0.02218	0.01440
Grey and dark grey limestones	0.01180	0.02289	0.01919	0.01318
Dolomitic limestones, dolomites 30/70	0.01190	0.02313	0.01938	0.01315
Beige and grey-beige dolomites	0.01195	0.02318	0.01944	0.01306
Grey and dark grey limestones, dolomitic limestones 10/90	0.01197	0.02346	0.01963	0.01286
Beige and gray-beige dolomites	0.01198	0.02350	0.01966	0.12680

For reasons of strength as well as cost efficiency, the individual casing columns are designed as a telescopic assembly composed of sections with different diameters and wall thicknesses. This stepped layout tailors material grade and geometry to the expected loads and hydrogeological conditions at depth, while minimizing steel use and simplifying installation.

Table 4 shows the details of the casing used for the borehole casing project, together with the diameters of the augers drilling the sections.

Figure 8 shows a diagram of how the borehole is lined up with the internal exchanger pipe: VIT 4 ½″ × 3 ½″ pipe.

Table 4. Data of casing and augers for drilling the given sections, one wall thickness is assumed for all sections of a given column

Casing pipe, OD		Steel grade	ID [m]	b [mm]	ODC [m]	D_{bit}	
[in]	[m]					[in]	[m]
$18^{5}/_{8}$	0,4731	K55	0.4510	11.05	0.5080	24	0.6096
$13^{3}/_{8}$	0,3397	J55	0.3153	12.19	0.3651	17½	0.4445
Section I, $9^{5}/_{8}$	0,2445	K55	0.2224	11.05	0.2699	12¼	0.3112
Section II, $9^{5}/_{8}$	0,2445	L80	0.2224	11.05	0.2699	12¼	0.3112
Section III, $9^{5}/_{8}$	0,2445	N80	0.2224	11.05	0.2699	12¼	0.3112
Section I, 7	0,1778	K55	0.1594	9.19	0.1945	8½	0.2159
Section II, 7	0,1778	L80	0.1594	9.19	0.1945	8½	0.2159
Section III, 7	0,1778	N90	0.1594	9.19	0.1945	8½	0.2159

Explanations: ID – inner diameter of casing pipe, *b* – wall of thickness, ODC – outer diameter of the connector, D_{bit} – borehole diameter, OD – outer diameter of the casing pipe

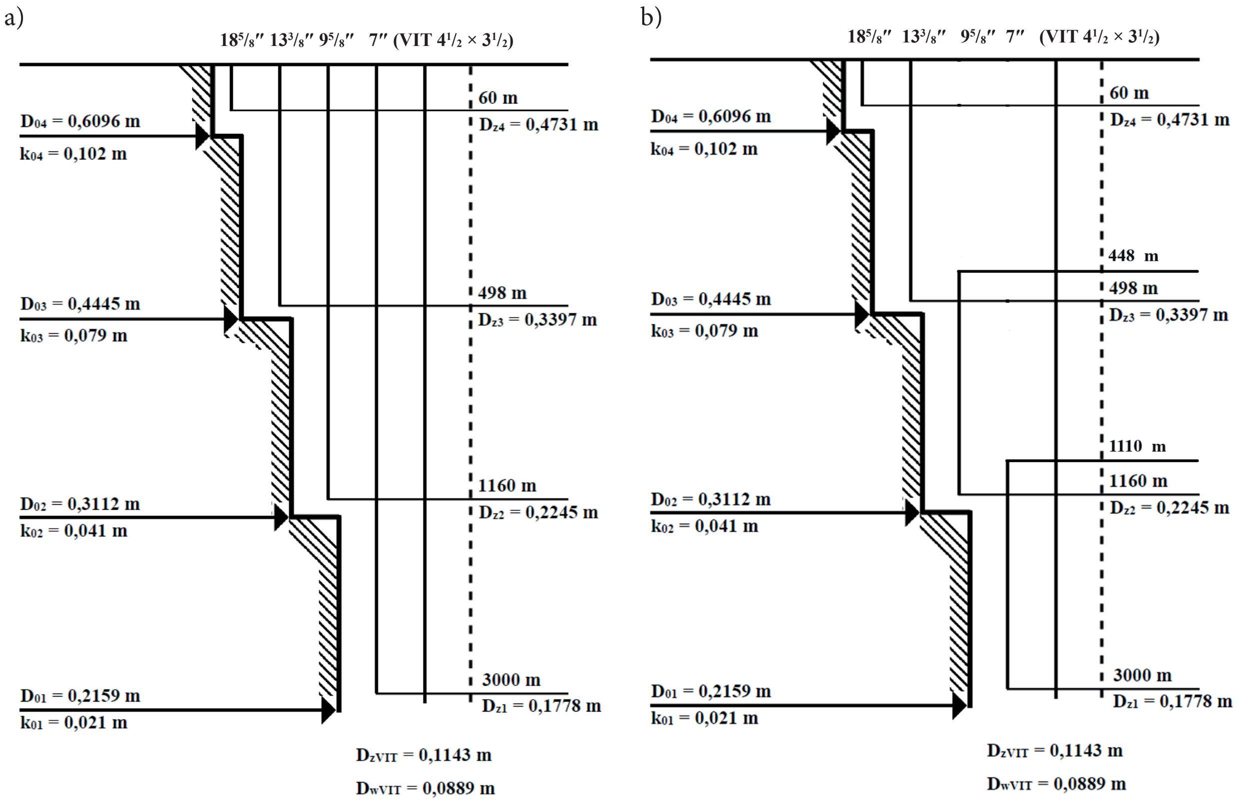

Fig. 8. Schematic of a borehole casing with VIT pipes. The design of the borehole with "overlapping" (liner) pipes can be implemented as decided at the borehole design stage: a) full casing option; b) economy option

Depending on the temperature of the injection medium, the method of cementing the cladding pipe columns can vary. Thus:

– If the temperature of the heat carrier to be injected into the GOWC is below the mean atmospheric air temperature, the entire borehole can be cemented with grout with increased thermal conductivity.
– If the temperature of the brine to be injected into the GOWC is above the mean atmospheric air temperature, the brine may additionally cool down during the initial flow phase. Therefore, up to a certain depth, thermal insulation is recommended. This can be realised by means of cement grout with reduced thermal conductivity or "overlapping" cementing and filling the inter-pipe space with nitrogen.

3.2. Deep borehole heat exchanger design

The first variant assumes the use of Vacuum Isolated Tubing (VIT). These tubes are designed to minimize heat transfer between the injected fluid, at a lower temperature (in the annular space), and the receiving fluid, at a higher temperature (flowing counterclockwise inside the column tubes). This variant assumes that the well is equipped with a column of double VIT-type tubing.

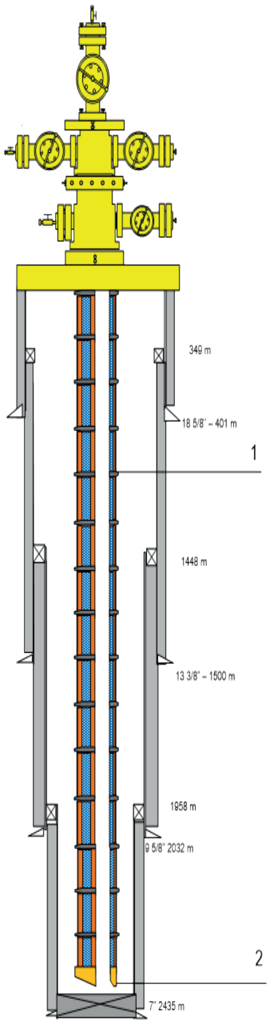

Fig. 9. Design of the Knott GT-1 well, Variant I using VIT tubing; 1 – VIT tubing 3½″ × 4½″, 2 – pipe shoe 3½″ × 4½″ [14]

The second variant involves casing two pipe columns which will be sealed at the bottom of the borehole with suitable components. Reduced-pressure nitrogen will be placed between the pipe columns as insulation to minimize heat transfer by using a vacuum pump. The sealing of the two pipe columns with the packer is shown in Figure 10.

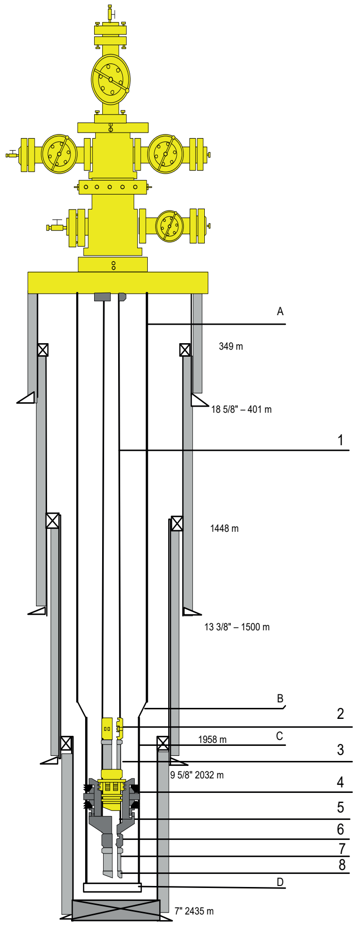

Fig. 10. Sękowa GT–1 well design, variant II using packer/sealer: A – 7″ pipes, B – 7″ coupling ×5″, C – 5″ pipes, D – 5″ open pipe shoe, 1 – 2⅞″ or 3½″ pipes, 2 – circulating sleeve, 3 – production pipe, 4 – packer, 5 – transition coupling, 6 – foundation coupling, 7 – production pipe, 8 – pipe shoe [14]

Vacuum tubes (VIT) have their origins in the oil industry, having been developed to minimize heat transfer between their interior and the annular space. They have found use in cases:

– When producing or circulating hot fluid through production tubing, e.g. in a permafrost zone, where it is undesirable to thaw the ground surrounding the well, which could cause it to lose its properties and uncontrolled subsidence of the ground around the wellhead could occur.
– When paraffin plugs and hydrates form during production of reservoir fluids and it is difficult or ineffective to use other methods that would prevent their formation.
– When hot fluids (e.g. solvents) or vapours are injected, with advanced extraction methods such as CSS (Cyclic Steam Stimulation) and SAGD (Steam Assisted Gravity Drainage), where cooling of the injected fluid is undesirable. In these meth-

ods, large amounts of energy must be expended to maximise the heating of the injected fluids, vapour, in order to transfer the elevated temperature to the in-situ reservoir fluids. The CSS method involves alternating periods of injecting superheated vapour into the reservoir and then extracting the heated oil through the same well. The SAGD method involves drilling two horizontal wells, where the horizontal part of the injection well is above the horizontal part of the production well. Steam is injected through the injection hole and the heated oil flows into the production hole.
– Where warm oil is transported along the seabed.

Variant II

This technology uses two columns of pipe that are plugged independently of each other. A packer is clipped onto the inner column which, when clipped, seals the space between the two pipe columns from the bottom of the borehole. A circulation sleeve is then opened, through which fluid is forced out of the supra-packer space using nitrogen. Once the space has been emptied of fluid, the circulation sleeve is closed and the nitrogen is drained from the space and then, using a vacuum pump, the pressure is lowered to reduce the thermal conductivity between the fluid being injected and the fluid being withdrawn from the borehole. Also important in this technology is the proper centralization of the inner column and the use of protectors made of a suitable material with low thermal conductivity.

Variant III

This technology uses two columns of pipe that are plugged independently of each other as with Variant II. Once the inner column has been collapsed, a locator at the end of the column is inserted into the PBR, ensuring a tight connection between the columns. Then, using nitrogen, the fluid between the tube columns is removed through a sleeve. Once all the fluid has been extruded from the space between the two columns, the nitrogen is released and the pressure is further reduced by using a vacuum pump. The reduction in pressure ensures a reduction in the thermal permeability of the entire insulating column. PBR – Polished Bore Receptacle, is a piece of borehole equipment into which a locator with a section of seals is inserted to ensure the tightness of the combined elements. The above solution allows the locator to move tightly in the PBR-e. In this variant, it is also important to use, among other things, plastic centralizers/protectors to avoid direct contact between the steel pipe columns and the formation of thermal bridges.

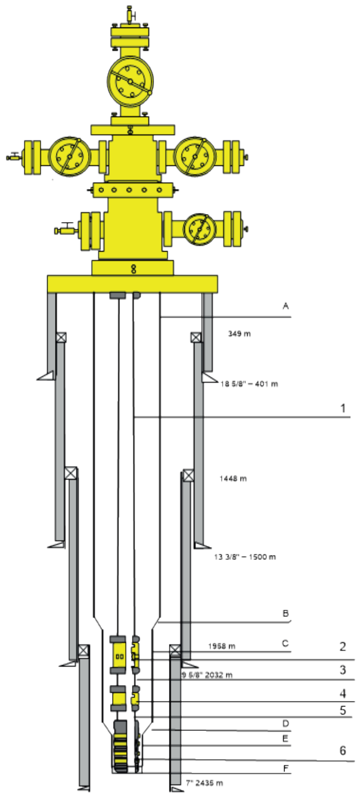

Fig. 11. Design of the Sękowa GT–1 well, Variant III using PBR: A – 7″ pipes, B – 7″ coupling × 5″, C – 5″ pipes, D – 5″ × 4,094″ ACME connector, E – PBR sealant, F – open shoe, 1 – 2⅞″ or 3½″ pipes, 2 – circulation sleeve, 3 – production pipe, 4 – foundation connector, 5 – production pipe, 6 – locator/stinger [14]

4. Summary

The results of drill stem test of the reservoir at various intervals in the borehole have ruled out the possibility of developing it as a classic geothermal borehole. Unfortunately, the requirements for the borehole to be used as a geothermal borehole were not met.

On the basis of the tests and analyses carried out, it can be concluded that the temperature in the designated measurement intervals stabilizes to certain values during both the plugging and pulling out of the loggers, so the measurement methodology employed can be described as correct. However, three measurements taken at longer intervals indicated a lack of complete stabilization, following a disturbance of the natural temperature during the drilling process. This can be concluded from the high accuracy of the thermometers used.

Variant III was chosen to proceed further for technical and economic reasons. The biggest disadvantage of Option I was its high price, due to the cost of purchasing and supplying vacuum tubes (VIT). Option II required a longer operation time – an additional walk to get the pacer on the tube. Variant III was the most financially advantageous, moreover, the length of the PBR and the locator allows some length tolerance in the selection of the packer and possibly easy replacement.

A large number of deep wells and boreholes have been developed for the oil industry in Poland, and they are not infrequently located close to urbanized areas. If even a small proportion of these were used to harness the heat of the rock mass, the amount of geothermal energy extracted could be increased. Counting only the 1980s, more than 4,500 boreholes with a depth of more than 500 m were drilled in Poland, according to Table 5, which shows the number of boreholes drilled in Poland since 1980, according to the Polish Geological Institute. In addition, after analyzing the map presented in Figure 12, it may be noted that high rock mass temperatures occur, inter alia, in the vicinity of Poznań and Gorzów Wielkopolski, where intensive work on hydrocarbon exploration and production was carried out for many years, so there are many boreholes in those areas which are nearing the end of their exploitation or are already destined for decommissioning. Therefore, the topic of adapting deep boreholes and boreholes for borehole heat exchangers should be developed further.

Table 5. Number of boreholes drilled in Poland since 1980 according to the National Geological Institute [1]

No.	Maximum borehole depth [m]	Number of wells drilled in Poland since 1980
1	500	4,563
2	100	3,676
3	1,500	2,575
4	200	1,721
5	2,500	1,228
6	3,000	826
7	3,500	385
8	4,000	188
9	3,500	84
10	5,000	38
11	5,500	13

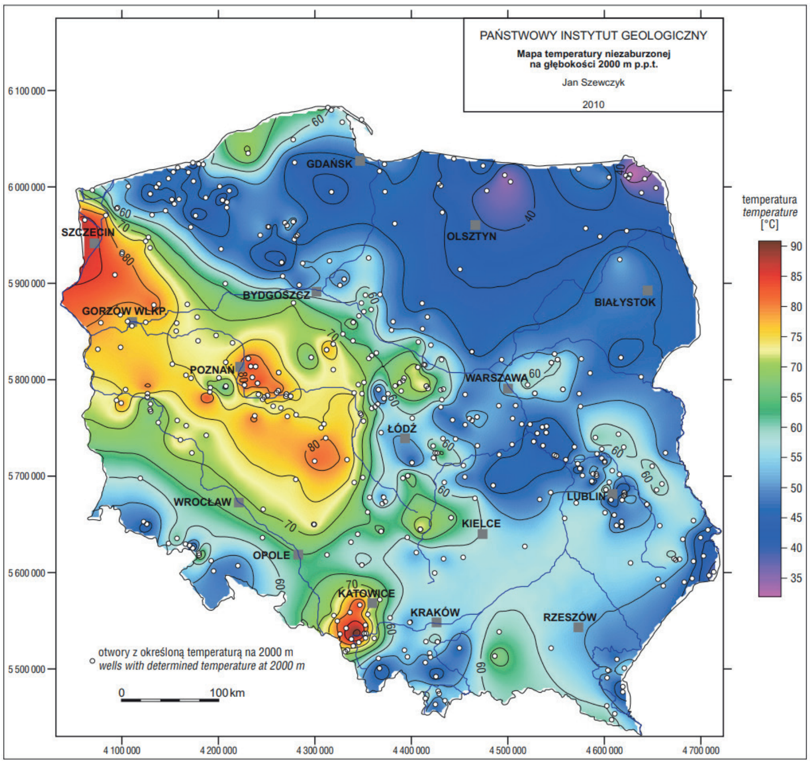

Fig. 12. Poland's geothermal potential at a depth of 2,000 m [3]

The third variant assumes an arrangement that is similar to variant II with the difference that a PBR and locator would be used instead of the sealing elements which are the packer in variant II [14].

5. Conclusions

- The low thermal conductivity of the inner column of the exchanger is very important for the thermal isolation of the heat transfer medium flowing into it, from the medium flowing in the annular space – especially the closer you get to the surface, because of the increasing radial temperature gradient.
- Each well should be approached individually, carefully analyzing the geological conditions of the well, the thermal parameters of the strata and the location of the future use of the deep borehole heat exchanger. The three proposed variants for the construction of a deep borehole heat exchanger will allow the developer to select one on the basis of the chosen criteria(s).

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