PROCEEDINGS, 47th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 7-9, 2022
SGP-TR-223

Increasing the Heating Power of Geothermal Wells Adapted from Liquidated, Existing and New Oil and Gas Wells and Borehole Geoenergetics

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Keywords: geothermal energy, geoenergetics, shale boreholes, shale gas&oil, borehole pads, well pads, oil&gas wells, liquidated wells, new boreholes

ABSTRACT

The work concerns the use of crude oil infrastructure in geothermal energy, focusing on the construction of boreholes created currently and in the future for crude oil and natural gas extraction purposes. Due to changes in energy policy almost all over the world, it is necessary to already introduce new rules in the design of boreholes for various purposes. This aims to re-use the wells after their purpose for the oil industry has been served. Such a possibility exists in the field of geothermal energy. There is an increasing tendency of adapting boreholes drilled for other purposes, e.g. exploration, for geothermal energy extraction. The structure of the boreholes designed and drilled, both currently and in the future, can be adjusted so that the well will perform more favourably working in the future as a geothermal well. One of the most important parameters of geothermal wells is their heating power. Many examples show that this power is influenced by the materials used in the well's equipment. This applies to both the pipes and the properties of the sealing slurry. Cementation of boreholes is necessary for both oil wells and geothermal wells. It should also be implemented in many cases for sealing of borehole heat exchangers. The selection of appropriately modified cement slurry parameters increases the heating power, and thus enables the acquisition of a bigger amount of heat from the geothermal heat source. Heat losses are reduced during the transport of water from deep geothermal wells. Modification of slurry parameters should also be implemented for borehole heat exchangers, which previously served as oil wells - already at the stage of designing/creating such wells. The work discusses the issues of oil wells, both the old ones that can be used in geothermal energy and those that will be drilled. Moreover, changes in the design of new geothermal wells are argued and advocated.

1. INTRODUCTION

Drilling is a branch of the economy dealing with the mining of rock mass by drilling methods (borehole mining). The following drilling methods are distinguished: ship, percussion, rotary and percussion-rotary. In addition, scientific work is being carried out on the implementation of thermal, ultrasonic, chemical and jet drilling methods. The result of the drilling method of mining the rock mass is a borehole, i.e. an excavation with a circular cross-section. Drilling is the basis for Borehole Engineering, a part of which is Borehole Mining.

The Faculty of Drilling, Oil and Gas at the AGH University of Science and Technology conducts research and educates students in the field of boreholes. It seems that drilling will be of great importance in the initiated civilization evolution consisting in transformations in the field of energy.

There are many reasons for drilling holes. There are also borehole utilization targets that are currently either not used or not common.

Drilling holes are made for the recognition of the geological structure and for the purpose of searching for deposits of solid (coal, ores, etc.), liquid (crude oil, water) and gaseous (natural gas) resources. Mine holes are drilled, both from the mine level (anchoring, leading, sealing, rescue) and from the surface to the underground workings, for example transport shafts, extraction shafts, ventilation shafts and rescue shafts are made from the surface of the ground.

More and more injection boreholes are being made (underground gas storage, underground hydrogen storage, underground pressure storage, underground heat storage, injection geothermal wells, co2 sequestration wells, storage and waste disposal). Thus, these are boreholes for the storage of substances (hydrogen, gas) or boreholes for the disposal of substances (CO_2, hazardous waste). Borehole geoengineering is developing intensively, where drilling is performed for piling, sealing leaks, anti-filtration, borehole injections, and hdd-controlled drilling. Freezing boreholes have been made for a long time. A specific group are emergency openings (eruption liquidation, ventilation). Test, measurement and observation boreholes are made for various needs. Geothermal energy (geothermal waters, borehole heat exchangers, thermopiles) is gradually developing. Geoenergetics is developing (including geothermal energy, energy storage, heat storage) as well as borehole geoenergetics (gravity borehole energy storage, pressure borehole gas kinetic energy storage, borehole heat exchangers, including those deep on depleted wells).

The largest group are exploitation boreholes for water, crude oil, natural gas, sulfur (in borehole exploitation), salt (in borehole exploitation), heat, etc. Among the hydrogeological wells we have water wells, research wells, piezometers, and drainage boreholes. Blast boreholes are drilled in geophysics, rock, opencast and underground mining.

2. CONVERTING PETROLEUM WELLS TO GEOTHERMAL ONES

Drilling boreholes, and among them the most frequently drilled, i.e. exploitation boreholes, may be used for other purposes. One such example is geothermal energy. If there are aquifers in the exploited boreholes (in the exploited reservoirs), the boreholes can be changed into geothermal ones (production and/or injection). If there are no such layers, they can be adapted to borehole heat exchangers – BHE (Fig. 1). The heat that BHEs extract is not always geothermal. When geothermal heat pump systems are reversed, i.e. in heating mode in winter and in cooling mode in summer (for air conditioning), solar (or anthropogenic) heat from the air conditioning is injected into the rock mass. So in winter, such heat is also brought to the surface, not geothermal heat. Especially when the amount of solar and / or anthropogenic heat introduced is equal to or greater than the amount of heat gained for heating in winter. In this case, the described system is not a geothermal system, but a geoenergetic system. The heat pump is not geothermal, but more ground-source. Ground is represents rock mass, which containes soil and rocks.

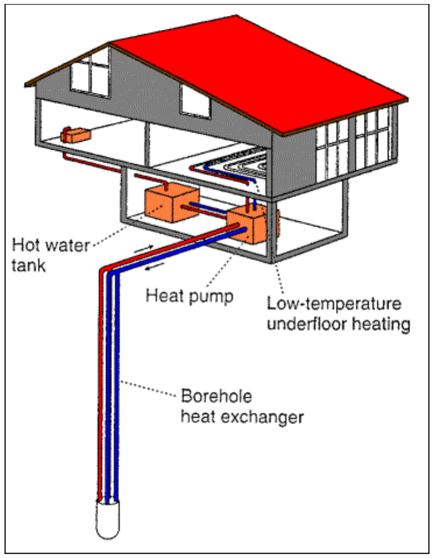

Figure 1: The fastest growing form of geothermal energy - borehole heat exchangers for systems with geothermal heat pumps (gtr.ethz.ch)

When replacing the exploited boreholes with wells for heat recovery, they must be located in the vicinity of potential heat consumers. Thousands of boreholes have been made in the Carpathians since 1863, when the first kerosene lamp was ignited (Fig. 2). Many old reservoirs and boreholes are now within city limits (eg Gorlice, Krosno, Biecz). Examples of borehole locations that can be changed into hole heat exchangers are shown in Fig. 3.

Figure 2: Old oil wells during an oil rush in the Carpathians (Borysław, photo from the PGNiG SA calendar)

Figure 3: Oil boreholes among buildings

Table 1 lists the numbers and depths of boreholes in Poland. Table 2 shows the potential heat capacities (heating power) of the borehole heat exchangers based on the old boreholes. The forecast was based on a pessimistic energy efficiency equal to 20 W/m of the borehole and the value of 50 W/m.

Table 1: The number of oil and gas wells drilled in Poland in individual provinces

Province	Reservoirs boreholes	Exploratory boreholes	All	Summary depth of all boreholes, m
dolnośląskie	389	5	394	610 697

kujawsko – pomorskie	21	1	22	78 226
lubelskie	120	8	128	273 270
lubuskie	295	6	301	674 880
łódzkie	42	2	44	125 701
małopolskie	1681	24	1705	1 592 431
mazowieckie	24	10	34	97 168
opolskie	0	0	0	0
podkarpackie	4523	40	4563	4 919 413
podlaskie	0	0	0	0
pomorskie	53	8	61	183 296
śląskie	105	4	109	73 614
świętokrzyskie	61	10	71	38 534
warmińsko -mazurskie	10	9	19	42 480
wielkopolskie	654	20	674	1 721 295
zachodniopomorskie	257	1	258	813 814
Total	8235	148	8383	11 244 819

Table 2: Theoretical total power of potential deep borehole heat exchangers in Poland

Province	Lower limit, kW, for 20 W/m	Upper limit, kW, for 50 W/m
dolnośląskie	7 880	19 500
kujawsko – pomorskie	440	1 100
lubelskie	2 560	6 400
lubuskie	6 000	15 000
łódzkie	880	2 200
małopolskie	34 100	85 250
mazowieckie	680	1 700
podkarpackie	91 260	228 150
pomorskie	1 220	3 050
śląskie	2 160	5 400
świętokrzyskie	1 420	3 550
warmińsko – mazurskie	380	950
wielkopolskie	13 460	33 650
zachodniopomorskie	5 160	12 900
Total	167 600	419 000

Remember that the heat from the bore exchangers is low temperature heat. Its use is possible together with geothermal heat pumps. And these require driving energy, which is most often electricity.

3. THE USE OF BOREHOLES IN GEOENERGETICS

Geoenergetics is defined as geothermics and energy storage in rockmass. Geothermics is defined as part of the economy and science dealing with:

- exploration,

- making available,

- exploitation (production and injection),

- transport,

- processing and

- use

of geothermal energy (heat) or heat contained in the rocks of the rock mass. Geothermal heat comes from our planet. It has been present in it since the formation of the planet and is generated during the decay of radioactive elements. Heat in the rock mass includes more options. It is geothermal heat, solar heat absorbed by the earth's surface and anthropogenic heat injected into the rock mass by various human activities.

Borehole geoenergetics includes borehole heat exchangers and energy storage in boreholes. One of the methods of storing (surplus in production) electricity is gravity borehole energy storage (Fig. 4). Fig. 5 shows the stages of the gravity operation of the in-hole energy storage.

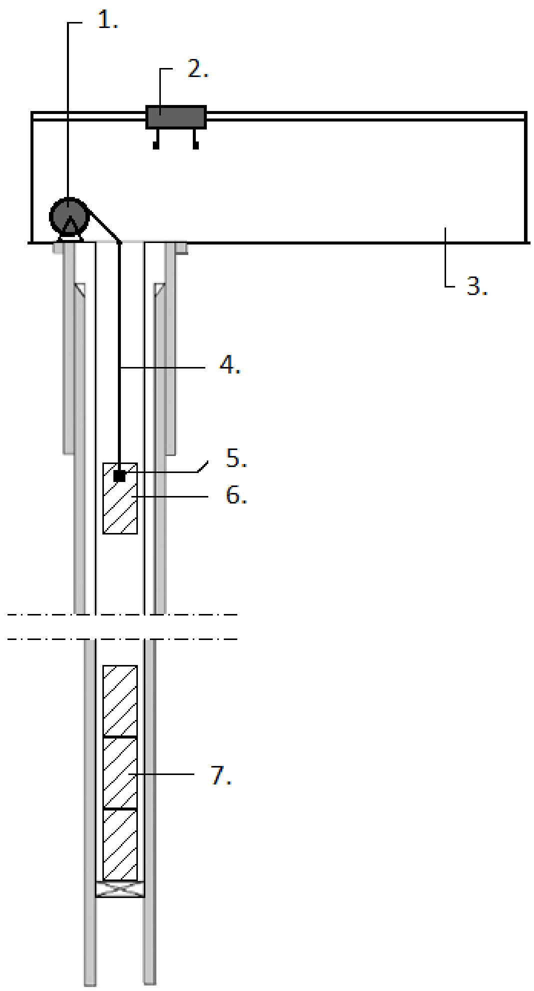

Figure 4: Components of a gravity energy store; 1 - drive system; 2 - crane (gantry); 3 - storage space for weights; 4 - rope on which weights are suspended; 5 - fastening the rope with the weight; 6 - single weight; 7 - weights already at the bottom of the borehole (Fabiś, 2022)

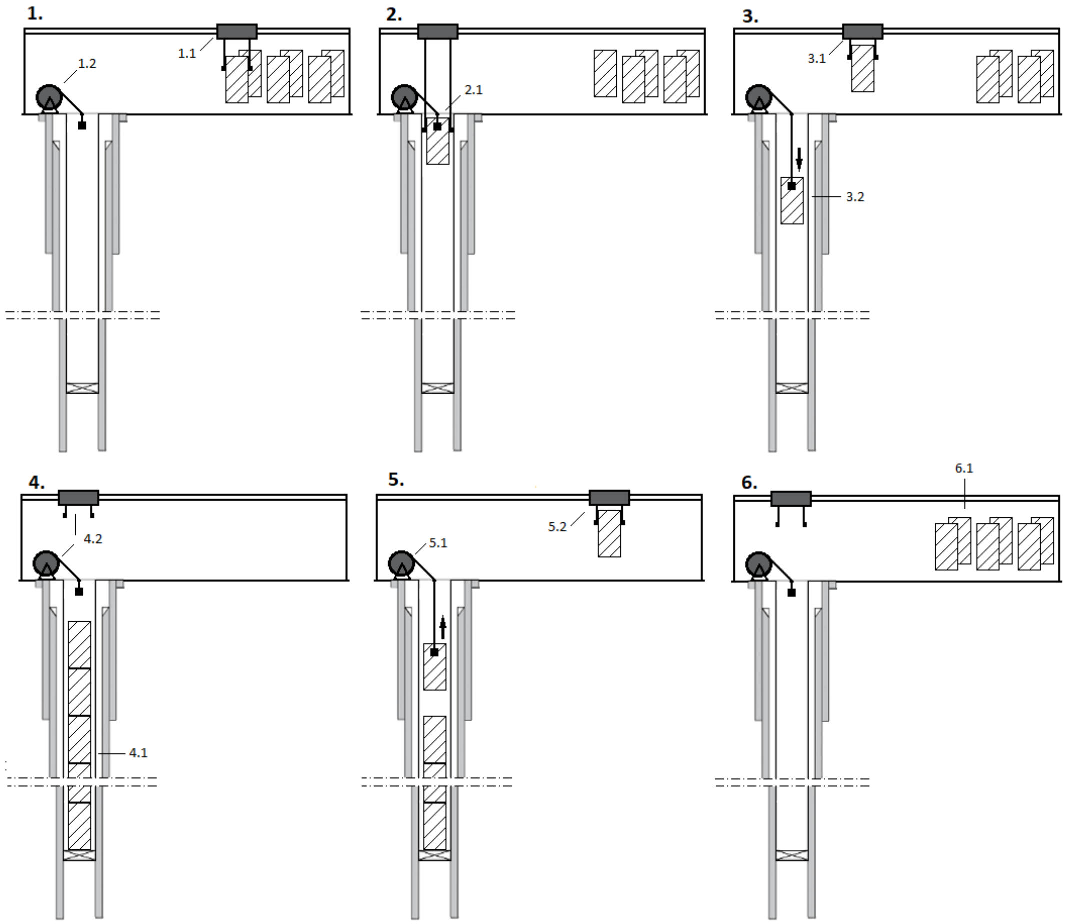

Figure 5. Stages of gravity operation of the underground energy storage, 1 - storage 100% full, 4 - storage 100% unloaded (Fabiś, 2022)

The second way is to store energy in the boreholes in the form of pressure. One form of visualization of a borehole filled with compressed gas is e.g. a compressed air cylinder (Fig. 6). Pressure can be a form of energy storage in old gas fields, in existing reservoir traps, but it is also possible to use the boreholes themselves. This method of storing energy, however, is more complicated for thermodynamic and technical (including strength) reasons.

Downhole energy storage does not need to be located in the vicinity of consumers, such as borehole heat exchangers. Building an electricity network is much cheaper than building a heating network.

Figure 6. The compressed gas cylinder is a pictorial representation of the orifice pressure store

4. HEAT LOSSES FROM GEOTHERMAL BOREHOLES

When extracting geothermal waters, there are transmission losses in the exploitation borehole to the surrounding rock mass. Table 3 lists the following: head temperature, lost heating power throughout the borehole, and the amount of heat that will be lost during the year with a constant flow rate of operation equal to 100 m3 / h. This is illustrated by the conversion to tons of oil equivalent (toe). The calculations were made for one of the Polish geothermal well. Various construction conditions of the well were assumed. The use of cement slurries with different thermal conductivities was assumed. In addition, in the configuration of the borehole, the use of other casing columns, which also differ in thermal conductivity, was adopted. The depth of the borehole is 2380 m, and the temperature of the geothermal water at this depth in the reservoir is 82.68°C.

Table 3: Parameters of the wellhead temperature and heat loss for each design configuration of a geothermal well with a water flow rate of 100 m^3/h

The material from which the pipes are made and its thermal conductivity coefficient, λ, $\frac{W}{(m \cdot K)}$	Thermal conductivity of the hardened sealing grout, λ, $\frac{W}{(m \cdot K)}$	Wellhead temperature, T_g, °C	Power lost (throughout the borehole), P, MW	The amount of heat lost per year (in the entire borehole with a constant flow rate of water exploitation), Q	
				GWh	toe
Steel – 50	1.0	79.14	1.86	58805.3	1404.54
Steel – 50	1.5	78.93	2.00	63033.1	1505.52
Steel – 50	2.0	78.81	2.07	65413.6	1562.38
Fiberglass – 0,361	1.0	79.71	1.51	47766.1	1140.87
Fiberglass – 0,361	1.5	79.56	1.60	50403.6	1203.87
Fiberglass – 0,361	2.0	79.48	1.64	51843.5	1238.26

In the table above it can be seen that with this water exploitation flow rate, the temperature changes at the wellhead are still noticeable, but their change compared to the value at the bottom is much smaller. Its size is more influenced by the change of the pipe material than the change of the thermal conductivity of the hardened cement grout. There are also noticeable changes in heat loss, which are significantly smaller when comparing the most advantageous variant with the least favorable one.

It is proposed to use the VIT technology (vacuume insolated tubing) for the implementation of casing pipes in geothermal boreholes. The best geothermal well in Poland, Bańska PGP-1, has a water temperature in reservoir of around 92°C. On the wellhead, however, the temperature is variable. After 23 years of water exploitation, i.e. in the conditions of a warmed rock mass, it can fluctuate within relatively large limits, depending on the instantaneous water flow rate, which is imposed by the degree of loading of the heating plant. Most often it fluctuates around 86°C. With the maximum capacity of the borehole of 550 m^3/h, the heat loss in the borehole is 3.75 MW. At the same time, the most valuable heat is lost, i.e. the one with the highest temperature and potentially possible used to generate electricity in a binary power plant.

5. CONCLUSIONS

New geothermal wells should have corrected designs.Based on the analyzes and calculations, it is concluded that due to transmission heat losses in production geothermal wells, glass fiber tubes or VIT vacuum tubes should be used - especially in the upper part of the well. In addition, such holes should be sealed with a grout that, after hardening, has the lowest thermal conductivity.

Other new boreholes should be considered at the design stage in terms of their use for purposes other than the original drilling purpose. Boreholes that can act as geothermal boreholes for the exploitation of water should be made in the same way as new production geothermal boreholes. In the absence of potential aquifers, the boreholes can act as (deep) borehole heat exchangers. Depending on the depth of the borehole, their radial thermal transmittances should be different. At smaller depths (up to 300-500 m), sealing grout with the highest possible thermal conductivity should be used, similarly to casing pipes. At greater depths, slurries with the highest conductivity as possible should be used in the lower part of the borehole, while slurries with the lowest possible conductivity may be used in the upper part. The heat carrier in deep bore exchangers may have a temperature higher than the surrounding rock mass when it flows into the borehole. Then it would lose heat to the surrounding rocks. The high heat resistance at the top of the borehole will reduce such losses.

Boreholes that can act as gravity or pressure energy storage do not have such requirements. This does not apply to cases where the openings have a combined function, e.g. a hole heat exchanger and a gravity hole energy storage.

ACKNOWLEDGEMENTS

This research was conducted as a part of the “Excellence Initiative – Research University” (IDUB) programme at the AGH University of Science and Technology in Krakow, Poland

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