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NEW BOREHOLE HEAT EXCHANGERS IN THE GEOENERGETICS LABORATORY AT THE FACULTY OF DRILLING, OIL AND GAS, AGH UST IN KRAKOW**

Abstract: The Geoenergetics Laboratory at the Faculty of Drilling, Oil and Gas in Krakow is presented in this paper to mark its 10th anniversary. The origins of the Laboratory, its equipment and the design of borehole heat exchangers belonging to the field research station are also discussed.
Recently, the construction of 14 new borehole heat exchangers was designed and the boreholes will be drilled in the area of AGH University. They will perform heating and cooling for the new S1 building of the University. Every borehole heat exchanger will be tested, with the effective thermal conductivity and borehole thermal resistivity calculated after a thermal response test on every borehole. The difference between boreholes should show the difference of borehole thermal resistivity, but the effective thermal conductivity should be the same.

Keywords: Laboratory of Geoenergetics, geothermal energy, geoenergetics, borehole heat exchangers, thermal response test, geothermics

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1. INTRODUCTION

The recovery of geothermal energy is growing in popularity both in Poland and globally. Geothermal heat is qualified as one of the renewable energy sources, and they commonly occur and can be developed in a number of ways. The geothermal waters resources in Poland are deposited at various depths in the Polish Lowland, Sudetes, Carpathians and Carpathian Foredeep. In Poland, geothermal waters are mainly used for heating purposes, with their outflow temperatures varying depending on the yield of the borehole (adjusted to demand) and the time of extraction. Low-temperature heat, exploited with the use of borehole heat exchangers is also frequently used [5, 6] without bulk production, as in the case of water. Borehole heat exchangers are closed systems which do not have any hydraulic contact with the rock mass.

With the development of the geothermics and geoenergetics, a number of tests and measurements should be performed to improve the recognition and use of geothermal energy. For this reason, the Geoenergetics Laboratory was established at the Faculty of Drilling, Oil and Gas in Krakow in 2008. Apart from the above, many other functions are also realized at the Laboratory.

2. THE ORIGINS OF THE GEOENERGETICS LABORATORY

The implementation of new heating-air conditioning solutions necessitated the working out of alternative methods for the operation of the assemblies that were based on definite assumptions, i.e. the efficient operation of the system over the year and low investment costs, mainly exploitation. The realization of these assumptions had to be based on the analysis of many variables at the stage of the design and exploitation of the system. The first project which considerably contributed to the formation and development of the Geoenergetics Laboratory was one devoted to a heating-cooling system with borehole heat exchangers in the Ecological Education and Entertainment Park in Rawa county at the turn of 2006/2007 [14, 15]. In 2006 the thermal response test (TRT) was performed for the first time in Poland [1, 6].

Another factor which spurred the organization of the Laboratory was the research grant from the Ministry of Science and Higher Education realized in 2007–2010 targeted at [2]:

- evaluation of the heat potential of the rock mass,
- analysis of techniques and technologies of drilling wellbores and their adaptation to borehole heat exchangers in various geological conditions,
- analysis of borehole heat exchangers design,
- proper selection of sealing slurries for sealing borehole heat exchangers,
- modeling of borehole heat exchangers,
- optimization of exploitation parameters of borehole heat exchangers,
- proper selection of the configuration of borehole heat exchangers.

For a fuller picture of the potential problems and verification of the obtained results, five different borehole heat exchangers were designed and constructed. They were equipped with measuring systems and automatic controls. These exchangers were a starting point for a Field Test Station, which is part of the Geoenergetics Laboratory [2]. Drilling works started in 2008. 14 new boreholes were drilled and the Geoenergetics Laboratory continues to develop. In the future, a Geoenergetics Laboratory II is planned.

3. LABORATORY EQUIPMENT

The Laboratory is equipped with ten or so test and measurement posts as well as mobile devices which can be used for Thermal Response Tests (TRT) and for the measurement of the natural temperature of the rock mass (probe NIMO-T) (Tab. 1).

Table 1

Equipment in the Geoenergetics Laboratory [6]

No.	Equipment	Characteristic
1	Thermal Response Test Apparatus	The thermal parameters of the drilled rock can be obtained with the thermal response test. This method is used for evaluating actual heat properties of the rock mass in the analyzed site. Thermal resistivity can be determined with TRT
2	Heat pumps working in a system of two-directional heat flow (heating and air conditioning)	Two heat pumps of heating power 26 kW as well as heat (0.75 m^3) and cold (1.5 m^3) storages were installed at the Laboratory. This installation is used for heating and air conditioning of the Aula at FDOG AGH-UST, bld. A-4
3	Borehole heat exchangers	The installation in Geoenergetics Laboratory consists of borehole heat exchangers of various designs and was performed at the turn of January and February 2008
4	Laboratory model of centric borehole heat exchanger	The Laboratory is equipped with a model for analyzing energy efficiency of centric borehole heat exchangers. A vertical heat exchanger consists of an outer layer, e.g. a casing protecting the system against mechanical damage. The inner part of the vertical laboratory model of a borehole is made of steel pipe
5	Apparatus for measuring heating power	Apparatus for measuring heat power is mainly used for didactic purposes. Students are asked to determine the effect of heat carrier (water) volume on the thermal parameters of flow. The volume flow rate of water and its temperature are measured before and after the electric heaters
6	Thermal conductivity meter	Thermal conductivity is measured with TT-TC-01 produced by ThermTest Inc. from Canada. This device TT-TC-01 is used for measuring thermal conductivity of solid samples with minimum thickness of 5 mm and surface adjacent to the sensor 20 mm× 50 mm [8]
7	Probe NIMO-T for temperature profiling in boreholes	Probe NIMO-T (Non-wired Immersible Measuring Object for Temperature) is a small, light, cordless probe consisting of pressure and temperature meters and also a programmable microprocessor. All was disposed in a metal, water-tight pipe withstanding pressure up to 110 bar. The sensor is about 235 mm long. It is 23 mm in diameter and weighs 99.8 g [4, 7]
8	Thermovision camera	The thermovision camera FLIR (model E60) has a high resolution and is easy to operate when making measurements. Measurements can be performed at temperatures from –20°C to 120°C or from 0°C to 650°C. This device has an accuracy of ±2°C or ±2% of readout [12]

Table 1 cont.

No.	Equipment	Characteristic
9	Ultrasonic flow meter	The ultrasonic flow meter MicronicsPortaflow 330 is used for non-invasive measurements of fluids flow rates in pipes (linear flow). It can be also used for measuring the volume flow rate [11]
10	Solids humidity meter	The solids humidity meter WIP-24 produced by Tanel is a double-function humidity meter used for measuring the humidity of solids: timber and construction materials (concrete). The measurement is non-invasive. The principle of the humidity meter is based on the measurement of the dielectric constant. The measured material is penetrated by a electromagnetic field [10]
11	Meteo mini station	This station is equipped with devices for measuring the speed and direction of wind, and also the intensity of solar radiation. These measurements are used for the analysis of power efficiency of solar collectors
12	Solar collectors	The Geoenergetics Laboratory is equipped with five solar collectors for the regeneration of heat resources in the rock mass. These are two flat collectors GAK 2.0, a vacuum collector NSC-58-18 and two vacuum collectors CPC 6. Two of them are portable (solar-track), and three are stationary
13	System for desnowing parking with heat of the rock	Laboratory is equipped with a system for de-icing/desnowing/drying of a car park with the heat of the rock mass. This installation can be also used for the recuperation and transport of heat to the rock mass in the period of increased solar radiation and high air temperatures
14	Water level meter in boreholes	Pressure meter mounted on the transmission line to be tripped to the borehole. The line is equipped with capillaries transmitting atmospheric pressure values to the submerged pressure sensor
15	Non-contact thermometer	FILR TG165 is an IR thermometer, connecting thermal imaging with traditional IR thermometer operation. The IR thermometer is used for measuring the temperature on the surface of an object, whereas the optical part of the thermometer detects emitted, reflected, and transmitted energy of the object. FLIR TG165 processed obtained information to a temperature readout [9]
16	Air heater	This is an air/glycol heating coil where glycol solution circulates from cold or heat storages held by the Geoenergetics Laboratory
17	New borehole heat exchangers	In 2017, on the 10th anniversary of the Geoenergetics Laboratory, 14 new borehole heat exchangers were drilled, each having a different design

The Laboratory is also equipped with computers with specialist software (Tab. 2).

Table 2

Computers with specialist software used at the Geoenergetics Laboratory [6]

No.	Software	Characteristic
1	TOUGH2.0 (Transport of Unsaturated Groundwater and Heat)	This is a basic simulator for non-isothermal flow of a multiphase medium in a porous environment. Apart from its main purpose related to the analysis of heat resources in the ground, TOUGH2.0 can be also used for a broader analysis of fluid and heat transport in porous media [3]
2	PetraSim	Pre- and post-processor PetraSim facilitates the operation of simulator TOUGH2.0. It makes the elaboration of the model easier and creates more possibilities of processing the results and their numerical modeling
3	BoHEx	Simulator BoHEx facilitates the modeling of single borehole heat exchangers of various designs and arbitrarily spatially distributed boreholes in the rock mass
4	Audytor OZC	Audytor OZC is software for engineers, energy auditors and all specialists dealing with heating installations and also problems with rational energy management. This software is used for aiding calculation of space heat demand in buildings and for determining seasonal heat demand for heating residential houses [13]
5	Earth Energy Designer (EED)	Earth Energy Designer (EED) is a calculation program for simulating the operation of borehole heat exchangers and heat pumps in the successive years of exploitation at varying heat load
6	Grapher	Graphical program used for plotting graphs and schematics

4. CHARACTERISTICS OF BOREHOLE HEAT EXCHANGERS

The Geoenergetics Laboratory owns 5 old borehole heat exchangers, which were constructed at the turn of January and February 2008. These exchangers were drilled to a depth of 78 m. Each of them had a different design and sealing. For details, see Table 3.

Table 3

The first borehole heat exchangers at the Geoenergetics Laboratory [6]

Parameter	LG-1a	LG-2a	LG-3a	LG-4a	LG-5a
Design	PE casing 90 mm in diameter and 5.4 mm wall thickness, inner PE tube 40 mm in diameter and 2.4 mm wall thickness	Single PE U-tube 40 mm in diameter and 2.4 mm wall thickness	Single PE U-tube 40 mm in diameter and 2.4 mm wall thickness	Single PE U-tube 40 mm in diameter and 2.4 mm wall thickness	Double PE U-tube 32 mm in diameter and 2.4 mm wall thickness

Table 3 cont.

Depth of BHE [m]	78	82	78	78	78
Depth at which BHE tubes were placed [m]	78	78	78	78	78
Sealing of the borehole	Sealing slurry based on cement	Sealing slurry based on cement	Sealing slurry (ThermoCem) based on cement with increased thermal conductivity	Gravel of 8 mm to 16 mm grain size and two silt plugs – Compactonit	Sealing slurry based on cement

In 2017 a new research area with 14 oblique borehole heat exchangers of various designs was built in the AGH University of Science and Technology (Tab. 4). The distribution of new borehole heat exchangers is presented in Figures 1 and 2.

Table 4

Designs of new borehole heat exchangers

OWC no in Figure 1	OWC	Tube	Sealing	Initial angle of deviation of borehole axis [°]	Initial azimuth of borehole axis [°]
1	2 × U ∅32	Traditional tube	TermorotaS	11	210
2	1 × U ∅32	Turbocollector	TermorotaS	4	90
3	2 × U ∅32	Turbocollector	TermorotaS	10	270
4	2 × U ∅32	Turbocollector	TermorotaS	4	90
5	1 × U ∅40	Traditional tube	TermorotaS	13	270
6	1 × U ∅40	Turbocollector	TermorotaS	4	90
7	1 × U ∅45	Turbocollector	TermorotaS	10	270
8	1 × U ∅32	Turbocollector + spacers	TermorotaS	4	90
9	1 × U ∅32	Turbocollector	20 m from top TermorotaS	10	270
10	1 × U ∅40 3 tubes (2 + 1)	Turbocollector	TermorotaS	4	90
11	1 × U ∅40 3 tubes (2 + 1)	Turbocollector	Slurry	0	–
12	1 × U ∅32	Turbocollector	Cement	4	90
13	First U-tube: – ∅32 – Turbocollector – ∅40 – Turbocollector Second U-tube: – ∅32 – Traditional collector – ∅40 – Traditional collector		TermorotaS	0	–
14	1 × U ∅32	Turbocollector	TermorotaS with graphite	10	180

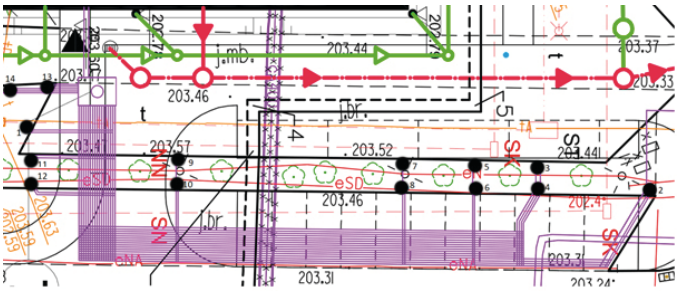

Fig. 1. Distribution of new borehole heat exchangers (black dots)

Fig. 2. New research area with oblique borehole heat
built in the AGH University of Science and Technology (2017)

5. CONCLUSIONS

1. Nowadays geothermics and geoenergetics is becoming increasingly popular and so there is a growing need to perform specialist tests on them.
2. The Geoenergetics Laboratory at the Faculty of Drilling, Oil and Gas has the requisite equipment and specialists to perform thermal response tests, interpret TRT results and profile temperatures.
3. The Geoenergetics Laboratory at the Faculty of Drilling, Oil and Gas is equipped with a variety of equipment and software to perform interpretations of the results of scientific and industrial experiments, on the basis of which larger installations can be built, and their exploitation predicted in detail.
4. The Geoenergetics Laboratory at the Faculty of Drilling, Oil and Gas is constantly developing, broadening its activity and technological offer.

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