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THE USE OF A HEATER AND BOREHOLE HEAT EXCHANGERS FOR THE REGENERATION OF HEAT RESOURCES IN THE ROCK MASS ON THE EXAMPLE OF THE GEOENERGETICS LABORATORY, AGH UST**

1. INTRODUCTION

Issues of obtaining energy and its sources for many reasons are the subject of research in many places. Energy heat pump systems based on borehole heat exchangers are used as research installations in many universities on the world. The examples are installation in University of Ontario Institute of Technology [3]. The UOIT borehole thermal energy storage system has almost 400 boreholes each over 200 m deep. Borehole fields also are spaced around the campus of Ball State University. The fields contain a series of closed pipes that are installed vertically in the rock-mass. Ball State's loop consists of approximately 3600 boreholes, 122–152 m deep. The boreholes are 4–5 inches in diameter. During Phase 1, 1800 boreholes were drilled. Phase 2 will include the drilling of 1800 additional boreholes, ending with more than 1610 km of geothermal piping installed [1]. On VSB-Technical University of Ostrava exists also laboratory BHE field [2].

The installation at the Geoenergetics Laboratory of the Faculty of Drilling, Oil and Gas AGH UST allowed the authors to investigate heat resources for their regeneration capacities in the rock mass [5]. The system is equipped with five borehole heat exchangers performed in 2008 [4], and making up a Borehole Thermal Energy Storage (BTES). Then, the installation for measuring heat regeneration was gradually developed. In 2010 it was connected to the Auditory hall owned by the Faculty of Drilling, Oil and Gas, and located between buildings A3 and A4. The old ventilation system was substituted with a new one, thanks to which the heat could be recuperated. This was the first stage at which the air temperature was changed. At the second stage the temperature was

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modified with an air heater, with glycol circulating from heat and cold storages at the Geoenergetics Laboratory.

The installation was also equipped with a source of peak heat, i.e. heat-supplied heater from the municipal district heating system. This is also an emergency source of energy [5]. In 2011 solar collectors were added to the installation. Their major task lies in regenerating heat resources in the rock mass with heat recovered while air conditioning the Auditory (comprising 150 students). The last element of the installation was the parking system in front of the Laboratory's building. Prior to lying concrete sett paving, a set of thirteen loops with circulating glycol, i.e. heat/cold carrier for the entire system, was disposed. In the winter period it protects the parking area against snow acumulations, whereas in the summer it can be used for recovering additional energy for heat regeneration in the rock mass.

This paper was focuses on analyzing an air heater at the Geoenergetics Laboratory FDOG AGH UST (Fig. 1), i.e. one of the systems to be used for regenerating heat in the rock mass. The presented data are a result of calculations oriented for the capacity of the considered system.

Fig. 1. Air-to-glycol heater in the installation owned by the Geoenergetics Laboratory, FDOG AGH UST (photo by A. Złotkowski)

2. CALCULATIONS OF AIR HEATER USABILITY

Research on the use of air heat through a heater, i.e. source of rock mass energy regeneration, started on 20 August 2013. In the case of an air heater it is not necessary to analyze the influence of the solar radiation intensity on the obtained result due to the permanently shaded location of the equipment.

At the first stage the operation of the laboratory system was so adjusted as to meet the requirements of the analyses. With properly selected valves the heater was connected to the cold-side storage, thus making the measurements possible. Each day, prior to the measurements, the temperature of the glycol was reduced to 0°C. This was done with heat pumps which transmitted energy from the cold storage to the heat storage. At that time the energy accumulated in the heat storage was transferred to the rock mass through the borehole heat exchangers. To accelerate the cooling process, successive borehole heat exchangers were activated. After the temperature of the cold storage was lowered to 0°C, heat pumps were turned off and the valves connecting the cold storage with the air heater were opened. Then, the heat from the heater resulted in the growth of water temperature in the cold storage for the next 24 hours. After the 24-hour period elapsed, the procedure was repeated. As a result data coming from 9 measurement days were obtained. Exemplary capacity measurement results obtained from an air heater during one day are presented in Figure 2.

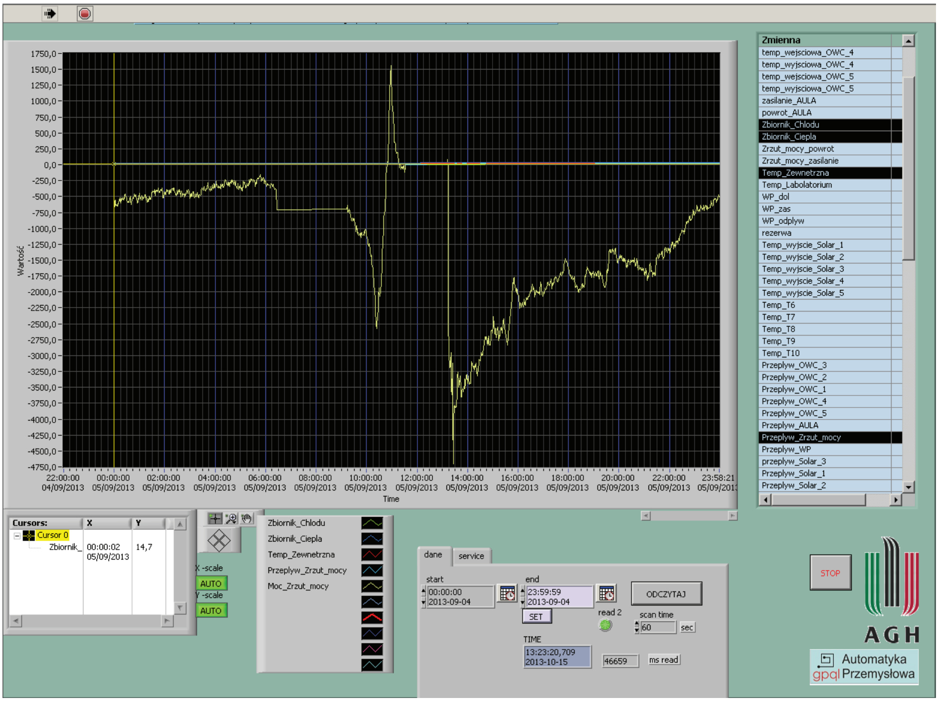

Fig. 2. Air heater capacity readout on an exemplary measurement day

The printscreen picture of a data reading program presented in Figure 2 has only a general informative character. It can be used for exporting data to the calculation sheets, thus enabling further analysis of the obtained results. An exemplary plot made for an air heater capacity on a particular day is shown in Figure 3. The data used there are analogous to those in the plot shown in Figure 2. However, a certain difference can be spotted there, i.e. between 6:27 hrs and 9:12 hrs the measurements stopped for some unknown reason. This moment is erroneously visualized on the printscreen (Fig. 2) as a period of constant capacity equal to –750 W. After exporting these data to a calculation sheet one can see that no data were recorded at that time.

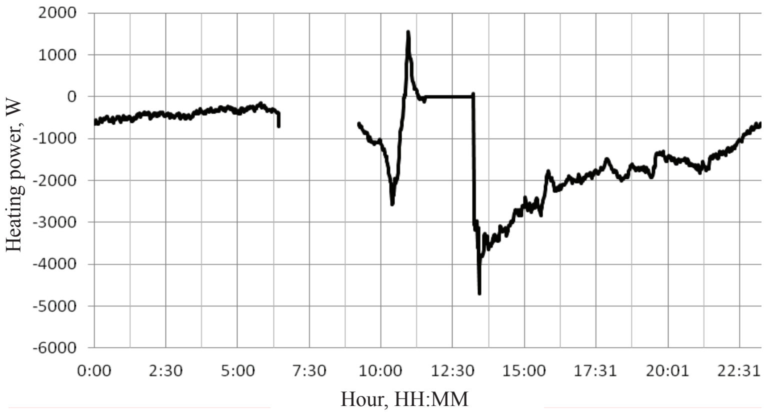

Fig. 3. Air heater capacity changes as of 5 September 2013

The negative capacity value in the plot (Fig. 3) denotes that at that time heat recuperated from the air heater was disposed in the cold storage. The temperature of the carrier flowing into the cold storage is higher than the temperature of the outflowing medium. When the plot cuts the OX axis the direction of heat transport changes, i.e. energy accumulated in the cold storage is transmitted outside the heater to the atmosphere.

Analysis of the obtainedresults

A set of complete data was obtained during 9 measurement days, then the data were analyzed. The measurement of time in which cold storage increases its temperature from 0°C to 10°C was considered to be reliable. An average air temperature was determined for this temperature range. The obtained results are listed in Table 1.

Table 1

List of results of cold storage heating time in the range 0–10°C

Day	ΔT [°C]	Heating time [min]	Average air temperature [°C]
20 August	10	213	15.6
21 August		205	17.3
24 August		209	21.0
26 August		260	19.2
27 August		315	17.0
28 August		269	19.5
4 September		205	19.2
5 September		168	19.4
7 September		253	14.5

To better illustrate the obtained result, the heating time of glycol in the cold storage was plotted against air temperature (Fig. 4). The results turned out to be very interesting, i.e. no direct influence of average air temperature on the obtained heating time of cold storage exists. The results of measurements are not indicative of any correlations, which can be evidenced by the obtained correlation coefficient value. The obtained results show to the necessity of performing more such measurements.

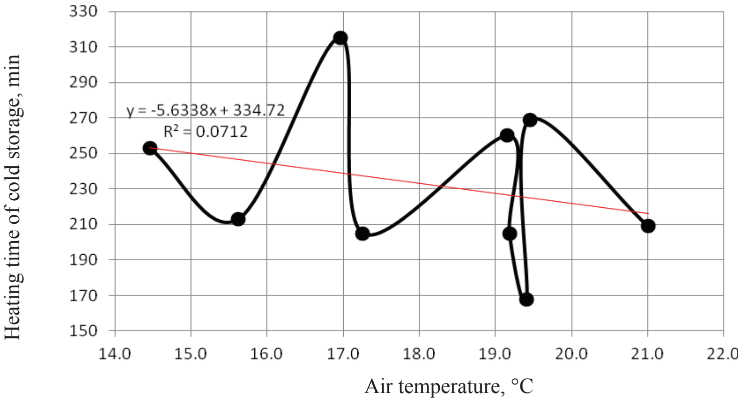

Fig. 4. Heating time of cold storage against air temperature (20 August – 7 September 2013)

The second stage of calculations lies in evaluating the amount of energy which can be recuperated from the air heater installation during one day, and listing these results against the maximum thermal capacity value. The results are visualized in Table 2, and the respective data used for plotting (Fig. 5). Unfortunately, these data cannot be used for determining trends due to the very low correlation coefficient for linear functions.

Table 2

List of maximum capacities and total energy recovered over successive measurement days

Day	Heat carrier flow rate [dm^3/min]	Maximum capacity of heater [kW]	Energy recovered during 24 hrs [MJ]
20 August	26.7	5840.5	92.78
21 August	26.7	5029.5	89.83
24 August	26.3	4928.0	77.21
26 August	26.3	3835.7	87.63
27 August	26.0	4029.0	80.53
28 August	26.3	4271.4	80.07
4 September	26.1	4080.6	83.05
5 September	26.2	4705.5	77.59
7 September	25.6	3283.5	53.07

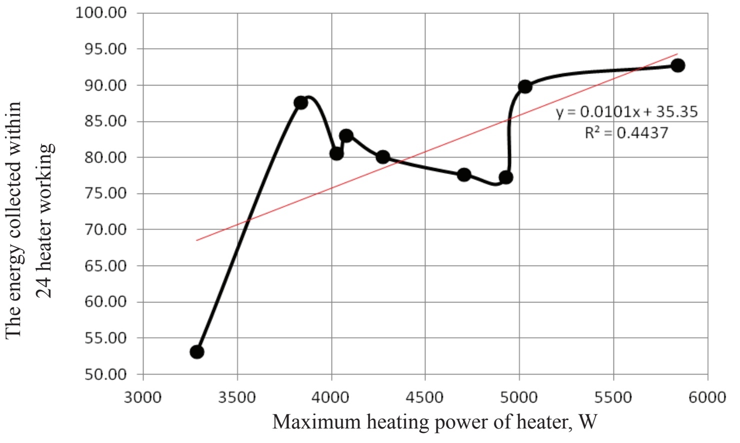

Fig. 5. Energy recovered during 1 day of heater operation against maximum capacity of heater (20 August – 7 September 2013)

The course of the plot (Fig. 5) reveals a trend which is, however, not fully legible. Generally, it can be assumed that with the growing maximum capacity of the heater the energy recoverable during one day of measurements increases as well. This is particularly well visible for a large spectrum of capacity values. Figure 5 represents a trend line determined as a linear function with a low correlation coefficient.

For the reason of obtaining a better picture of the influence of temperature and capacity on accessible thermal energy one should perform additional studies. They should be performed when the heat pump operates constantly; this would give onesome information about energy available in given temperature conditions.

3. CONCLUSIONS

1. The Geoenergetics Laboratory of the Faculty of Drilling, Oil and Gas AGH UST is a place where various analyses are made, in that studies devoted to the regeneration of heat resources in the rock mass. Four installations are used for this purpose: solar collectors, air conditioning, air-to-glycol heater and parking area.
2. When calculating energy accessible from the air heater, the solar radiation intensity can be neglected due to the localization of the system in a permanently shaded area.
3. As far as the measurement of heating time of the storage of a cold water solution of propylene glycol from 0°C to 10°C is concerned, no correlation with the air temperature was observed. Many more such measurements should be performed.
4. The amount of energy obtained during 24 hrs, when the cold storage was cooled down during one cycle, depends on the maximum capacity of the air heater. This trend becomes more vivid, the bigger is the difference between the obtained maximum capacities.
5. Not all planned analyses could be performed due to the failure of one of the circulation pumps in the system.This considerably limited the ability to interpret the obtained results.

6. For the reason of investigating the regeneration potential of the air heater further analyses should be performed as in the case of the parking area, e.g.measurement of the heater capacity during when the system operates constantly, i.e. heat is pumped to the rock mass with a heat pump steadily.

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