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BTR-4 BOREHOLE THERMAL RESPONSE TESTING EQUIPMENT AND APPLICATION RESEARCH

Summary. An equipment for in-situ testing the mean thermal conductivity of formation and borehole resistance is introduced in this paper, which provide a new approach to test the parameters of rock and soil for designing the ground source heat pump system(GSHPS). The parameters are tested under heat extraction situation of a single U-pipe heat exchanger and heat injection situation of a double U-pipe heat exchanger by using the device, and the conclusions are drawn that the mean thermal conductivity of formation of heat injection situation is larger than heat extraction situation, the calculating result of thermal conductivity of line source model is greater than cylinder source model, and the borehole thermal resistance of the double U-pipe is less than the single U-pipe heat exchanger.

APARATURA BTR-4 DO BADAŃ METODĄ ECHA TEMPERATUROWEGO (THERMAL RESPONSE TEST) I JEJ ZASTOSOWANIA BADAWCZE

Streszczenie. W artykule zaprezentowano aparaturę do badań in-situ średniej wartości przewodnictwa cieplnego i oporu cieplnego skał w otworach. Umożliwia ona nowe podejście do oceny parametrów skał i gruntów dla potrzeb projektowania systemów pomp ciepła (GSHPS). Stwierdzono między innymi, iż średnia wartość przewodnictwa cieplnego zmierzona w reżimie iniekcji ciepła jest wyższa od tejże, określonej w reżimie poboru ciepła. Wartości obliczone dla modelu źródła liniowego są wyższe niż dla modelu cylindrycznego.

1. Introduction

GSHPS is being widely applied in the world by the way of building heating, cooling and underground heat storage. In the GSHPS design, the thermal conductivity of formation and borehole thermal resistance are two main parameters. If they are not accurate, the system would not satisfied the need for heating/cooling load or result in an increased initial investment. There are two methods to determine the parameters in the past, one method is to check the manuals based on the rock and soil types; another one is to drill and get the sample in the field, and then derived the value from laboratory. Because of the impact of groundwater and disproportionate of formation, the value determined by these two methods is larger different with the actual value, sometimes reaching about 20%. Currently, in-situ borehole thermal response testing is often used to test the thermal physical properties of ground.

2. Borehole Thermal Response Testing Method

The idea of on-site borehole thermal response test first appeared in the international conference(IEA) in 1983, which was held in Stockholm. Mogensen P. [1] put forward a method to determine the thermal conductivity and borehole thermal resistance in field. By extracting/injecting constant heat from the borehole, fluid temperature in the heat exchanger are tested, and then heat transfer process between the heat exchanger and the soil and rock is evaluated by using a variety of heat transfer model.

The principle of the test is as follows (shown in Figure 1 [2]): Drill the borehole and the depth of it is same with real project, then, put HDPE pipe into the borehole and backfill the materials as design requirements. When testing start, the heat exchanger connect with the pipe in the testing equipment, and operate heat pump continuously for tens of hours(the general requirements more than 48 hours), so, the temperature and flowrate of the fluid are gotten, and then, the mean thermal conductivity of formation and borehole thermal resistance could be calculated by using heat transfer model.

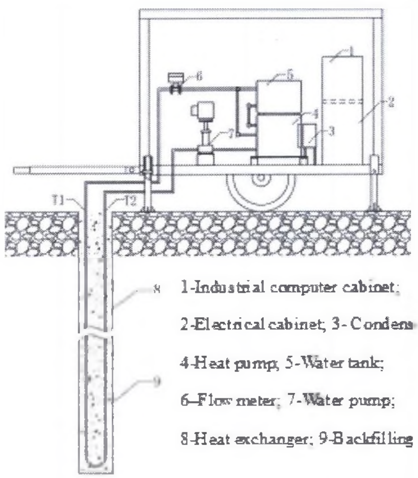

Fig. 1. Test principle diagram
Rys. 1. Schemat ideowy testu

3. BTR-4 Borehole Thermal Response Testing Equipment

The equipment shown in Figure 2 [3] is consist of the heat pump, water pumps, electrical three shunt valve, flowmeter and temperature sensor etc. The electrical three shunt valve is used for adjusting the temperature of fluid, in order to ensure inject/extract constant heat to/from ground.

The different functions are realized by adjusting valves. For example, when opening the valves 20,21,22,24, the pipes can be cleaned and filled with fluid(sometime may be ethylene glycol). When closing valve 22、23、24, and the others open, the test could be carried out. Because the structure and materials of heat exchanger is same with actual project, the testing result is meet mostly the needs of GSHPS design.

The equipment can realize many fuctions of manual control and automatic control, and light and sound alarm. The control functions include: power supply of heat pumps, water pumps, flow meters etc.; heating or cooling state of heat pump; the shunt ratio of three shunt valve. In addtion, it would also alarm by sound and light and show the corresponding prompt when temperature, pressure, flow or power anomaly occurs. The testing system is controlled by industrial computer, which installed configuration software. The computer controls the switch of each circuit and deal with such acquisition data of the temperature, flow, and pressure etc., and output signal to PLC controller. Then, in accordance with design of control requirements, PLC controller output signals to the control objects to achieve the control functions. The data acquisition and control system block diagram shown in figure 3.

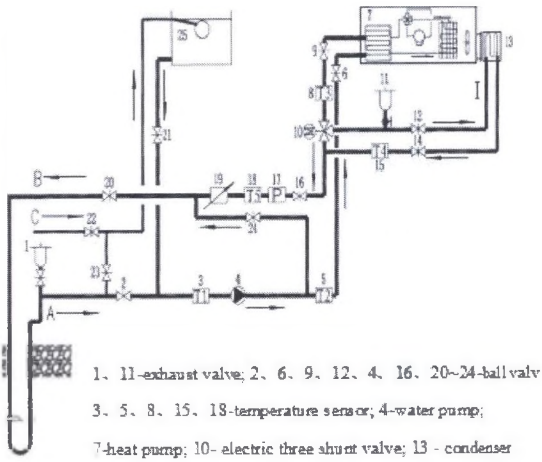

Fig. 2. Flow chart of the circulation system
Rys. 2. Szkic obiegu w analizowanym systemie

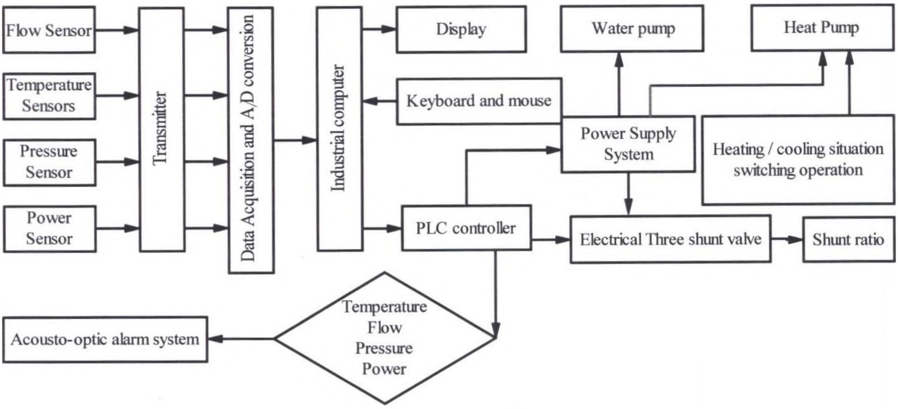

Fig. 3. Data acquisition and control system block diagram
Rys. 3. Diagram pozyskiwania danych i sterowania układem

4. Application of Thermal Response Test

4.1. The Testing Boreholes

The solar-assisted GSHPS of Green Energy Lab in Jilin University has 5 heat exchange boreholes, which stratum consist of 5 meters backfilling, 25 meters loess, and red mudstone left. The depth of boreholes is 100 meters, and the distance is 6 meters. Single U tube, double U tube and coaxial tube are installed in the boreholes respectively. The arrangement of borehole is shown in Figure 4.

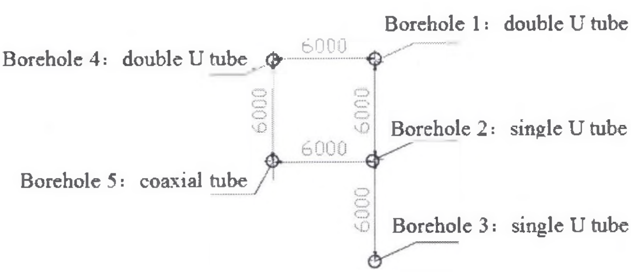

Fig. 4. The arrangement of the boreholes
Fig. 4. Usytuowanie otworów

4.2 Heat Injection Test

This test [4] was done from July 20, 2008 to July 23, 2008. The conditions of the borehole are: (1)Type of heat exchanger: Φ32 single U HDPE pipe; (2) Effective depth of borehole: 89 meters; (3) Borehole radius: 0.09 meters; (4) Backfilling: sand 20% + bentonite 80%; (5) Initial temperature of soil: 11.8 deg C; (6) Operating mode of heat pump: cooling operation; (7) Testing time: 73h.The testing and simulating curves are shown in Figure 5, and the thermal physical parameters are shown in Table 1.

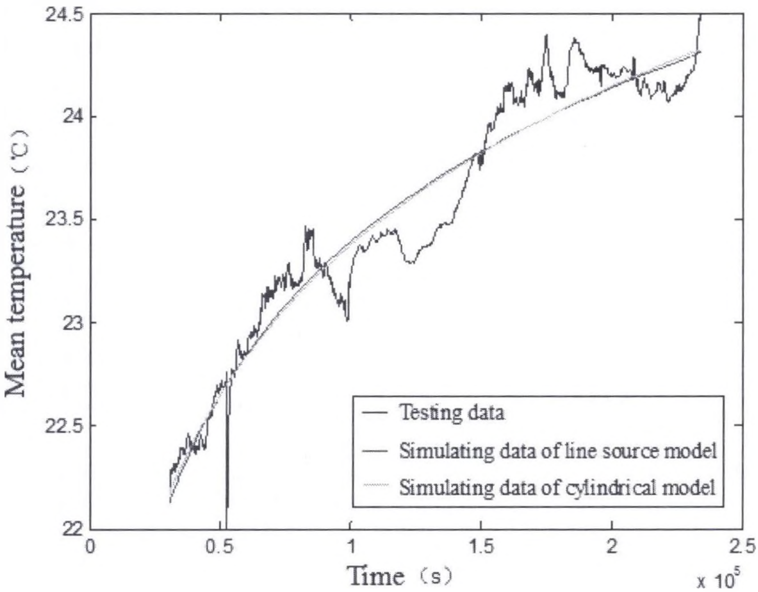

Fig. 5. The mean temperature of fluid under heat injection situation
Rys. 5. Średnie temperatury płynu – iniekcja ciepła

Table 1

The calculating results

Calculating model	Calculating parameters	
Line-source model	thermal conductivity λ W/m·K	2.978
	borehole thermal resistance R m·K/ W	0.109
Cylindrical model	thermal conductivity λ W/m·K	2.708
	borehole thermal resistance R m·K/ W	0.094

4.3. Heat Extraction Test

The test was carried out from March 16, 2009 to March 21,2009. The conditions of the borehole are: (1) Type of heat exchanger: Φ32 double U HDPE pipe; (2) Effective depth of borehole: 80 meters; (3) Borehole radius: 0.09 meters; (4) Backfilling: sand10%+cement20%+ bentonite 70%; (5) Initial temperature of soil: 9.6 ℃; (6) Operating mode of heat pump: heating operation; (7) Testing time: 75h.

The testing and simulating curves are shown in Figure 6, and the thermal physical parameters are shown in Table 2.

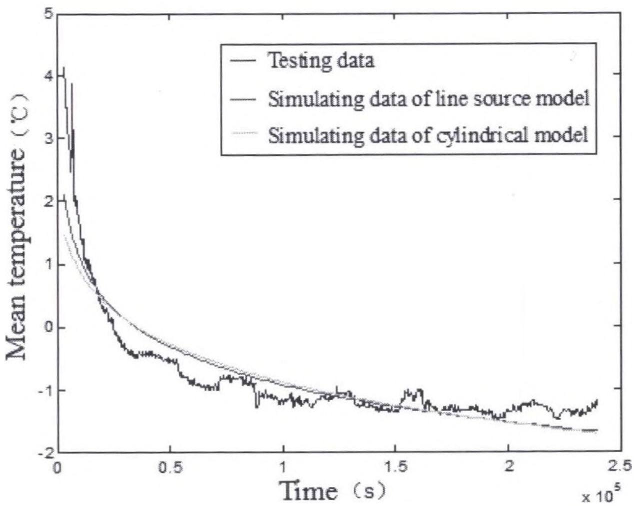

Fig. 6. The mean temperature of fluid under heat extraction situation
Rys. 6. Średnie temperatury płynu – pobór ciepła

Table 2

The calculating results on heat extraction situation

Calculating model	Calculate parameters	
Line source model	Thermal conductivity λ W/m·K	2.789
	Drilling thermal resistance m·K/ W	0.056
Cylindrical model	Thermal conductivity λ W/m·K	2.543
	Drilling thermal resistance R m·K/ W	0.047

5. Conclusions

By analyzing the testing data and simulation results, conclusions could be obtained as follows:

1. The mean thermal conductivity of ground obtained on heat injecting condition is greater than the one obtained on heat extraction condition.
2. The mean thermal conductivity of ground and borehole thermal resistance obtained by line source model are greater than the ones obtained by cylindrical model.
3. Borehole thermal resistance of double U pipe is less than single U pipe, that is, heat transfer effect of double U heat exchangers is better than single U ones.

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