Paper VI

Reduction of Thermal Resistance by Air Injection into Boreholes Field Test and Analysis

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Abstract

The design of ground heat exchanger (GHE) systems requires knowledge of ground thermal properties, e.g. ground thermal conductivity and thermal resistance of the borehole. The main purpose of this study was to increase the heat transfer by forced convection in the borehole. In order to achieve this goal air bubbles were injected at the bottom of a borehole. Two thermal response tests (TRT) were carried on the same borehole, before and after the injection of air bubbles. It was found that the thermal resistance of borehole was reduced by 27.65%. The effective thermal conductivity was also changed and increased by 27.71% because the injected air bubbles caused convection in the groundwater surrounding the borehole

Keywords: Ground heat exchanger; Thermal response test; Thermal resistance; Forced convection

Introduction

Heat transfer from the heat carrier fluid in a ground heat exchanger (GHE) to ground occurs through four stages, see Fig.1:

1. Convection in side the pipe.
2. Conduction through pipe wall.
3. Convection through the ground water between the pipe and borehole wall (or conduction through the filling in filled boreholes)
4. Conduction through the surrounding ground.

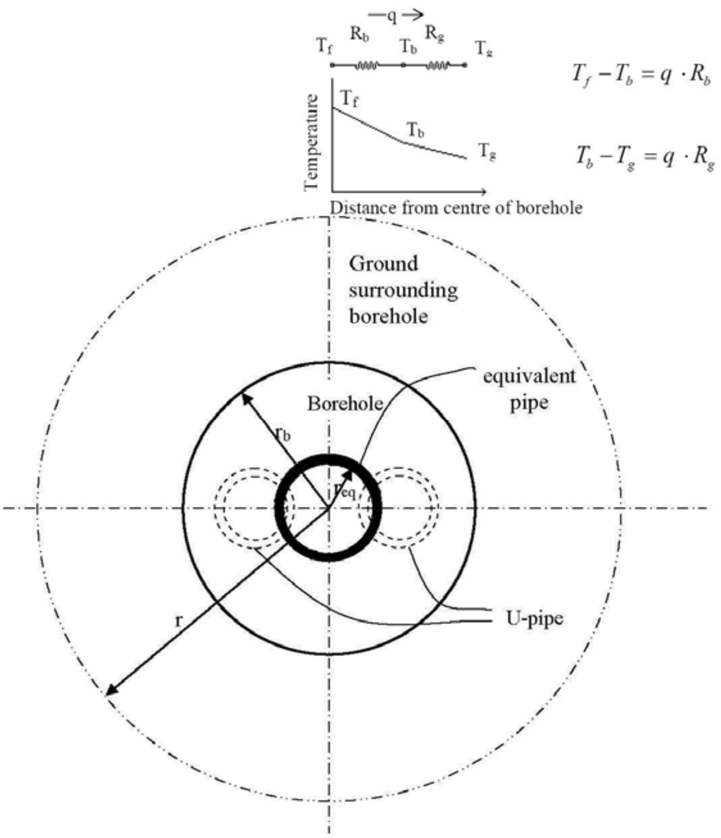

Fig. 1. Schematic representation of the BHE system model with heat transfer and temperature distribution for heat injection.

The sum of the first three stages is called borehole thermal resistance R_b[1]-[2]:

$$R_b = R_{cvi} + R_{cd} + R_{cve}$$

Where

R_{cvi}	internal convection thermal resistance due to convection inside the pipe i.e. from heat carrier to internal pipe's wall
R_{cd}	thermal resistance due to conduction through the pipe's wall
R_{cve}	external convection thermal resistance due to convection outside the pipe i.e. from the external pipe's wall to well's wall

There are many experimental and theoretical studies on the influence of groundwater flow on the performance of borehole heat exchangers have been published[3]-[4]-[5]-[6]. These studies show that increasing ground water flow increases the heat transport from the borehole by increasing the natural convection in the groundwater; accordingly alleviate buildup of heat in the borehole field over time. Gustafsson et al (2008) showed that convective flows result in a *2–4* times more effective heat transfer through the borehole relative to pure conductive transfer would have caused within the temperature interval of *10 – 30ºC*. Her simulations show that a temperature increase from *15 – 30ºC* decreases the borehole thermal resistance from *0.075* to *0.065 K·m/W*[7].

In current work, the aim was to reduce the external convection thermal resistance, by enhancing heat convection between the U-pipe and borehole wall, in order to reduce borehole thermal resistance. Despite the fact that there is no direct way to measure the ground heat conductivity and the borehole thermal resistance[8], the thermal response test (TRT) is considered as the most exact way to determine the thermal properties of GHE. Such measurements give data from which the thermal properties can be calculated.

Experimental apparatus and methodology

Mogensen[9] suggested the (mobile) thermal response equipment in 1983 and Gehlin (2002)[3] developed this idea between 1996-2002. We tried to apply Gehlin's experiences in this test.

Experimental data analysis and methodology

The thermal response data i.e. temperature development in the borehole for a certain heat injection/extraction rate, allow estimation of the effective heat conductivity of the ground and the thermal resistance of the borehole heat exchanger. The analysis of the response test data is based on a description of the heat as being injected from a line source.

Thermal Response Test Equipment

The equipment was set up on a small trolley (Fig.2). It consists of a 1.1kW water pump that circulates the heat carrier through the GHE and the electrical heater (water container). The heater has an adjustable and stable power in the range 2.25-9 kW. The fluid temperature is measured at the inlet and outlet of the borehole by thermocouples, with an accuracy of 0.2 C. The temperatures were logged each 10 minutes.

In order to avoid energy losses and the influence of temperature changes of ambient air, the equipment was placed inside the building where the temperature was almost constant.

Fig. 2. Used thermal response test equipment.

Experiment installation and equipment

The test was made at in Karlstad, Sweden, in collaboration with Willy´s CleanTech AB. This office building has been heated by a GSHP system of five boreholes with diameter of 115 mm since 2002. The boreholes, which are of different depths (128-130-131-151 m) are located around the building as shown in Fig.3. The red colored borehole, was chosen for the experiment.

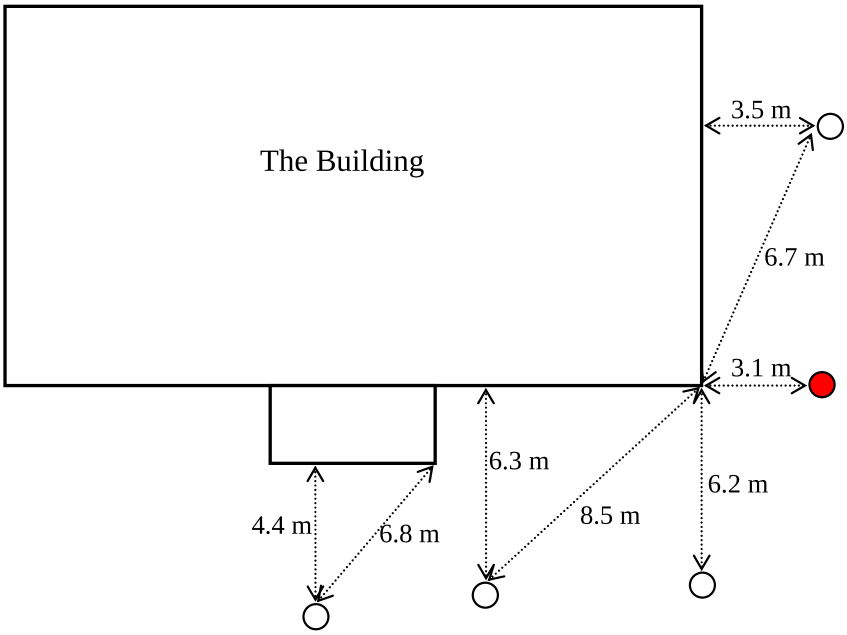

Fig. 3. Location of the boreholes and the building .

Figure 4 outlines the experiment setup. The heater has an adjustable and stable heat power in the range 2.25-9 kW. The circulation pump (PKM 60-1, Pedrollo) has a nominal electrical power of 1100 W, working at 2600 rpm with a flow rate between 60 l/min to a maximum height of 50 m. The air compressor (Danfoss Kompr SC12CL) was connected to a plastic hose of 6 mm diameter to inject air bubbles at the bottom of the borehole. The volumetric air flow was measured by a TopTrak meter (model 662-13-OV1-PV1-V1-MP) and the water flow rate by a LadistGyr (Ultraheat). Ambient air temperature and the borehole temperatures were measured by thermocouples (Standard Temperature Probe PB-4724). The equipment was calibrated prior to the test.

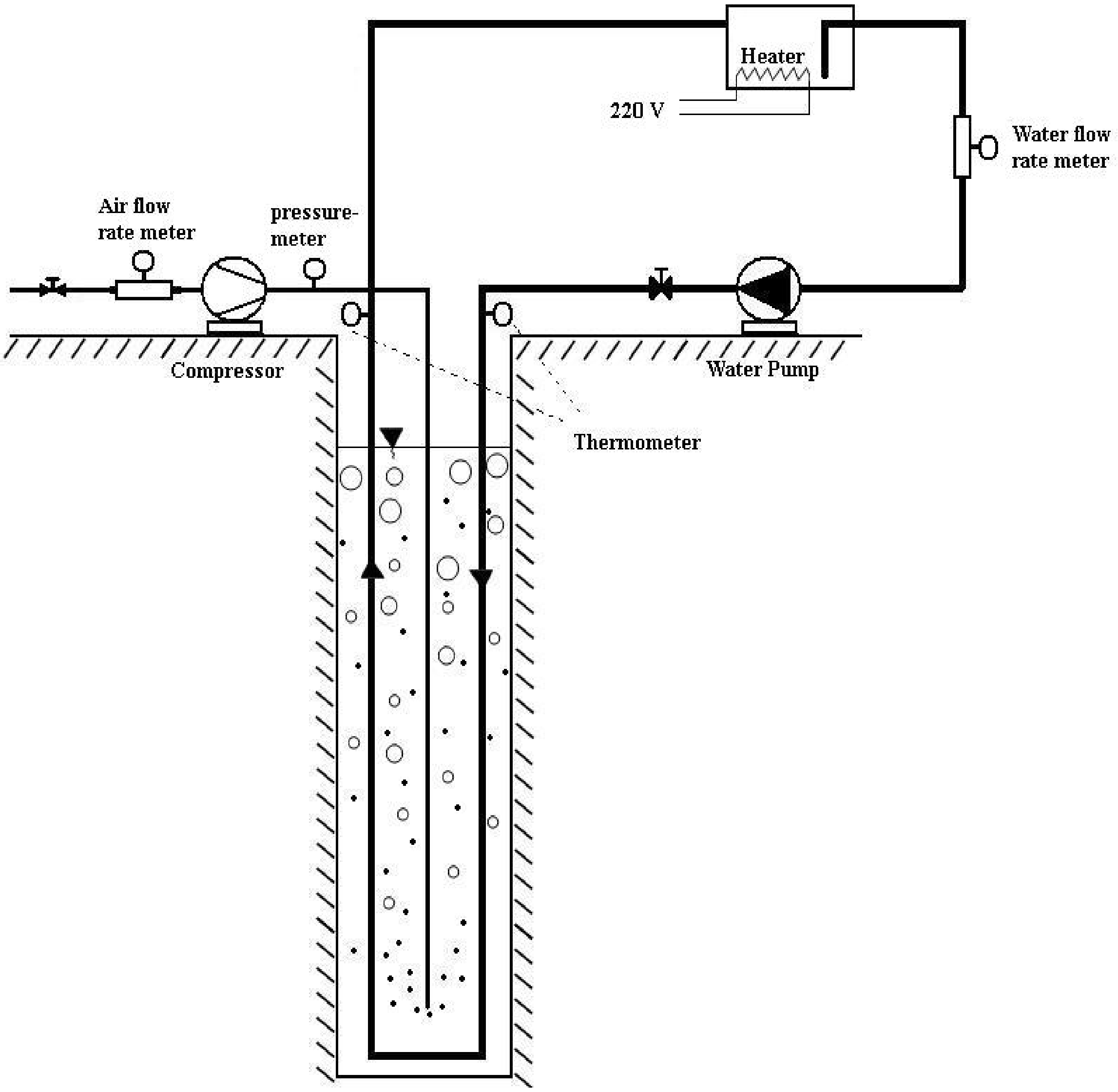

Fig. 4 Outline of experimental setup in Karlstad.

Thermal response test

The temperatures of ambient air, inlet and outlet water of the borehole were measured. Although the flow rate was fixed at the constant value of 3510 l/h, it was continuously measured and controlled. The electrical power was regulated and maintained at constant capacity. The volumetric air flow rate was held constant at 4.1 Nl/min (Normal liter per minute).

On 2009-02-09 at 16:30, the circulation pump was switched on for one hour without injecting any thermal capacity. After that the electrical heater was switched on for 40 hours. The total heat power injected into the borehole was 5.284 kW. At the end of this stage the experiment was switched off for 12 hours. After that, two failed attempts to inject air to the bottom of the borehole, the old compressor was replaced. The time between the last failure and the first injection of air was 117 h and 40 min.

On 2009-02-18 at time 18:10, the experiment started with air injecting for 24 h and 20 minutes. Figure 5 shows the total results of all tests. It should be mentioned however that in last step the total heat power injection (i.e. total heat supplied by the heater; water pump, and air compressor) was 5600 W.

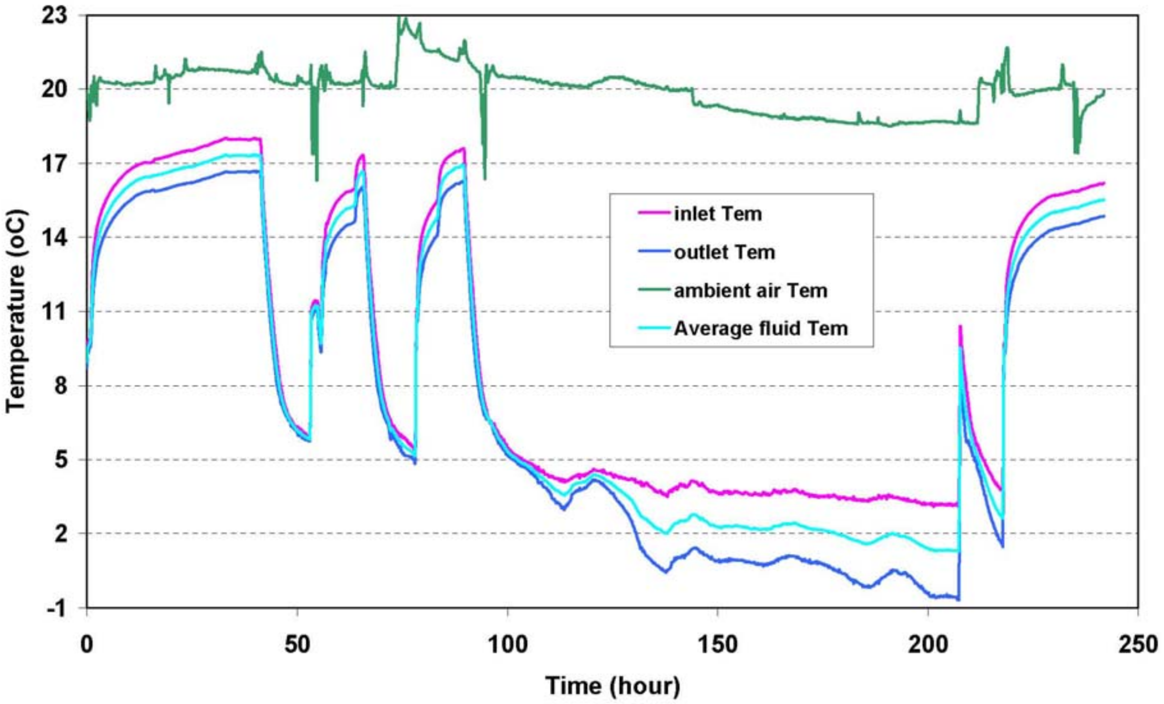

Fig. 5. Measured thermal response.

Response Analysis

Fig.6 shows a comparison between mean fluid temperature development before and after air injecting into the borehole. It is seen that even though injected thermal energy was increased due to the use of the air compressor, the fluid temperature was reduced by injecting air. The slope of the line is reduced too. This means borehole thermal resistance was reduced and thermal conductivity was increased by injecting air. The thermal resistance of the borehole and the effective thermal conductivity of the ground were estimated using classical base line source model, see Figs. 6-7 and Table 1.

Table 1: Calculated results

Type of experiment	Thermal Resistance m.K/W	Effective ground thermal conductivity W/m.K
Without air injection	0.0753	3.44
With air injection	0.0545	4.39

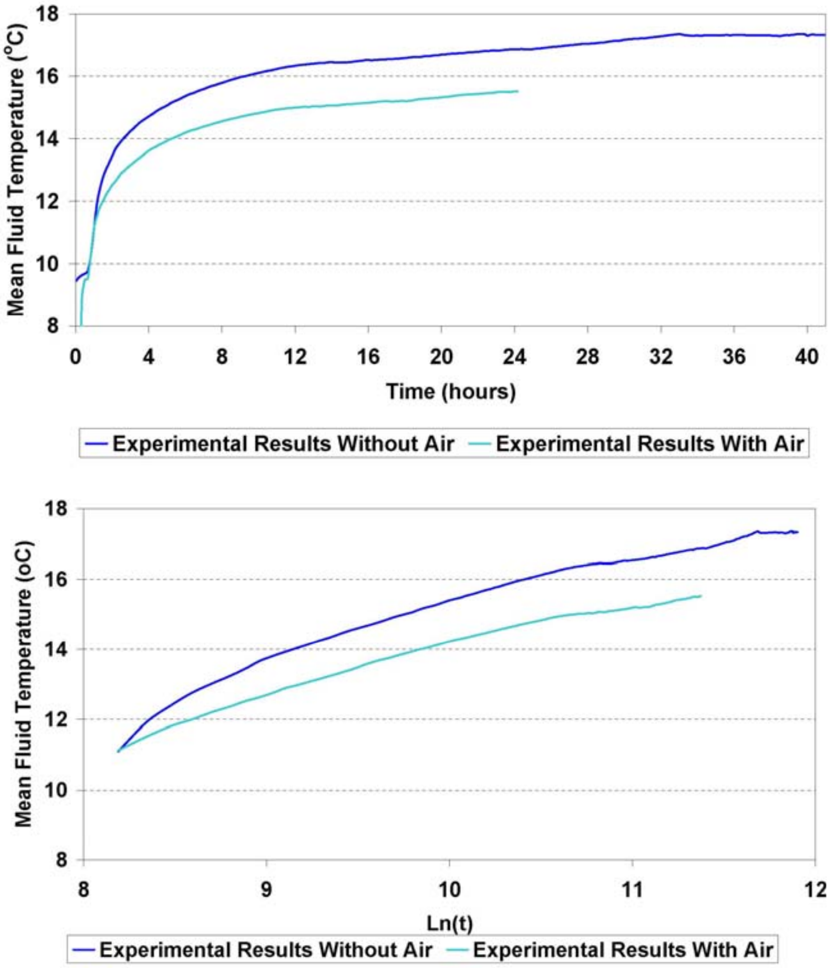

Fig. 6. Thermal response with and without air injection.

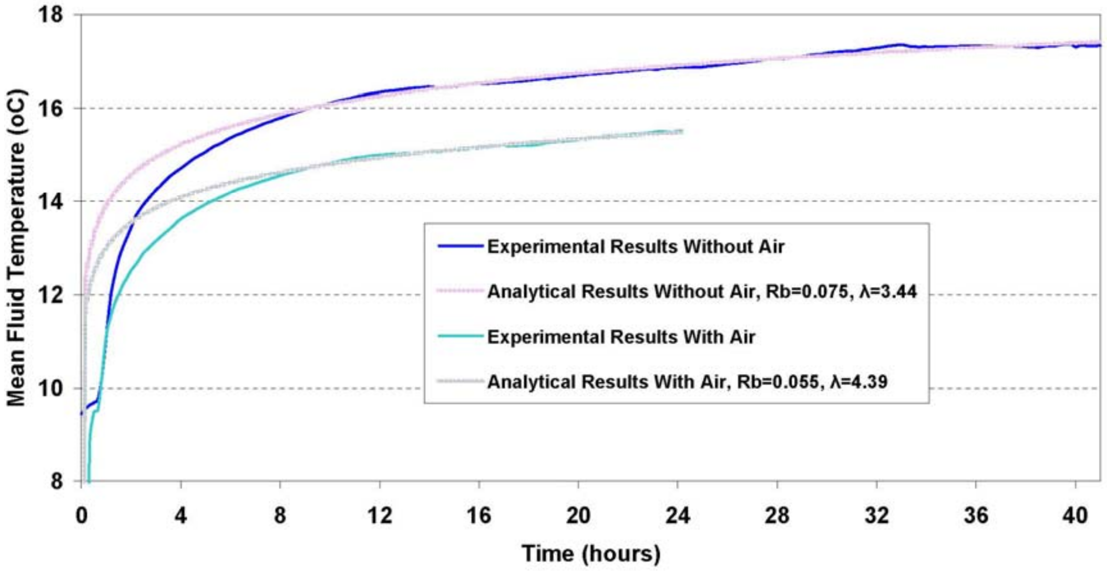

Fig. 7. Thermal response with and without air injection.

Conclusion

The thermal resistance of the borehole before injecting air to borehole was 0.0753 K,m/W while thermal conductivity of the surrounding ground is 3.437 W/m.K. After injecting air into borehole these values became 0.0545 K.m/W and 4.389 W/m.K, respectively.

Consequently, the air injection reduced the thermal resistance of the borehole by 27.7%. Since injected air bubbles caused convection also in the groundwater, surrounding the borehole, the effective thermal conductivity was increased 27.7%.

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