DISTRIBUTED TEMPERATURE MEASUREMENTS ON A MULTI-PIPE COAXIAL BOREHOLE HEAT EXCHANGER

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Abstract: The first experiences with a multi-pipe borehole heat exchanger prototype consisting of an insulated central pipe and twelve parallel peripheral pipes are described. Secondary fluid distributed temperature measurements along the borehole depth, being the only ones of its kind in this type of heat exchanger, are presented and discussed. The measurements are carried out with fiber optic cables during heat injection into the ground, giving a detailed visualization of what happens both along the central and peripheral flow channels. The heat exchange with the ground mainly occurs along the peripheral channels and an indication of almost no thermal short circuiting, even while having large temperature differences between the down and upwards channels, is observed.

Key Words: ground source heat pumps, borehole heat exchanger, coaxial

1 INTRODUCTION

Designers of Ground Source Heat Pump (GSHP) systems normally have several alternatives on how to plan system connections, i.e. ground loops connected to a heat pump, ground loops used for free cooling, connection with solar collectors, chillers, ventilation, heat recovery systems, etc. Even combinations of all these may sometimes be of interest.

Regardless of how the system is designed, it is of vital importance to account for how the ground would respond to the different thermal power regimes to which it would be submitted, meaning that the short and long term thermal response of the borehole and ground thermal resistances must be evaluated.

The usual method to exchange heat with the ground in GSHP installations is by means of U-pipe Borehole Heat Exchangers (BHE), consisting of two equal cylindrical pipes connected at the bottom and through which a secondary fluid travels down an upwards while exchanging thermal energy with the ground. U-pipe BHEs are relatively inexpensive and easy to install, and the systems installed so far with this technology have shown to be very efficient. However, the thermal performance of U-pipe BHEs is rather poor, primarily due to unknown and varying pipe positions along the borehole (with respect to each other and to the borehole wall), the relatively low thermal conductivity of eventual grouting materials, and the low thermal conductivity and the thickness of the pipes. All these result in one way or the other on large temperature differences between the secondary fluid and the ground and on thermal shunt flow between the U-pipe channels, especially at low volumetric flow rates.

The experimental works published until now about BHEs have been mostly concentrated on U-pipes whilst few publications have included practical experiences on coaxial BHEs (consisting of one central flow channel and one or several peripheral channels, all sharing the same longitudinal axis).

Coaxial borehole heat exchangers have, in general, a stronger basis for allowing lower thermal resistances between the ground and the circulating fluid, meaning that the short term operation of GSHP systems using coaxial BHEs would depend more on the thermal response of the ground rather than on the thermal resistances in the borehole. Some of the few experimental works in the coaxial BHE field have been discussed in (Hellström et al., 2000), (Hellström, 2002), (Platell, 2006), (Erdwärme-Systemtechnik GmbH & Co, 2006) and (CRES, 2008), and (Acuña, 2010).

(Hellström, 2002) mentions an annular coaxial open BHE system where the fluid travels in direct contact with the rock in the annular channel, having almost no thermal resistance, (Platell, 2006) describes a Thermal Insulated Leg (TIL) consisting of one central insulated pipe and several outer pipes. (Hellström et al., 2000) presented results from such a design at laboratory scale, resulting on thermal resistances significantly lower than U-pipes. (Erdwärme-Systemtechnik GmbH & Co, 2006) and (CRES, 2008) presented the installation methods and the different parts of annular (pipe-in-pipe design) BHE consisting of one PE63x5.3mm outer and an inner PE40x3.7mm pipe. Similarly, results from a multi-pipe prototype manufactured by Mateve Oy (Finland) having five outer channels all within the same pipe package, and from an annular prototype manufactured by PEMTEC, Sweden, have been published by (Acuña, 2010) . The latter design consists of a flexible external hose that is attached to the rock wall as it is filled with water after installing it into the borehole, followed by the insertion of a standard PE40mm pipe. Measurements on the latter pointed at low temperature differences between the borehole wall and the secondary fluid.

This paper focuses on a TIL prototype which working principles have been described in Swedish reports about twenty years ago by Ove B. Platell within the frame of different projects. The design is similar to the ones discussed in (Hellström et al, 2002) and (Platell, 2006), and consists of a multi-pipe coaxial borehole heat exchanger with a thermally insulated central pipe and twelve peripheral pipes. The prototype (TIL G-12) is manufactured by UPONOR and it is at the moment being tested at KTH as part of two research programs, EFFSYS2 (www.effsys2.se) and EFFSYSplus (http://effsysplus.se).

2 DESCRIPTION OF THE INSTALLATION AND MEASUREMENT SET UP

The installed TIL prototype consists of 100 m deep water filled BHE with 12 thin peripheral tubes placed around an insulated central pipe. A cross section of the geometry is shown in Figure 1. The insulation thickness includes the width of a plastic protection.

This heat exchanger is delivered as a whole package with all 13 pipes rolled around a drum, as shown in Figure 2.

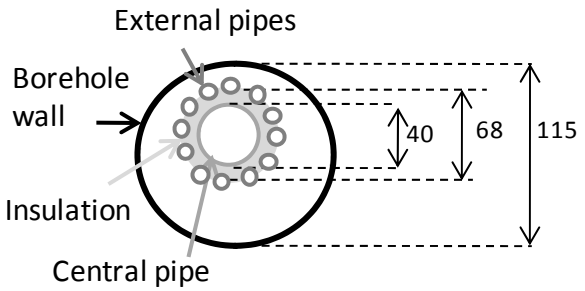


Figure 1. Illustration of the BHE cross section

2.1 The installation procedure

The installation consists of rolling out the whole heat exchanger pipe package as it is inserted into the borehole. Inserting the BHE into the borehole is relatively simpler at the beginning, but gets more difficult as more pipe volume is sent down into the well due to buoyancy forces and possibly to friction against the borehole wall. A special tool such as the one used for U-pipe BHEs but adapted to this design would greatly facilitate the installation.

The installation procedure, in our case, was considerably more special than what a normal installation would look like, due to the insertion a single fiber optic cable first inserted through

the central pipe, then bended at the BHE bottom part, and finally sent through one of the peripheral channels.

Figure 3 and Figure 4 illustrate the fiber cable at the bottom and top parts of the heat exchanger after cable installation, respectively. The cable preparations added a considerable amount of extra time to the installation. Extra bottom weights were also needed at the bottom part of the heat exchanger for overcoming the buoyancy forces during pipe insertion into the well.

A picture of the TIL-G12 BHE taken during the installation in the borehole is shown in ***Figure 5***. The peripheral pipes are kept together during installation with a tape which, after being in contact with the groundwater, loosens and allows for free placement of the pipes. This may, perhaps, contribute to better placement of the pipes with respect to the borehole wall.



Figure 2. TIL G-12 delivered to the site



Figure 3. Fiber cable bend at the BHE *bottom*

2.2 Measurement set up

The secondary fluid temperature is measured by sending laser pulses through the optical fiber cable and interpreting the backscattered light. The intensity ratio between up- and down-shift is a function of the temperature, and this ratio and the delay time are converted to temperatures and positions by the HALO instrument.

Temperature measurements with fiber optics in BHEs have so far only been presented by (Fujii et al. 2006) with an optical fiber cable located on the external part of a U-pipe, by (Fujii et al. 2009) with a cable along one of the two U-pipe shanks, and by (Acuña, 2010), who measured both, inside and outside, along both shanks a U-pipe and an annular coaxial borehole heat exchanger design.

In this case, distributed temperature measurements every two meters have been taken in the secondary fluid side along the TIL-G12 BHE with an instrument of the type HALO, during heat injection into the ground.

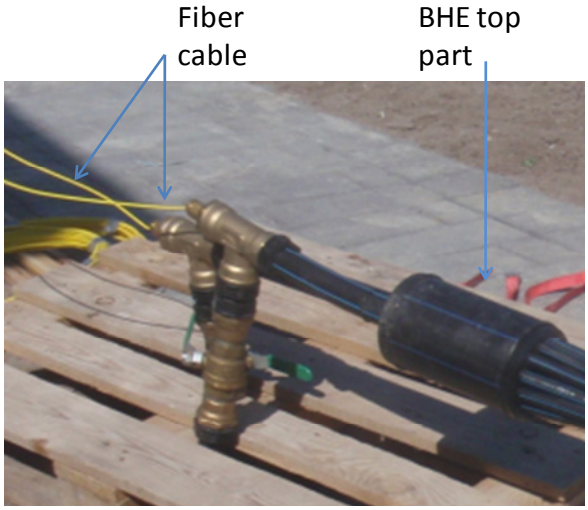


Figure 4. Fiber cable at the BHE top

Different combinations regarding volumetric flow and heat injection rates have been tested, as well as different fluid directions. Measurements from three cases (*A, B*, and *C*) are presented in this paper.

Case A and *B* illustrate scenarios where relatively high volumetric flow and heat injection rates, and low volumetric flow and heat injection rates, are respectively combined, resulting in small differences between the inlet and outlet temperatures at the top of the borehole. In *case A*, the fluid is injected through the central channels and it comes back upwards through the peripheral pipes, while the opposite flow direction occurs in *case B*.

Case C corresponds to a case of high heat injection combined with low volumetric flow rate, resulting in large temperature difference between the inlet and outlet points. The fluid is injected through the peripheral pipes, coming back upwards through the central pipe.

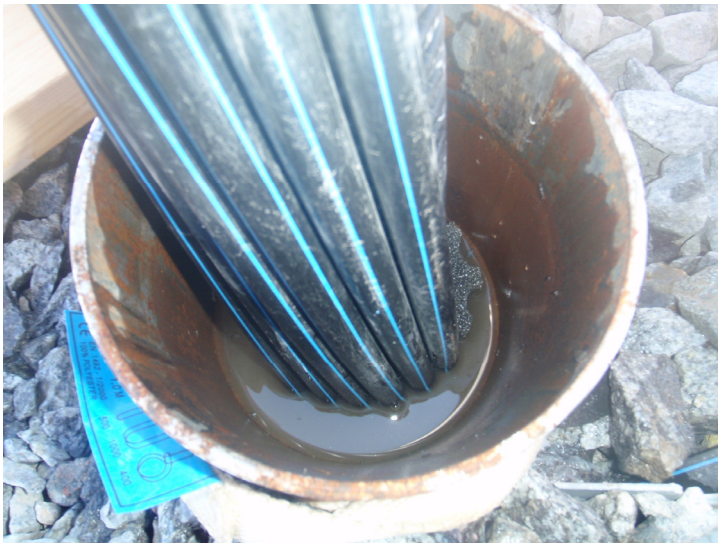


Figure 5. Picture of the borehole during installation

3 TEMPERATURE PROFILES AND DISCUSSION

As described above, temperature measurements are taken during heat injection into the ground. Figure 6 presents the secondary fluid temperature profiles along the whole TIL G-12 heat exchanger for the measurements corresponding to case *A*, *B* and *C*. The temperature differences have been imposed by varying the flow and heat injection rate. The global temperature difference is almost 2°C for cases *A* and *B* and about 5.5°C during *case C*.

When evaluating the temperature profiles in cases A and B, it can be preliminarily stated that the thermal performance in this specific borehole heat exchanger, does not depend on the flow direction. This should not be generalized because the shape of the temperature profile in the ground may change from place to place, as shown by (Acuña, 2010), and an influence of the local temperature gradient on the fluid temperature distribution may be expected in Coaxial BHEs when shifting the flow direction.

Another fact observed in Figure 6 is that the fluid temperature along the central pipe is almost constant for all three cases (changing just some tenths of degree from bottom to top), meaning that the thermal short circuiting between pipes is practically eliminated with this design. Larger temperature difference between the down and upwards channels induces larger heat fluxes between them, so higher thermal shunt would be expected. However, even with the similar geometry along the depth in this case, the insulation seems to efficiently correct for this unwanted effect.

The profiles shown in Figure 6 could be extrapolated to hypothetical cases of heat extraction cases from the ground with the same volumetric and thermal power rates. A secondary fluid

traveling in directions opposite to the ones indicated in Figure 6 would result on similar temperature profiles.

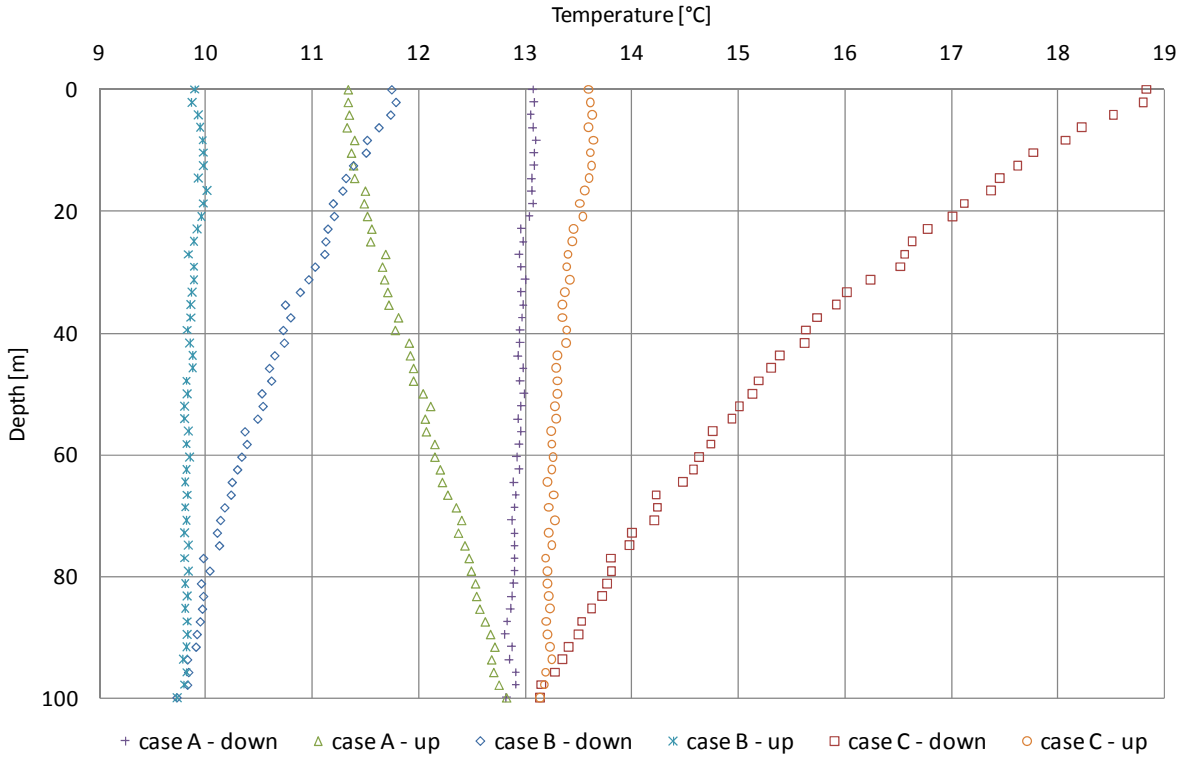


Figure 6. Temperature profiles along the depth for different operating conditions

It can be inferred from these measurements that the TIL G-12 borehole heat exchanger may be of interest in applications where the advantages of large temperature difference (as shown in measurement *case C*) can be used. Systems operating with small temperature differences and high flow rates would still be efficient. However, a full profit from using TIL designs would be obtained if designing the ground loop for large temperature differences. The elimination of the thermal contact between the downwards and upwards channels allows for designs where the temperature levels could satisfy specific needs (e.g. hybrid ground couple solar and/or ventilation systems with heat pumps, direct cooling systems, etc). Moreover, the low volumetric flow rates that result in large temperature differences also allow for low pressure drops.

4 CONCLUSIONS

The installation of a multi-pipe borehole heat exchanger prototype consisting of an insulated central pipe and twelve parallel peripheral pipes is described, including the installation of a fiber optic cable for temperature measurements along the borehole depth on the secondary fluid side.

The heat exchanger is installed in a 100 m deep water filled borehole, being the installation procedure to some extent difficult due to buoyancy forces and possibly to friction between the pipe package and the borehole wall during pipe insertion into the borehole.

Three different induced temperature profile cases taken during heat injection into the ground give a detailed visualization of what happens with the secondary fluid along the central and outer flow channels. The heat transfer with the ground occurs predominantly along the peripheral channels and a strong indication of almost no thermal short circuiting (observed

along the whole borehole heat exchanger length) is revealed, even while having large temperature differences between the down and upwards channels.

5 ACKNOWLEDGEMENTS

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