Experimental studies for improving the performances of compact coil ground heat exchangers

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ABSTRACT

A test facility for closed-loop shallow ground heat exchangers has been implemented in Orléans (France) in 2008. Different configurations have been tested and evaluated, beginning with the traditional horizontal and vertical ground heat exchangers. For five years, a special attention has been given to this test facility to innovative ground heat exchangers with a focus on “compact coil ground heat exchangers” (CGHE).

CGHE are ground heat exchangers with a coil spring shape which are installed at a depth between 2 and 10 m. These systems represent an alternative solution to borehole heat exchangers, installed at about 100 m and requiring a drilling machine, and horizontal ground heat exchangers, installed at about 1 m depth and requiring a sufficient land area. The CGHE are installed with a simple backhoe and require less land area than horizontal ground heat exchangers.

In order to improve the design and thermal performances of these CGHE, research works have been carried out in the four following axis:

- First, different types of CGHE have been tested in order to compare their performances and to propose improvements to the CGHE design.

- Second, coupled heat and mass transfers in the vicinity of the heat exchanger pipe have been investigated in a laboratory experiment to better understand soil temperature and moisture content evolution as a function of heat-carrier fluid temperature.

- Third, the soil – atmosphere interaction has been characterized by means of a detailed instrumentation in the subsurface soil (temperature and humidity probes) and in the atmosphere (weather data station).

Finally, two same geometries of CGHE have been installed in different environmental conditions to improve the installation process by changing the properties of the filling material.

This study aims at showing these experiments and results obtained through a pluri-annual research program on these CGHE using a scale 1 test facility. In conclusion, some recommendations will be proposed to better install these particular types of ground heat exchangers.

1. INTRODUCTION

In France, the energy transition law for a green growth has been promulgated August 17, 2015. This law includes the following objectives :

- Reduce of 40% greenhouse gas emissions between 1990 and 2030

- Reduce of 30% the fossil energy consumption between 2012 and 2030

- Reach 32% of renewable energy in final energy consumption in 2030

The heat pump systems especially ground source heat pumps could significantly contribute to reach these objectives. One important brake to the development of ground source heat pumps in the French market (only about 3 000 ground source heat pumps installed in 2015 [AFPAC 2016]) is mainly due to a too important investment cost.

Some studies have been recently carried out on theses specific GHE, especially in France (Moch 2013, Moch et al. 21014, Moch et al. 2015)).

In such a context, experiments have been carried out on the BRGM test facility to improve the design and installation processes of compact ground heat exchangers (CGHE). These CGHE are a promising solution to reduce the cost thanks to their shallow depth of implementation allowing an installation with a backhoe.

To optimize these CGHE, four experimental studies have been carried out:

- Test of different CGHE geometries in order to optimize the CGHE design

- Study of heat and mass transfers in the vicinity of the heat exchanger pipe to optimize the thermal characteristics of the soil surrounding the pipe

- Evaluation of the soil – atmosphere interaction impact on the moisture content and temperature in the subsurface soil

2. TEST OF DIFFERENT CGHE GEOMETRIES

In the framework of a French Research Project Micro-Geo, 4 CGHE have been tested in the BRGM test facility. To be compared in similar test conditions, the 4 CGHE have been connected in parallel to a heat pump dedicated to heat a cottage of 22 m² (Figure 1). This cottage, non-insulated, has thermal losses estimated to 7.7 kW and is heated through a heat pump installed inside the cottage. The heat is emitted through a fan coil unit (Figure 2).

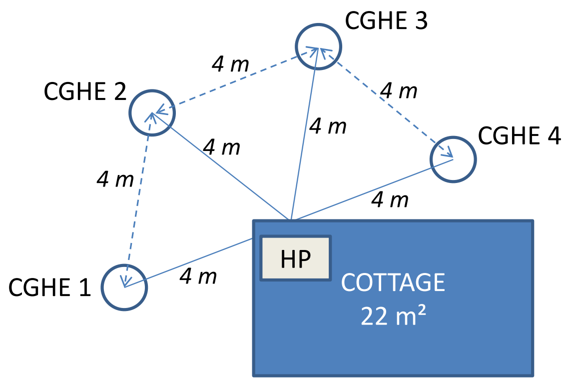

Figure 1 : layout plan of the 4 CGHE installed in the vicinity of the cottage

Figure 2 : Thermodynamic machinery to heat the cottage (from left to right: water tank, heat pump and fan-coil unit)

The 4 CGHE have each specific characteristics. Indeed, 2 parameters are investigated through these tests: the size and the pipe. CGHE 1 and 2 are small models (diameter = 1.0 m and height = 2.3 m). CGHE 3 and 4 are bigger (diameter = 1.2 m and height = 2.7 m). The pipe is standard for CGHE 1 and 3 and improved especially for convective heat transfer in laminar flow for CGHE 2 and 4.

All the 4 CGHE have been implemented with the same process in a hole dug with a backhoe (Figure 3). The CGHE pipe is filled with water and maintained in pressure during filling. The soil is copiously watered through a big hosepipe during the filling phase in order to maximize the compaction of the soil.

Figure 3 : Filling of the hole after installation of a CGHE

An instrumentation has been implemented in the soil at the centre of each CGHE and farther, in an undisturbed area. These temperature are monitored with a 1 min time step during the whole heating period of year 2014-2015. These temperature measurements are reported on Figure 4.

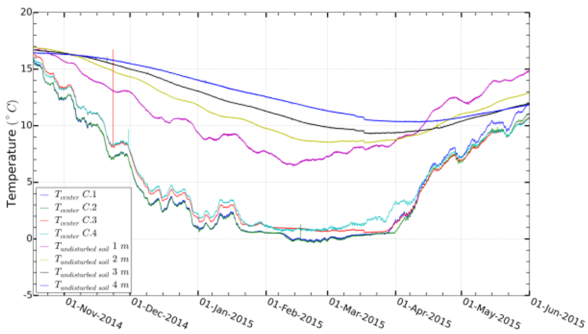

Figure 4 : Temperature at the centre of each CGHE and in an undisturbed area at a 1, 2, 3 and 4 m depth

We can observe on these curves that the temperatures at the centre of each remain at a quite constant level between 0 and 1°C from January to Mars. After this period, the soil retrieves nearly its "natural" temperature, the 4 temperature curves at the centre of the CGHE approaching the measurements in the undisturbed area.

To complete these interpretations, the heat transferred through each CGHE has been measured by a flowmeters and temperature probes. The heat amounts transferred each month and cumulated during the heating period are reported on Table 1.

Table 1 : Heat transfers in each CGHE during the heating period 2015-2016

Month	Heat transferred through each CGHE [kWh]			
	1	2	3	4
nov-14	73,89	76,92	83,81	97,28
dec-14	134,39	138,14	147,00	185,33
jan-15	136,36	137,72	141,11	178,36
feb-15	128,25	130,67	135,17	168,08
mar-15	85,75	88,00	88,31	121,31
apr-15	39,31	39,06	36,44	50,31
mai-15	19,36	18,39	16,42	19,33
heating period	617,31	628,90	648,26	820,00

We can observe that the biggest CGHE with enhanced pipe (CGHE 4) transfers much more energy to the soil than the other ones, especially the reference CGHE (CGHE 1) with an improvement of 33%.

Nevertheless, it is difficult to identify the respective influence of each parameter (size and pipe type) on this improvement due to the close values of heat transferred through CGHE 2 and 3.

3. EXPERIMENTAL STUDY OF HEAT AND MASS TRANSFERS IN THE VICINITY OF A HEAT EXCHANGER PIPE

Compact coil ground heat exchangers are located in the first meters of soil (c.a. 1 to 4 m depth). This often leads to CCGHE lying in the unsaturated – or vadose – zone. Besides, thermal properties depend upon the soil water content. As a consequence, thermal transfer from the CCGHE to the surrounding ground may be impacted by varying ground water content.

An experimental device was designed to measure the influence of the heat-carrier fluid temperature and ground moisture content upon the ground temperature evolution (cf. Figure 5). The device consists in a cylindrical container whose internal diameter is 1 m. The container is filled with Fontainebleau sand up to 80 cm. A vertical pipe is located on the symmetry axis of cylinder, where a heat-carrier fluid circulates. Temperatures in the close vicinity of the pipe are measured at 4 depths at a radial distance from the pipe ranging from 0 to 7 cm. Tensiometers are located close to the pipe on the same distances. Sprinklers disposed on the upper face of the container allow changing the sand moisture content. The container is temperature-regulated by a second heat-carrier fluid circuit at a temperature in the range 15 to 19 °C.

Figure 6 reports the evolution of the soil temperature when a 40 °C warm fluid circulates in the inner pipe for 30 h, measured at the interface pipe/soil (l = 0 cm) and at l = 4 cm, 10 cm, 20 cm and 30 cm, at the mid-depth of the container. The initial temperature is 18.6 °C. A fast increase in the temperature at l = 0 cm can be observed. Within 5 hours it reaches 34 °C and tends to 35 °C after 30 h of heating. A sharp gradient in the radial direction is observed too, since 4 cm from the pipe the temperature is 24 °C. Further from the pipe (10 cm, 20 cm and 30 cm) the temperature increases as the heat diffuses in the soil. The presence of tensiometers in the close vicinity of the pipe (indeed at the same radial distances as the thermometers) will help us understand to which extent the heat injection may modify the soil water content, as have been reported by in the litterature (Ewen and Thomas 1989, Yong et Mohamed 1996, Krishnaiah and Singh 2003).

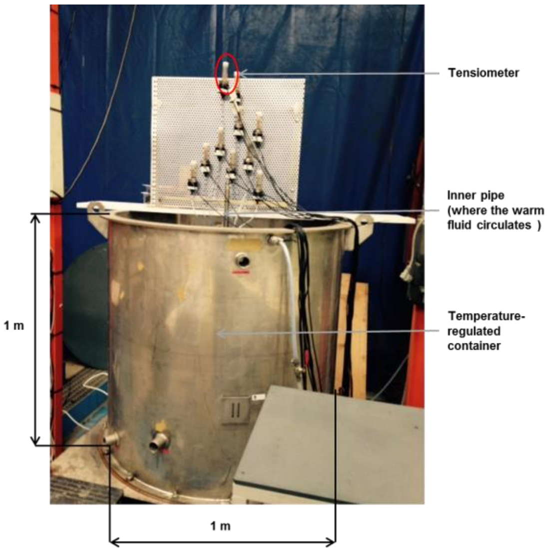

Figure 5 : Picture of the experimental device

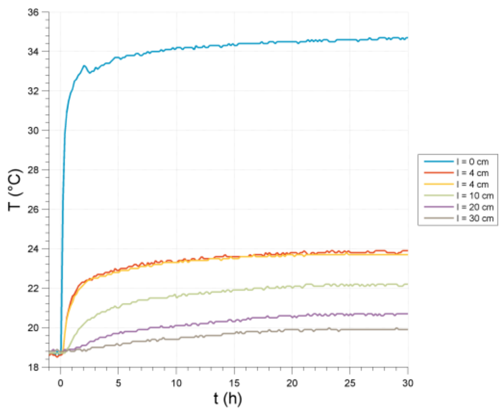

Figure 6 : Temperature evolution measured at 30 cm depth for radial distances from the pipe ranging from 0 to 30 cm. A 40 °C warm fluid circulates in the inner pipe.

4. SOIL – ATMOSPHERE INTERACTION IMPACT ON THE MOISTURE CONTENT AND TEMPERATURE IN THE SUBSURFACE SOIL

This last part is dedicated to the understanding of the influence of soil – atmosphere interaction on thermal performances of CGHE. Such knowledge could then allow us to better size CGHE installations depending on soil type, cover and local climate.

Instrumentation has been implemented at the BRGM test facility. A weather station and a detailed instrumentation in the first two meters of depth below a grass area have been installed (Figure 7).

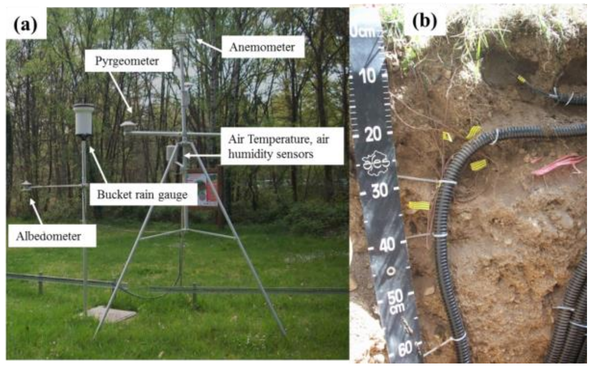

Figure 7 : Weather data station (a) and instrumentation of the first 2 m of soil by temperature probes, heat flux plates and tensiometers (b) in the BRGM test facility

The temperature is measured at different depths, especially in the vicinity of the soil surface. The temperature measurements during the whole year 2014 at 0.03, 0.5, 1 and 1.5 m are reported in Figure 8.

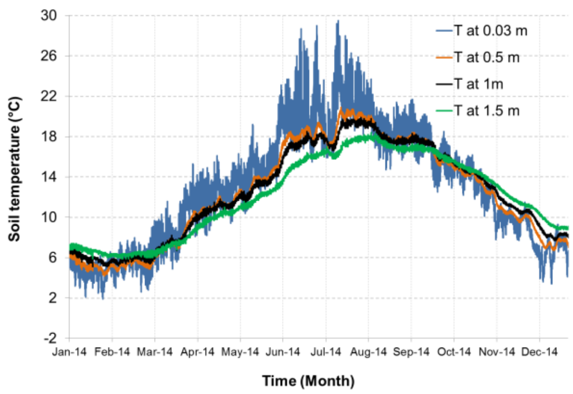

Figure 8 : Temperature measurements in the soil covered by a grass at the BRGM test facility

We can observe that the temperature at the top of implantation depth of CGHE, 1 m fluctuates only in the range of 5 – 20°C. Such a temperature level basis represents a substantial benefit compared with air heat pumps which can operate with temperature levels reaching -6°C in winter season in Orléans climate.

To better take into account the cover of the soil (bare or grass for example) into the sizing of CGHE, the net energy balance at the soil surface has been measured and is represented for example in 2 days period in .

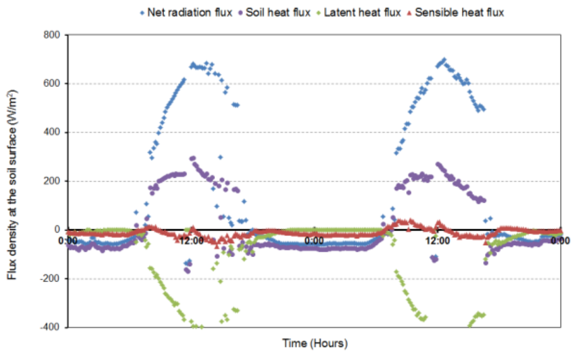

Figure 9 : Heat flux measured at the soil surface in July 2nd and 3rd, 2014

These measurements have been investigated more in details by Chalhoub et al. (Chalhoub et al. 2015). In the framework of a research project, models are currently in development to evaluate the temperature and humidity of soil at depth of implementation for sub-surface GHE from the three following parameters: soil type, soil cover and climate. This can then allow to better size GHE and consequently reduce the investment cost.

5. CONCLUSIONS

Some different and complementary works have been carried out at the BRGM test facility to improve design and sizing of CGHE. Different aspects have been investigated: design of CGHE, heat and moisture transfers in the vicinity of pipes, influence of soil – atmosphere interaction. Thanks to these works a new sizing tool for GHE dedicated to individual houses has been finalized and will be soon available online on website dedicated to the BRGM test facility for GHE: http://plateforme-geothermie.brgm.fr

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