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Heat transfer in quaternary deposits: how thermal conductivity is affected by moisture content

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Abstract

The performance of very shallow geothermal systems, as horizontal collector systems or special forms (i.e. heat baskets), interesting the first 2 m of depth from ground level, is strongly correlated to the kind of sediment locally available.
In detail, the thermal properties (i.e. thermal conductivity) of quaternary deposits are greatly affected by two parameters, the soil moisture content and the grain size.
A key challenge for very shallow geothermal systems is to understand how to enhance the heat transfer of the sediments surrounding the pipes, taking into account the interactions between the soil, the horizontal heat exchangers and the surrounding environment and the daily and seasonal variability of weather conditions, able to modify the moisture and water content in the first ground meters’ depth.
Trying to answer these questions, the ITER Project (Improving Thermal Efficiency of horizontal ground heat exchangers, European project funded by European Commission under the Marie Skłodowska Curie Fellowship Program Horizon 2014-2020) focuses on testing thermally enhanced backfilling material (TEBM), created using natural sediments and acting on their ability to preserve a constant thermal behavior in the long term.
In fact, the heat transfer exchange between the ground, the collectors and the ground heat pumps is improved in water saturated soil, where the presence of water in the pore size favors the heat transfer continuity in the medium.
Given the heterogeneity of sedimentary deposits in alluvial plain and the uncertainties related to the estimation of thermal parameters for unconsolidated material affected by thermal use, here are presented the preliminary results determined for the same material (sand and loamy sand) both on a field test site and in laboratory, under different degree of water saturation.

1. Introduction

In the near future, the shallow geothermal energy resource is becoming increasingly important as renewable energy resource for heating/cooling residential and tertiary buildings.
Therefore, it is worthy of interest a better comprehension of how the different soil typologies (i.e. sand, loamy sand...) affect and are affected by the heat transfer exchange with heat collectors (Farouki 1981; Saxton et al 2006; Nikolaev et al 2013), especially when horizontal ones (very shallow geothermal installations) are adopted (Bertermann et al 2014; Bertermann et al 2015).
The development of geothermal energy applications is a multidimensional process undergoing rapid improvement (Nagy et al 2012). There are still several challenges in the successful exploitation and in the profitable use of the earth's heat, including the environmental impacts in the short and long term. There is required, on the one hand, a better knowledge of the thermal properties of the ground and, on the other, the efficient implementation of thermal energy transfer technologies (Angelino et al 2013).

The ITER Project focuses on understanding the contribution that applied, quantitative geosciences can make to the successful engineering of genuinely sustainable horizontal type heat exchangers. A key challenge to improve the performance of ground heat exchangers is to enhance the heat transfer of the ground surrounding the pipes. In this regard, knowledge of the thermal conductivity of sediments and filling materials is fundamental, also because these values are one of the main input parameters in geothermal modelling (Alishaev et al 2012).

2. Methodology

Main parameters determined in laboratory and on test field are:

- thermal conductivity by thermal properties analyzer (KD2Pro apparatus, Decagon Devices, Inc.), operating according to the transient line source method (ASTM D5334-08);
- moisture content and bulk electrical conductivity (measured simultaneously) by time domain reflectometry (TDR) device (TRIME IMKO GmBH).
- electrical resistivity by using a high precision instrument for determination of soil resistivity (4point light hp earth resistivity meter, Lippmann Geophysikalische Messgeräte)
- bulk density is determined on duly collected sample according to the DIN 52102;
- water content is determined on duly collected sample according to the DIN 18121;

Grain size and mineralogical content analyses for each mixture are now under processing and are being completed in the next future.

3. Results and discussion

Following the laboratory working plan, more than 100 samples have been prepared, gradually varying the reference material (sand or fine sand), the kind of additive (bentonite or clay), the water content (fresh water added gradually to the dry unconsolidated sediment in incremental steps) and the pressure applied.
The choice to perform measurements on large volumes of materials (about 57 dm^3) compared to the common laboratory scale is due to compare them with the results given at local scale (i.e. field test), trying to minimize the scale effect.
The relationship between thermal conductivity (λ) and volumetric water content (θ) shows for all mixtures and at each pressure load an improvement of heat transfer with the increase of the water content, until oversaturated conditions are reached. For example, at 1t, the pure material (sand or fine sand), with respect to the corresponding clayey or bentonitic mixtures, shows in laboratory the highest λ values, due to the mineralogical composition, linked to quartz presence.

Instead, at the test site in Eltersdorf, the results obtained are slightly different. Five trenches, hosting each a horizontal collector (3m length), have been filled in using as backfilling material three natural sediments and two mixtures, also tested in laboratory:

1. fine sand 0-1 mm (fs);
2. fine sand 0-1 mm with 15% bentonite (fs15B);
3. sand 0-5 mm (s);
4. sand 0-5 mm + 15% bentonite (s15B);
5. sandy clay (sc).

At the time of paper writing, nine data acquisition campaigns (16.11.2015; 25.01.2016; 22.02.2016; 05.04.2016; 26.04.2016; 31.05.2016; 01.07.2016; 05.08.2016; 07.10.2016) were completed and the preliminary results for thermal conductivity and moisture content were collected. In situ, the mixtures specially created for the project reveal a better performance than the pure material only (Fig.1). The difference in behavior between pure and mixed materials is connected to the moisture content. In fact, there is a remarkable improvement in the ability to retain water in the pores when bentonite is added to the pure material. In the same climatic conditions, this factor seems greatly contribute to a better performance of the heat exchange within the sediments. Therefore, this topic will be further analyzed in the ongoing research.

4.Acknowledgements

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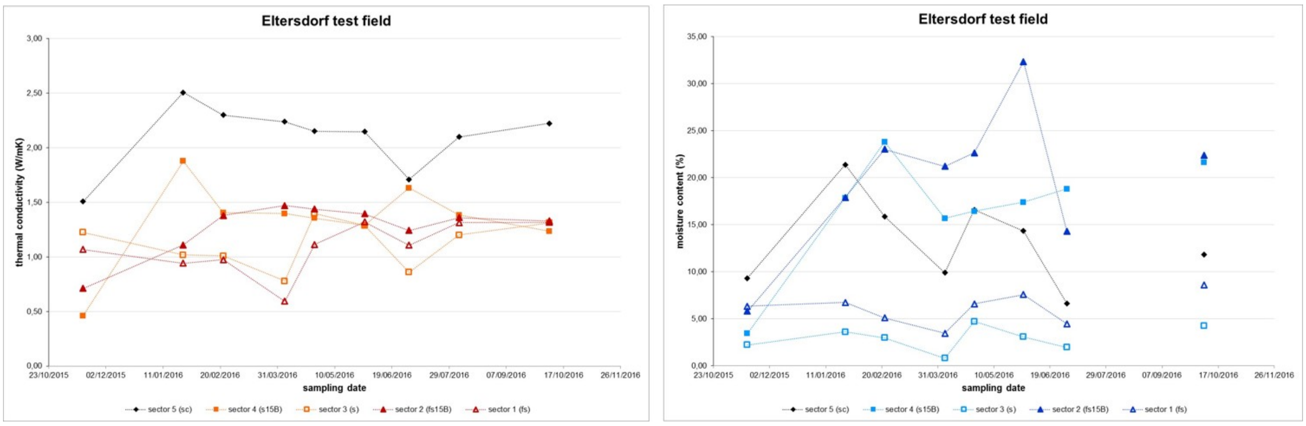

Fig. 1: Thermal conductivity and moisture content determined monthly on five different soil mixture in the ITER test site in Eltersdorf.

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