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Laboratory Measurements of Gravel Thermal Conductivity: An Update Methodological Approach

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Abstract

Direct measurements of gravel thermal properties are usually quite challenging to be performed in laboratory, due to the very coarse sediments size. As a consequence, the reference thermal values provided by literature for gravels are quite limited and dispersed. A guarded hot plate Taurus Instruments TLP 800, usually used for measuring the thermal conductivity of buildings materials, was slightly modified in order to measure the thermal conductivity of some gravel samples. The tests were performed both in dry and wet conditions. The paper presents the first obtained results.

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Keywords: Cheap-GSHPs; gravel; thermal conductivity; guarded hot plate.

1. Introduction

The EU Horizon 2020 project entitled "Cheap-GSHPs: Cheap and Efficient Application of Reliable Ground Source Heat Exchangers and Pumps" (grant agreement No. 657982) focuses on improving the efficiency and the

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safety of shallow geothermal systems and on the reduction of their installation costs. Moreover, the project develops a Decision Support System (DSS) and other design tools for the newly developed technologies compared to other low enthalpy geothermal systems. In the DSS the local geological aspects as well as the feasibility and economic assessments are evaluated, by considering different plant set-up options, selection, design, installation, commissioning and operation. These tools will be made publicly available on the web to users (see the web site), including comprehensive training to lower the market entry threshold.

In order to optimize the total probes length design, one of the most important aspects to be taken into account during the design phase of a Ground Source Heat Pump (GSHP) system is a good estimation of the heat exchange capacity of the ground where the probes are inserted. The evaluation can be performed indirectly on site, by deriving the thermal exchange capacity from the interpretation of the outputs obtained from the Thermal Response Test (TRT) carried out on a testing probe already built. These well-developed methodologies are usually employed [1,2] to estimate a global value of the heat exchange capability of the whole probe-ground system. It is governed firstly by the thermal properties of the geological materials that constitute the entire stratigraphy intersected by the probe; and, in addition, it is also influenced by the heat exchange advection processes in the aquifers due to the groundwater flow. Secondly, the global heat exchange capability value also depends on the thermal properties of the pipes' materials and of the grouting used to fill the borehole as well as on the heat carrier fluid flow conditions inside the pipes (turbulence/Reynolds number) and on the quality of the borehole grout sealing.

Another option is to evaluate directly the local ground heat exchange capability by defining the thermal properties of each layer or deposit intersected by the probe [3,4]. That way, it is necessary to collect samples from the cores extracted at the site and to measure directly the thermal properties of each deposit.
Alternatively, after a definition of the local geological sequence intersected by the probe, in first approximation, it is possible to assume the thermal properties values recommended in literature. Usually, the underground materials' conductivity values reported by regulations and guidelines are quite generic mainly owing to the very different geological (consolidation status, moisture content and saturation, compaction level, etc.) conditions as well as to the high variability of mineralogical composition of materials belonging to the same granulometric category.

In order to provide a more defined database of the ground thermal properties to the DSS and to improve the definition of thermal properties reported in literature, one of the objectives of the Cheap-GSHPs project is to build up a dataset of thermal properties of geological materials (hard rocks and unconsolidated sediments), by implementing literature values as well as collecting thermal properties directly measured on samples coming from several European sites. The database will include gravels as well as sands, silts and clays, and finally hard rocks thermal parameters, in order to improve the definition of the thermal properties of defined granulometric sub-categories of sediments. Where available, the database will contain also the measuring device and method employed in the test, and the related geotechnical (granulometry, Atterberg Limits, etc) or petrophysical information (density, porosity, etc).

2. Gravel thermal properties measurements

Direct measurements of gravel thermal properties are quite challenging mainly due to technical issues related with the very coarse sediment size, which impedes an appropriate physical contact between the material and the traditional measuring sensors. In addition, the variability of the mineralogical composition of the polygenic samples in many cases requires a quite large volume of geological material to be involved in the measurement procedure, in order to obtain representative thermal properties values. Considering the traditional sensors, the gravel sediment size and the presence of the large interstitial voids close up a continuous physical contact between the material and the measuring sensor (usually needle or plane probes). However, an appropriate physical contact between the sediment and the sensor is necessary and, in case of gravel, it is not achieved due to the coarse dimensions of the clasts.

In addition, the effective thermal conductivity of a porous media depends on the thermal conductivity of the solid grains [5] and a sample of gravel could be composed by clasts of different mineralogical and lithological composition due to their different origins. For this reason, the measurement has to involve a quite large volume of unconsolidated sediments in order to reach the elementary representative volume. In the past, some researchers proposed original devices for measuring gravels' thermal conductivity [6,7]. Barrie W. Jones (1988) [6] for the first time developed a probe method of measuring thermal conductivity of gravel and tested it on an unconsolidated