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# Experimental characterization and performance evaluation of geothermal grouting materials subjected to heating–cooling cycles

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## HIGHLIGHTS

- An experimental study of five different geothermal grouting materials was carried out.
- The use of high water/solid ratios in grouts was analyzed and their suitability assessed.
- Thermal, mechanical and permeability tests were conducted for characterization purposes.
- The durability of the grouting materials against heating–cooling cycles was assessed.

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## ABSTRACT

In recent years, the increasing rise in environmental awareness among energy consumers has led to an increasing use of renewable energies such as the geothermal energy. An important role in the efficient exploitation of the geothermal resource is played by the grouting material placed in the borehole between the pipes and the ground. Actually, the use of proper grouts is essential to provide an effective heat transfer between the ground and the heat carrier fluid in the pipes, and also to comply with the mechanical and environmental demands. However, when it comes to the construction of the GHP installations, the grout is especially required to be easy to work with (workable) and for this reason more water than required is sometimes added. In order to assess the suitability of grouting materials with significant water/solid ratios, the thermal conductivity, mechanical strength and permeability of five different grouts and grout–pipe specimens were measured for their laboratory characterization. In addition, the grouts were subjected to heating and cooling cycles to evaluate their durability with time in terms of the potential degradation of the materials and the loss of quality of the grout–pipe interface. According to the results obtained, the grouts here tested are appropriate for most of the geothermal heat pump installations, especially for those with low to medium ground thermal properties.



## 1. Introduction and background

The environmental impact caused by the extended use of the energy for lighting, heating and cooling purposes [1] is leading to the gradual increase of consumer attitude towards the mindful use of the natural resources [2] and the efficient consumption of alternative energies. Accordingly, the use of vertical shallow geothermal energy systems or ground source heat pumps (GSHP) is emerging. This technology offers a renewable, clean and efficient source of energy. However, its installation is slightly more difficult as compared to more conventional systems and therefore, more expensive [3].

In this context, the optimum design of a vertical shallow geothermal closed-loop heat exchanger that shortens the return of investment period, requires the accurate analysis of all the components involved in the process through which heat is exchanged with the earth. Among these components (Fig. 1), the grouting material located between the pipe and the ground is very important due to its crucial functions: allow the borehole stability, make possible an efficient heat transfer between the pipe and the ground and provide a hydraulic barrier that avoids the pollution of the aquifers if leaks are present. Therefore, a suitable grouting material should satisfy the following conditions: (1) to possess a very low hydraulic conductivity; (2) to provide a high thermal conductivity; (3) to guarantee a good coupling pipe-grout that avoids harmful

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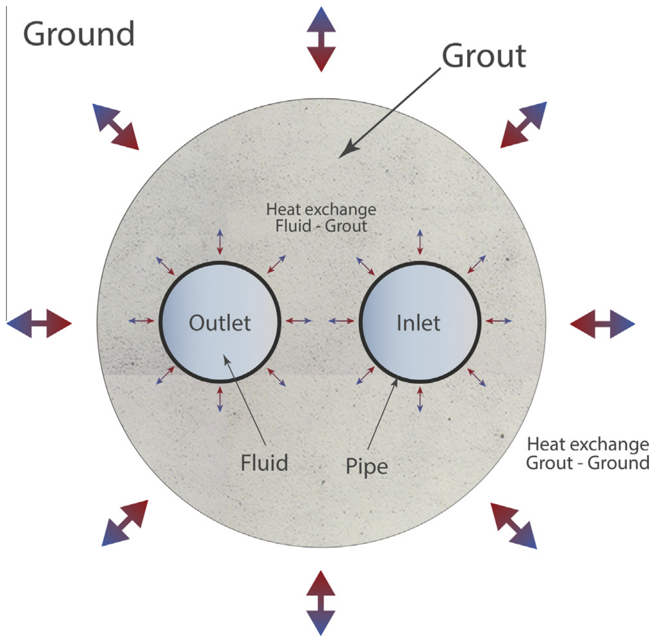


**Fig. 1.** Main components of a typical vertical shallow geothermal closed-loop heat exchanger.

debonding effects [4]; and (4) to possess proper mechanical properties that protects the heat exchange system. However, some of these conditions are sometimes sacrificed for the sake of the grout's workability. Thus, when it comes to the construction of the GSHP installation a liquid enough grout is sought so that it can be easily injected within the borehole.

Grouting materials for GSHP purposes are mainly divided in two groups: bentonite-based grouts, in which the bentonite is the main component; and cement-based grouts, in which the cement is the prevailing component. The addition of bentonite to cement-based grouts is very common to improve the rheological properties of the resulting mixture.

As geothermal grout, the bentonite offers an easily placed, flexible and very low permeability sealing. On the other hand, its low thermal conductivity and volumetric instability lead to an adverse decrease of the GSHP efficiency. In order to enhance its properties, several authors have analyzed the addition of other filling materials [5,6]. Thus, Smith and Perry [7] tested several bentonite-to-sand gradations and analyzed the influence of this variable on the performance of real installations. Similarly, Lee et al. [8] tested seven different type of bentonites and compared the values of thermal conductivity and viscosity obtained when different percentages of silica sand and graphite were added. The graphite was proved to bring about higher conductivities. More recently, Delaleux et al. [9] evaluated the thermal performance of bentonite-graphite composites elaborated with different forms of graphite. Very high values of thermal conductivity were achieved (up to 5 W/m K) for low graphite contents. However, a clear dependency between this parameter and the water content was detected. On the other hand, Erol and François [10,11] carried out a characterization of bentonite-based grouts enhanced with natural-flake graphite among other forms. Results demonstrated that a 5% graphite addition is enough to highly influence the thermal conductivity of the grout as well as a cost-effective solution.

Concerning cement-based grouts, it is more than remarkable the research work carried out by Allan et al. [12–16,4,17]. In terms of thermal performance, the addition of silica sands to neat cements was largely studied by the authors. An optimum grout that met the balance between the required properties, economics and ease of use was chosen for further tests. Theoretical values of required borehole length were calculated by the authors when this grout was used, giving arise reductions of up to 22–37% depending on soil type and borehole diameter.

Permeability tests were also carried out on the grout to evaluate its sealing performance. Results showed that hydraulic conductivity of the grout itself was very low but increased flow occurred when pipes were incorporated within the test specimen. This was attributed to an existing pathway at the grout–pipe interface and accordingly, an imperfect physical bonding between grouts and pipes was assumed. Therefore, the mechanical bond strength between both components was measured by means of push out tests in which higher loads were necessary to push the pipe inserted in the cement-sand grout as compared to the pipe inserted in neat cement grout. The effect of temperature was also evaluated and results showed a distortion of the micro-annuli at the grout–pipe interface due to the different thermal expansion coefficients of the pipe and the grout. Taking advantage of the previous work, a numerical model was developed that allowed the authors to determine that a total debonding produces a 66% reduction of the overall heat transfer coefficient [18]. More recently, Berndt [19] and Borinaga et al. [20] studied the addition of steel fibers and recycled materials such as steel slags, respectively.

But apart from possessing suitable thermal hydraulic and mechanical properties, a grouting material should be capable of keeping those properties along its service life. Only a limited number of authors have dealt with this issue. In this sense, permeability of cementitious grout–pipe specimens subjected to thermal cycles was evaluated by Allan and Philippacopoulos [13,14] and compared to neat cements' behavior. Small increase of the permeability occurred after cycles but remained of the same order. In contrast, neat cement grouts cracked after the test. The effect of thermal cycles on the hydraulic conductivity of cementitious grout–pipe specimens was also analyzed by Park et al. [21]. Results showed no significant change.

According to the background exposed above, the main objectives of this paper are the following: characterize and compare mechanical, thermal and hydraulic properties of five different grouting materials with a high-level workability due to an excess of mixing water; and evaluate the durability of these grouts when they are exposed to heating–cooling cycles that represent the temperatures to which the grout is mostly exposed along its lifetime.

## 2. Research methodology

### 2.1. Materials and characterization tests

Five different grouting materials for geothermal purposes were considered for this study. Proportions of these mixtures are shown in Table 1. Four of them consisted of ordinary Portland cement, bentonite, and silica sand and/or graphite as the necessary conductive filler. High water/solid ratios provide these grouts a great workability. The fifth one is a silica-sand based grout with bentonite.

Different characterization tests were carried out. Thus, fresh and hardened density, water-accessible porosity, Marsh viscosity and bleeding were determined for the five grouting materials. The bulk density of the fresh specimens was determined according to the standard UNE-EN 1015-6 [22] while the dry bulk density and the water-accessible porosity of the hardened grouts were measured in agreement with the UNE-EN 1015-10:2000/A1 [23].

The plastic viscosity of the grouts was determined by using the Marsh Funnel as defined in ASTM D6910/D6910M – 09 [24]. According to this standard, the grout is poured into the funnel and then allowed to flow into a graduated cup. The Marsh Funnel