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Analysis and study of different grouting materials in vertical geothermal closed-loop systems

Cristina Sáez Blázquez*, Arturo Farfán Martín, Ignacio Martín Nieto, Pedro Carrasco García, Luis Santiago Sánchez Pérez, Diego González-Aguilera

Department of Cartographic and Land Engineering, University of Salamanca, Higher Polytechnic School of Avila, Hornos Caleros 50, 05003 Avila, Spain

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ABSTRACT

In vertical closed-loop geothermal systems, the material used to fill the boreholes is an essential element since it facilitates the exchange of heat between holes and pipes which contain the heat transfer fluid. Therefore, the thermal conductivity of this grouting material plays a vital role in conducting heat to the installation; not only does it increase its efficiency with higher thermal conductivity values, but it also makes the reduction of the total drilling length required to cover some particular energetic needs, possible. In view of the importance of this grouting material, a series of mixtures were produced and both thermal and mechanical properties were analysed in the laboratory. The use of aluminium shavings and sulpho-aluminate cement improved the thermal conductivity of these mixtures and offered excellent mechanical properties. However, non-satisfactory results were obtained for the bentonite due to the contractile effects caused in samples of this nature.

1. Introduction and background

As a renewable, efficient and environmentally-friendly source, geothermal energy is, at the moment, in an expansion process, which places it at a very important position in the energy sector. With respect to very low temperature geothermal energy, commonly used to produce SHW (Sanitary Hot Water) or to heat/cool a certain place [6], heat exchangers can be divided into two main groups: open and closed geothermal systems. Open systems use groundwater coming from an adjacent aquifer to exchange heat with the ground, while closed systems use a fluid flowing inside a pipe to carry out the thermal exchange. The latter system is not conditioned to the existence of a nearby aquifer to provide the water exchange. Closed systems can be classified as: horizontal closed-loop systems, in which pipes are buried up to 5 m, and vertical closed-loop systems, constituted by deeper vertical drillings [16]. The grouting material injected inside these holes must fulfil a series of functions. It must guarantee the stability of holes and pipes. It must constitute a hydraulic barrier, avoiding the pollution of close aquifers due to a possible leak. Finally, grouts must allow the heat exchange between ground and pipes fluid. This last function will determine the right working and efficiency of the installation; hence one of the most important properties of grouting materials is the thermal conductivity or the capacity to conduct heat. Fig. 1 shows the schematic of a geothermal borehole [19].

Numerous authors have analysed the thermal conductivity of a wide variety of grouting materials to discard those materials whose thermal properties make them unsuitable for use as grout in these installations. As a rule, it is considered important that the grouting material has a thermal conductivity value equal to or higher than that of the surrounding ground, so as to avoid reducing the efficiency of the system. It should also be noted that the possible gaps (pores of different geometry filled with air of water) in the grout negatively affect the installation reducing the heat flux to the pipes [2,21,24,26,37]. Grouting materials are typically grouped into grouts whose primary components are either bentonite or cement. Bentonite is flexible, with low permeability and easy placement, although it has a relatively low thermal conductivity: a range of between 0.65 W/(m K) and 0.90 W/(m K) in saturated conditions [11]. It is, however, commonly used in geothermal boreholes in spite of its limited capacity to conduce heat. In order to improve this thermal property, the addition of other materials to bentonite has been analysed. Remund and Lund [20], demonstrated that the thermal conductivity of bentonite is substantially improved by the addition of sand and can vary by modifying the water content of the mixture. Allan and Philippacopoulos [27], elaborated a mixture

* Corresponding author.
E-mail address: u107596@usal.es (C.S. Blázquez).

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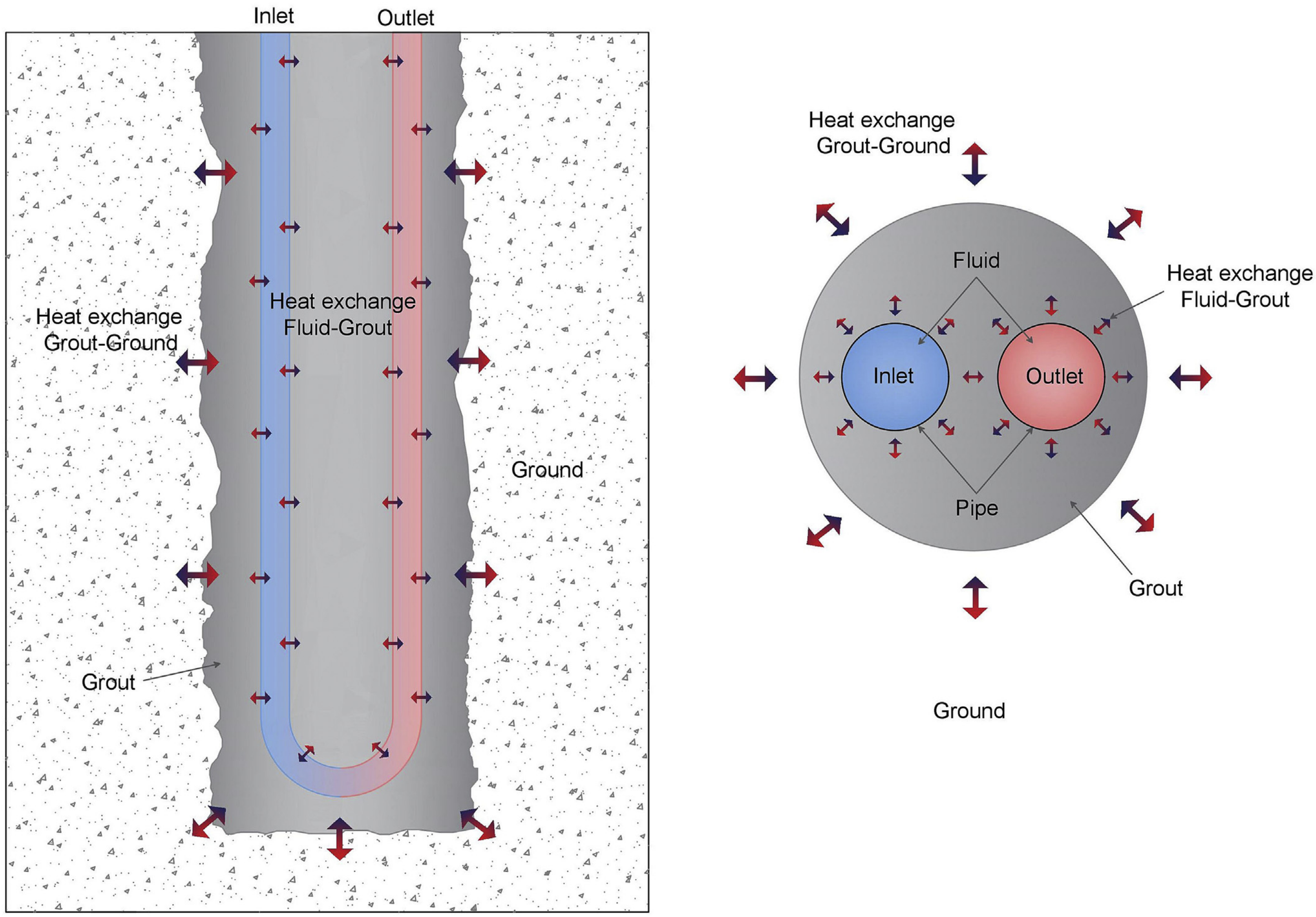

Fig. 1. Two different views of a geothermal borehole.

enhanced with silica sand which tripled the thermal conductivity of a bentonite mixture. Jobmann et al. [25], studied the influence of adding graphite to the grouting material and recorded a thermal conductivity of 3 W/(m K) for a mixture with a basis of bentonite constituting 14% water and 15% graphite. Lee et al. [8,9], noted that by increasing the quantity of silica sand and graphite, the thermal conductivity of the sample increased; although so did its viscosity. In this way, by adding 30% graphite; they attained a thermal conductivity of 3.5 W/(m K). They also obtained 2.6 W/(m K) of thermal conductivity for a mixture of cement, silica sand and graphite. Delaleux et al. [14], have recently pointed out that by adding less than 15% of graphite powder, thermal conductivities of around 5 W/(m K) can be achieved. Engelhardt [18], added ballast to bentonite, acquiring thermal conductivities up to 2.6 W/(m K). The shrinkage potential of bentonite is another important factor to be considered. In this field, Olson and Mesri [35] focused on the impact of pore fluid on the volume change of bentonites under various stress states.

With respect to cement based mixtures, the addition of silica sand was studied in depth by Allan et al., [28–32]. They demonstrated that the total drilling length could be reduced by around 22–37% with the use of this grout, depending on the type of ground and the diameter of the drilling in question. Xu and Chung [44] proved that by adding silica sand to cement, the thermal conductivity of the mixture increased by 22%. Alrtimiri et al. [1], made mixtures with different amounts of sand, cement, fluorite, glass and PFA (Pulverized Fuel Ash) obtaining thermal conductivities of up to 2.88 W/(m K) for a PFA of 20%. Recent studies based on energy piles deal with the use of cement as concrete in deep foundations [7,23,34].

The main objective of the present research is to suggest new alternatives, suitable to be used as grouting materials in a geothermal installation. On the basis of the information mentioned before, experiments with grouts that incorporate aluminium as a new element were carried out. Thus, a series of test tubes of different materials (including aluminium) were produced and analysed to check its suitability as geothermal grouting materials. Aluminium was added to the grouts in two ways: from a batch of cement or added to the mixture separately. Parameters like thermal and hydraulic conductivity, workability, compression strength and the possible contractions or reductions of volume over time have been considered in this work.

The innovative element in these mixtures is aluminium, which, due to its extraordinary capacity to conduce heat, was incorporated in the shape of cement and shavings or small filings. Thus, its cohesion with the rest of components of the mixture was significantly easier.

2. Experimental methodology

2.1. Materials

Specimens produced in laboratory are composed by: water (w), sodium bentonite (b), silica fine-grain sand (s), detritus from a hole