Simulation of Ground Heat Exchanger for Cryogenic Applications

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Abstract

To increase the mechanical resistance of the ground, it is common use to freeze the groundwater present in a soil by circulating liquid nitrogen or brine in a ground heat exchanger (GHE). The latter is usually made of a loop of copper pipe lowered in a borehole filled with mineral slurry. This technique can be used to create solid wall for excavation or to repair infrastructure under roads and railways without interrupting the service. To increase heat transfer, and thus reduce the time required to freeze the interstitial water of a soil, novel GHE designs are emerging. Figure 1 compares a standard GHE with a novel design where the copper pipes are embedded in an aluminum cast. The objective of this work is to quantify numerically the efficiency of the new GHE design by quantifying its thermal behavior.

The studied GHE is 20 m long, lowered in a borehole of 152 mm in diameter and embedded in a geological media of 5 meter of radius. The study was conducted over a period of 7 days. The ground has a porosity of 30 percent and is composed of groundwater (0.561-0.6 W/mK) and sand particles (2 W/mK). Liquid nitrogen at 77 K and 1 atm is sent through the copper loop at a flowrate of 25 L/min. The insulation inside the aluminium structure is polystyrene.

The GHE model was created in the COMSOL Multiphysics® environment. The Heat Transfer in Solid with Phase Change interface was used in order to simulate the heat transfer in ground while the Heat Transfer in Liquid interface was used for the liquid nitrogen. The mesh was created using free triangular on surface and then swept throughout the 20 meters.

Since the goal of the process is to increase the mechanical properties of the ground by freezing its groundwater, Figure 2 shows the volume of ice created by the GHE as a function of time. The rate at which the volume of ice is formed outside the borehole is decreasing over time, as it is expected. Figure 3 shows the fluid temperature along the pipes. It shows that the aluminium cast helps the liquid nitrogen to absorb heat. However, the aluminium structure and the temperature difference between the downward and upward pipes induces a thermal short circuit. Figure 4 shows the thermal short circuit between the downward and upward pipes caused by the aluminium cast after only 60 seconds of operation. It is easy to see that the aluminium is increasing the thermal short circuit.

The system performance could be improved by either increasing the flowrate of the liquid nitrogen or by modifying the geometry of the aluminium structure, a work in progress. The

evaporation of liquid nitrogen in the pipes as well as groundwater flow are currently not taken into account. This would contribute to increase the accuracy of the simulation.

Figures used in the abstract

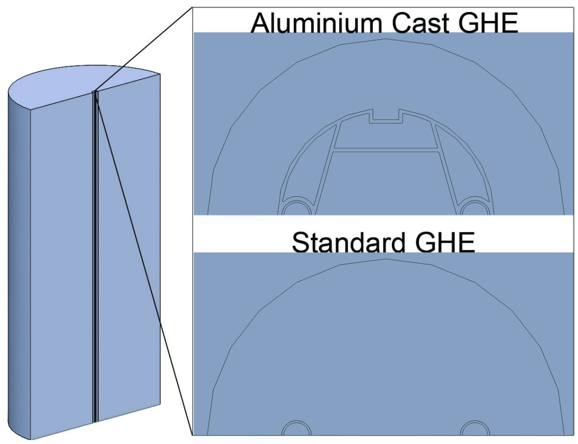

Figure 1: Aluminium and standard GHE

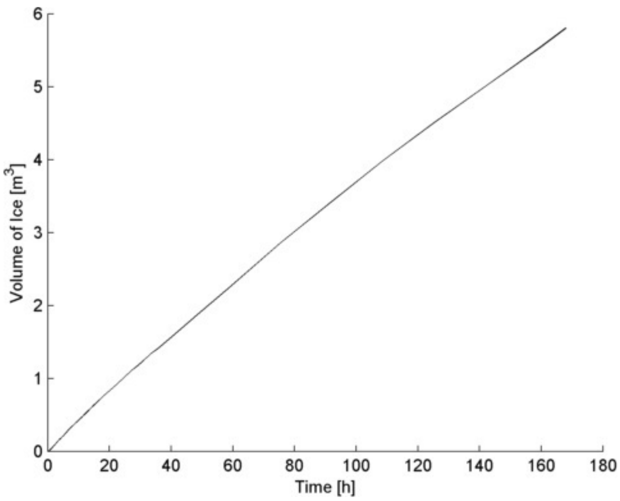

Figure 2: Volume of ice created after 7 days

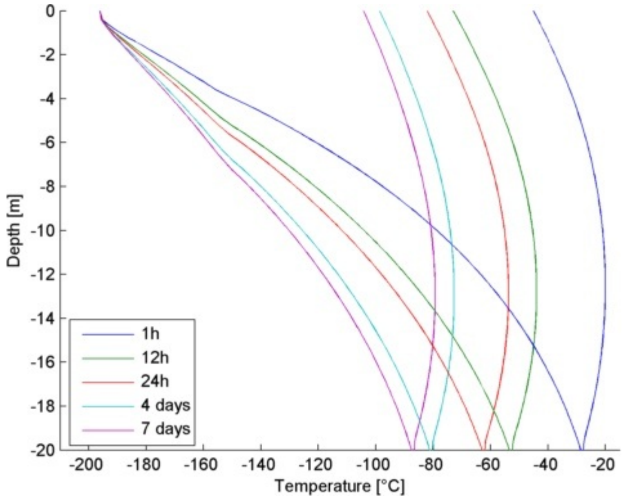

Figure 3: Temperature inside the copper pipes

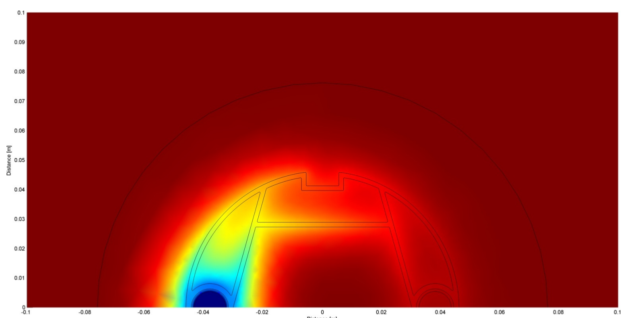

Figure 4: Thermal short circuit in the aluminium cast