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THM experiments for the investigation of freeze-thaw processes around borehole heat exchanger systems

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The utilization of shallow geothermal energy with closed-loop heat pump systems is a successful and sustainable technology for domestic heating and cooling. However, the construction and operation of borehole heat exchangers (BHEs) necessitate a high level of diligence in order to avoid potential conflicts with drinking water production. A BHE must not constitute any pathway, which penetrates natural geologic barriers and might facilitate a vertical input of contaminants into groundwater resources. Therefore, an often cementitious grouting material, which has to seal the system and ensure its integrity under all operating conditions, is used to backfill the annulus between the BHE pipes and the borehole wall. During the heating or cooling period the thermal stress may effect material disruptions and could create secondary fluid pathways. As a consequence, some authorities do not permit working fluid temperatures below 0°C anymore.

The aim of the presented work within the research project OPTIMOG is to determine how the system integrity of BHEs can be preserved over a long-term operating period with multiple freeze-thaw-cycles. Therefore, the freezing processes in the grouting material and the surrounding soil have to be determined in a thermo-hydraulic-mechanical (THM) experiment. The content of unfrozen water has a strong impact on important material properties influencing the overall heat and mass transfer processes. Moreover, freezing strongly depends on various boundary conditions such as the soil type or pore water chemistry. Accordingly, it is essential to have adequate information about the freezing interval of the investigated materials. One possibility to quantify this material behaviour is to use ultrasonic measurements: The wave velocity in solid particles is constant and not affected by temperature changes. However, with descending temperature, the ice content increases, which leads to an improved cross-linking of the skeleton particles. As a consequence, the bulk P-wave velocity increases linear with decreasing unfrozen water content. Hence, this relationship can be used to determine the content of unfrozen water during a freeze-thaw-cycle. Apart from this, the growing of ice lenses is observed and the resulting mechanical stress is monitored.

The experimental findings will be implemented in numerical models. This will enhance the general process understanding. Moreover, it will enable an improvement of the grouting materials and thereby contribute to a permanent integrity of BHE systems and their efficient operation.