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Reliable and Durable Grouting of Borehole Heat Exchangers

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ABSTRACT

Borehole heat exchangers are installed for the use of sustainable geothermal energy for domestic heating and cooling supply. Vertical heat exchangers are a reliable and common technique to make geothermal heat accessible. A well-engineered heat pump technology already exists, whereas the quality of the borehole heat exchanger constructions could be improved. The grouting of the borehole, shortly after the heat transfer pipes have been installed, plays a prominent role. The cementitious grouts are supposed to ensure the performance of these systems for a very long time. According to the applicable regulations the grouting of the borehole has to secure the heat transport from the rock to the heat carrier fluid, to seal the borehole to the surface to prevent contamination and to seal penetrated aquifers. So far most of the boreholes in Germany are grouted with clay/cement or thermally enhanced suspensions that were designed especially for this use. In practice sometimes quality problems appear due to the lack of suitable equipment, construction and documentation. At the moment there are few quality checks after the installation of the borehole heat exchangers in the ground. Laboratory methods and grouts have been tested and adapted to the requirements of the system. Practically used grouts are not frost proof and show structural damages by freezing. Nevertheless it is possible to mix freeze-thaw consistant grouts for borehole heat exchangers.

1. INTRODUCTION

Shallow geothermal energy can be used for domestic heating and cooling supply with the installation of borehole heat exchangers. The pipes abstract heat from the ground at a low temperature level that is rised by a heat pump for utilisation in the heating circuit. For the installation of the systems, first a borehole is build to depths of around 100 meters or below. Then the borehole heat exchangers as double-U-pipes of polyethylene are installed and the borehole is filled with hardening cementitious suspensions. In the majority of cases water mixed with alcohol is circulating as a heat exchanger fluid in the pipes.

It is important to install systems of good quality to ensure the durable operation for a long time. Therefore planning, construction and quality of the grouting must be handled with care.

2. GROUTING MATERIALS

In Germany the Guideline 4640 "Thermal use of the underground" of the VDI (Association of German Engineers) part 2 "Ground source heat pump systems" (2001) defines the requirements of the grouting as follows: "securing the heat transport from the rock to the heat carrier fluid" and "sealing the borehole to the surface to prevent contaminants from entering" and sealing aquifers that may have been penetrated. According to the guideline the grouting "must guarantee a watertight and durable, physically and chemically stable incorporation of the borehole heat exchanger in the surrounding rock". The accomplishment of the grouting has to be recorded accurately in accordance with guidelines and administrative decisions.

So far most of the boreholes in Germany are grouted with building materials that are used for well construction or soil improvement (so called "Dämmer"). These materials are based on cement and clay components and are not thermally enhanced. In addition several mixtures that are defined in the Guideline VDI 4640 part 2 (2001) can be prepared on the construction site consisting of cement, bentonit and optional quartz sand. If the borehole is located in one porous aquifer along the whole of its length, it is allowed to wash in fine gravel or fine-grained drill cuttings. Also thermally enhanced materials that were especially designed for geothermal boreholes are frequently used. A survey among drilling companies in 2005 showed that in practice 38 % fill in cement/clay mixtures ("Dämmer"). Most commonly used are thermally enhanced grouts with 52 % and only a few companies (10 %) mix their own grouts.

During the operation of the ground coupled heat pumps especially for pure heat extraction the circulating heat carrier fluid (water, containing alcohol) in the heat exchanger pipes is cooled to temperatures below zero. Borehole fillings that are not frost proof could get cracked and damaged due to the expansion of freezing pore water. This can lead to a worsening heat transport up to a fully damage of the system and unwanted mixing of groundwater (Figure 1).

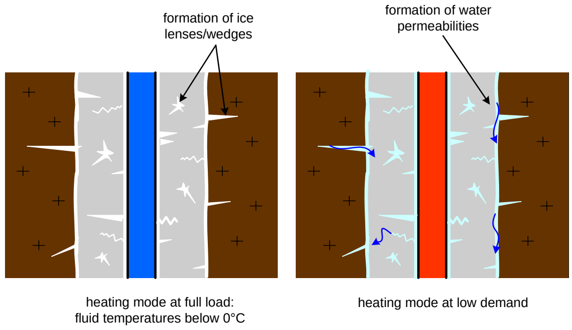

Figure 1: Scenario of BHE operating with low fluid temperatures and formation of ice lenses in the grout.

If temperatures below zero appear for any length of time, the heat pipes and the grout can get damaged by the formation of ice lenses and wedges. After thawing of the ice, vertical cracks for groundwater movement appear and the protection of the groundwater and the durability of the system can no longer be guaranteed (Lenarduzzi et al. 2000; Rohner & Rybach 2001). Hence the specifications of guidelines and authorities can not be assured any longer. Due to the installation of the boreholes close to buildings as garages or access roads, these structural damages often result in geotechnical problems. These problems manifest themselves in terms of ground uplifting and subsidence in the surrounding of the BHEs and their connections up to equipment failure.

3. METHODS

Laboratory testing was done to proof if the materials used in practice for grouting are reliable and durable. Therefore tests of the chemical and physical properties were accomplished such as lixiviation, thermal conductivity, durability and water permeability.

The main focus of this work rested on testing the freeze-thaw resistance of the grouts. At the moment there are only testing methods for concrete or soil established but none concerning especially cementitious grouts for geothermal borehole fillings. Hence accepted testing methods were used and adapted to the requirements of geothermal energy use. Several specimens were cyclically freeze-thaw tested and the structural alteration (cracks, disaggregation) was examined using ultrasonic and microscopy methods. Mercurial measurements showed the porosity distribution and the pore sizes and their changes due to frost damages.

Freeze-thaw testing was done according to a standardized method described in DIN CEN/TS 12390 part 9 (2006) in a specially build testing chest (Figure 2). The samples consist of square matters with hindered sideward expansion. The temperatures vary from +10°C to -10°C in accordance with the temperatures achieved by borehole heat exchangers.

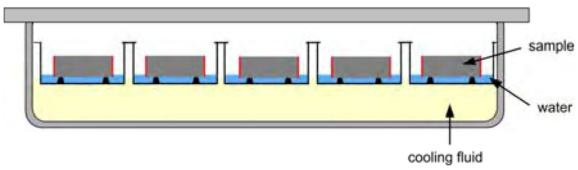

Figure 2: Sketch of freezing chest (based on Setzer et al. 2001)

Additional testing has been done in a small test plant in the lab. Heating and cooling cycles have been simulated and the temperature distribution in the heat pipes, the grout and the surrounding soil has been logged.

Based on the testing results of the grouting materials used in practice, new grouting materials have been created and tested.

4. RESULTS

Grouts tested in the freezing chest got damaged after several freeze-thaw-cycles. The samples show cracks and volume expansion due to the building of ice lenses after 14 freeze-thaw cycles. Most of the established grouts were totally affected to the point of complete collapse while samples of new mixed grouts rested nearly uninfluenced (Figure 3). Accompanying investigations using ultrasonic measurements and weathering also emphasize that.

The grouts have thermal conductivities between 0.6 W/mK and 2.6 W/mK. Thermal stress by freeze-thaw cycles leads to decreasing values about 4 to 20 %. That applies to the measurement of the water permeability too. Samples that are frost affected reveal higher permeability values up to one order of magnitude.

Figure 3: Samples in the freezing chest of the CIF testing method after 14 freeze-thaw cycles (left figure: practically used grout; right figure: new grouting material), Herrmann & Czurda 2007a.

The impact of the freezing process can also be seen in the mercuric measurements (Figure 4) and the structural investigations by microscopy. The pore diameter of the practivally used grout alters due to freezing processes and widens from 2-3 µm to 11 µm. The pore size of the new mixed grout on the other hand keeps at 0.7-0.8 µm.

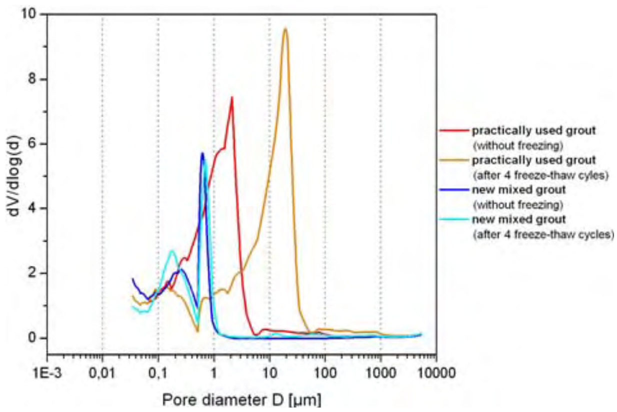

Figure 4: Porosity analysis by mercuric measurement, Herrmann & Czurda 2007b.

Figure 5 shows thin sections of a grout without freezing (left) and after two freeze-thaw cycles (right). Initially a dense matrix without cracks or fissures exists, then cracks appear and get widened by ice lenses and lead to the breakup of the grout. Expanding ice lenses also cause changes in the porosity distribution and increase the pore sizes up to higher water permeabilities.

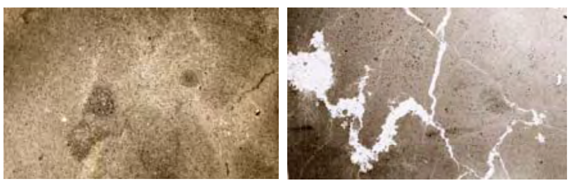

Figure 5: Thin section (5 times magnified) of grout without freezing (left fig.), grout after second freeze-thaw cycle (right fig.), Herrmann & Czurda 2007a.

Investigations and tests show that it is possible to create new frost-proof grouting materials. Detailed testing parameters and recommendations are under examination.

4. CONCLUSIONS

Grouts that are practically used for borehole re-filling in Germany do not behave frost-proof in the realized laboratory tests. It is possible to create new mixtures for grouting that accomplish these properties. If water and an anti-freeze medium are circulating in the heat exchanger pipes at temperatures below zero centigrade, it is necessary to utilize adapted filling materials.

Moreover it is important to take the following recommendations into account to achieve a reliable and durable grouting:

- Utilization of finished products and suitable building materials respectively
- For finished products: keeping the mixing conditions and time written in the technical data sheet of the manufacturer
- Grouting with suitable and fully functional equipment with powerful pumps
- Grouting of the annular space of the borehole from the bottom upwards without trapped air and voids
- Complete backfilling up to the surface area
- Sufficient dimensioning of the heat source
- Observing the grouting standards
- Considering the setting of cement sufficiently

Most important are quality checks with documentation, samples of the grouted material at the construction site and in-situ testing to guarantee the durability and a long run operation of the heating and cooling systems. Furthermore recommendations concerning suspension components, grouting and testing methods resulting of this work can be given.

5. ACKNOWLEDGEMENT

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