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Chrono Thermography - Fiber Optic-Based Integrity Testing Of The Backfill Of Geothermal Probes Via Distributed Temperature Sensing (DTS)

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ABSTRACT

This paper presents a method for assessing the quality of the backfill around existing geothermal probes. Using a heat pulse test in conjunction with simultaneous fiber-optic temperature measurement (DTS), the quality of the backfill can be assessed and flowing groundwater detected. Ideal conditions were found at one site to demonstrate the effectiveness of this method. At this site, three geothermal probes positioned very close together (Figure 4) with varying backfill quality were examined. Since they were installed in the same stratigraphic sequence, rock-related influences can be ruled out. The results of the backfill investigations using this method reveal one intact backfill and two defective backfills of varying severity. With the help of detailed knowledge of the subsurface conditions, causes of damage can be identified or ruled out. This information is essential for developing remediation concepts to repair the backfill in the event of damage.

1 INTRODUCTION

In most cases, the probe is constructed with a backfill. The material used (cement, clay) fills the remaining cavity in the borehole between the probe and the rock. The backfill serves two purposes. Backfilling the probe creates a force-fit connection between the probe and the surrounding rock for optimum energy transfer. Secondly, it seals off different groundwater horizons from each other. This is important for the protection of groundwater. When thermal energy is applied to the probe (heat pulse), heat flows from the fluid in the probe through the backfill to the surrounding rock. In those areas where the rock has relatively better thermal conductivity, the temperature increase is relatively lower than in those areas where the thermal conductivity is relatively poorer. This is because the energy can be transferred more quickly in the rock or dissipated from the probe when the thermal conductivity is better. At those points where the energy cannot flow away as quickly due to relatively poorer thermal conductivity, a correspondingly higher temperature is established. Areas influenced by groundwater flow also show an apparent higher conductivity, as heat is continuously dissipated from the probe by the groundwater flow.

2 MEASURING METHOD

With a thermally excited probe (heat pulse test), temperature depth profiles can therefore be correlated with the geology to derive information about thermal conductivity, groundwater influence, and backfill. If the measurements are repeated continuously (chrono-thermography), the thermal properties of the space surrounding the probe are shown in high contrast in the graphical representation. In the case of vertical flows in the borehole—due to short circuits between aquifers with different pressure potentials—the mass flow in the incorrectly backfilled borehole can be estimated using this high-resolution measurement. With this fiber optic-based method, anomalies in correlation with the geology can be reliably detected and evaluated.

2 FIELD IMPLEMENTATION

For the measurement, a fiber optic cable is inserted into the existing geothermal probe and the temperatures are automatically recorded via the DTS controller. The length-related resolution is usually at least 0.5 m. Temperature measurement via fiber optics is now an established method and will not be described further here. A GRT device is connected to the probe with the fiber optic cable. This device is used to heat the probe for approx. 2 to 3 hours and then observe the cooling behavior for the same amount of time. The procedure is non-invasive. The glass fiber can be removed after the measurement and reused. The probe is in the same condition as before the measurement. Since the measurement is performed with a mobile fiber, the procedure can be performed on any existing probe. The diameter of the cable is approximately 6 mm.

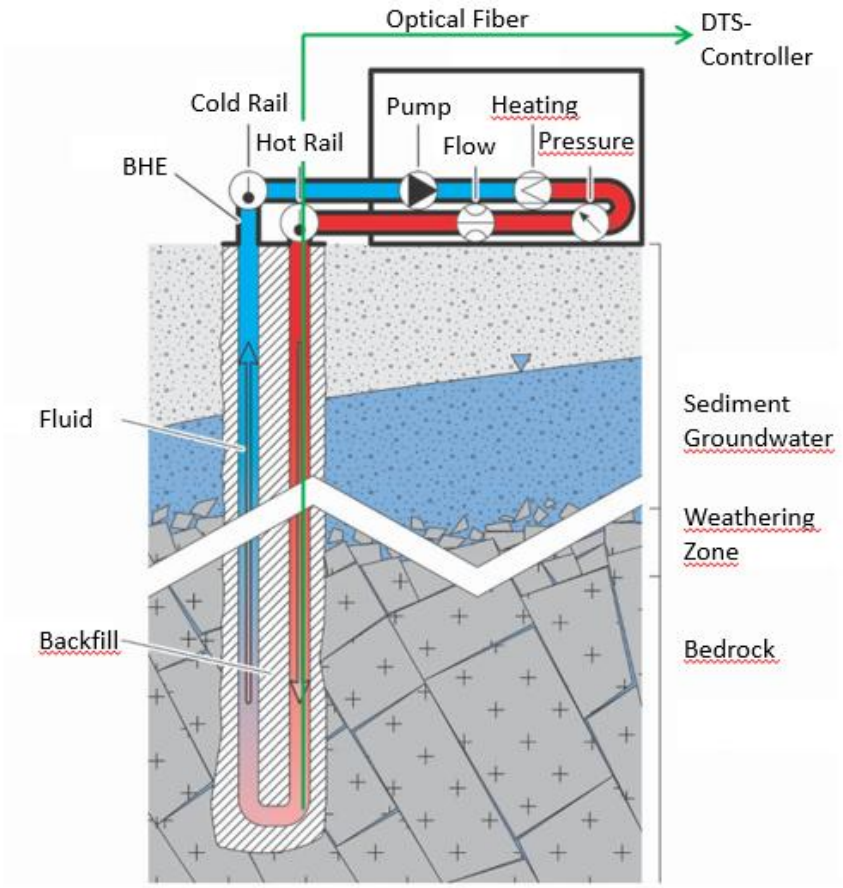


Figure 1. Scheme of the measurement setup

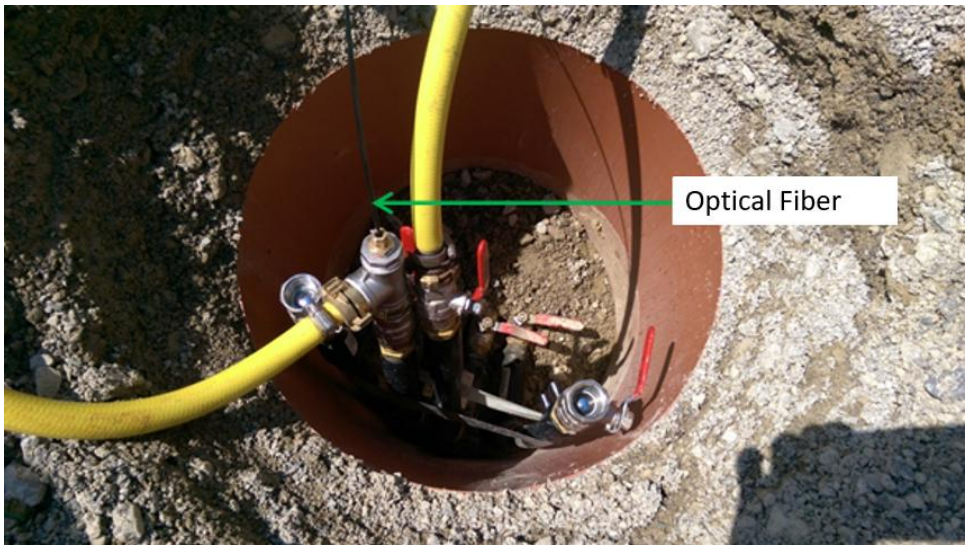


Figure 2. Head of probe - setup on site



Figure 3. Measurement equipment

3. APPLICATION EXAMPLE

In one case, ideal conditions were found, as three probes with a small horizontal distance were examined here. The geology is therefore identical for all three probes.

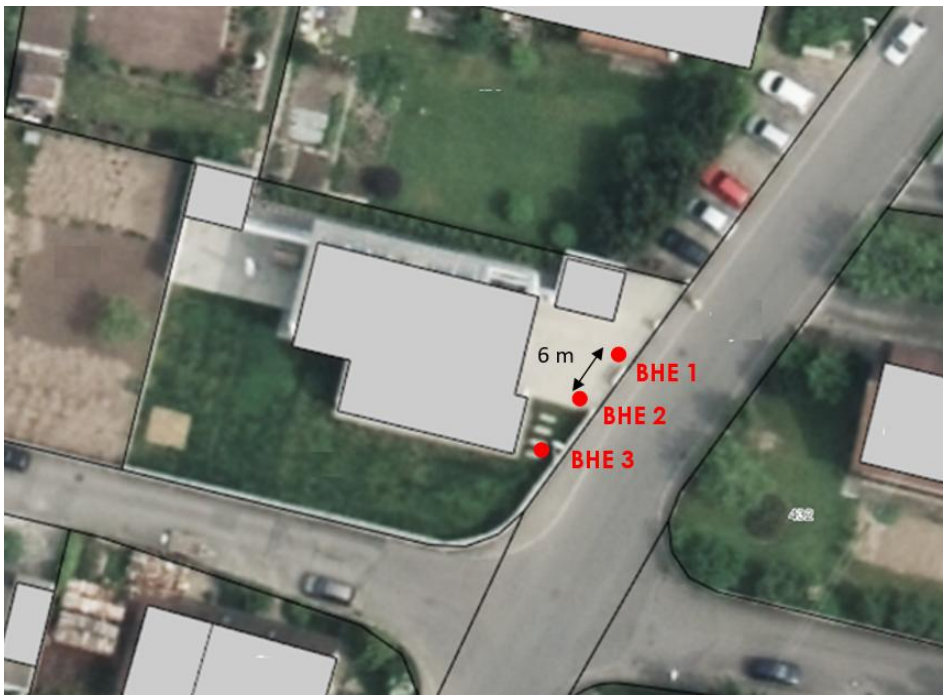


Figure 4. Investigation site

Four aquifers were identified in the subsoil. In the area of the aquifers, the probe is cooled by the inflowing water during heating. These horizons are therefore clearly visible in the temperature profile.

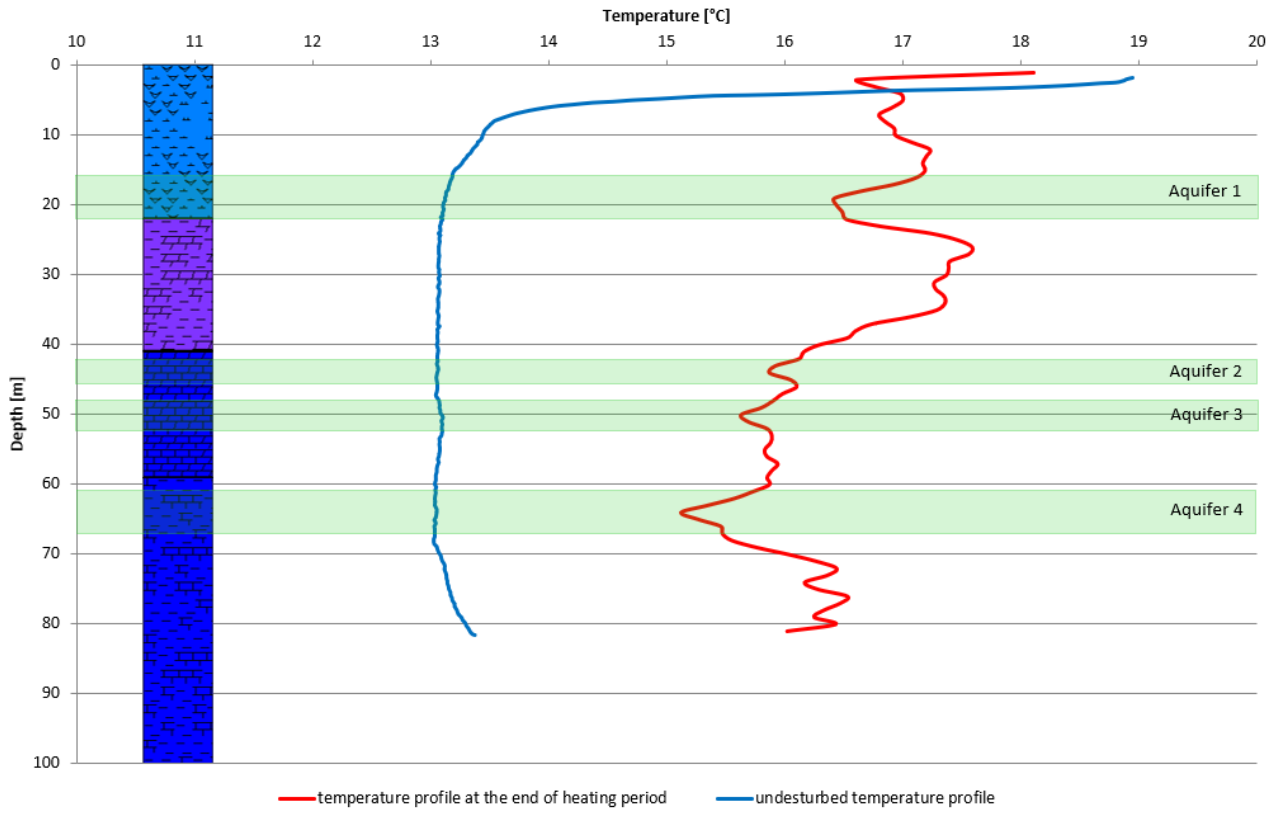


Figure 5. Geology, aquifers and temperature profiles

The heating behavior of the individual probes also provides clues. Probe 2 could not be heated. Probe 1 could be heated slightly, and probe 3 behaved as expected. If a probe cannot be heated, this indicates energy loss due to groundwater flow.

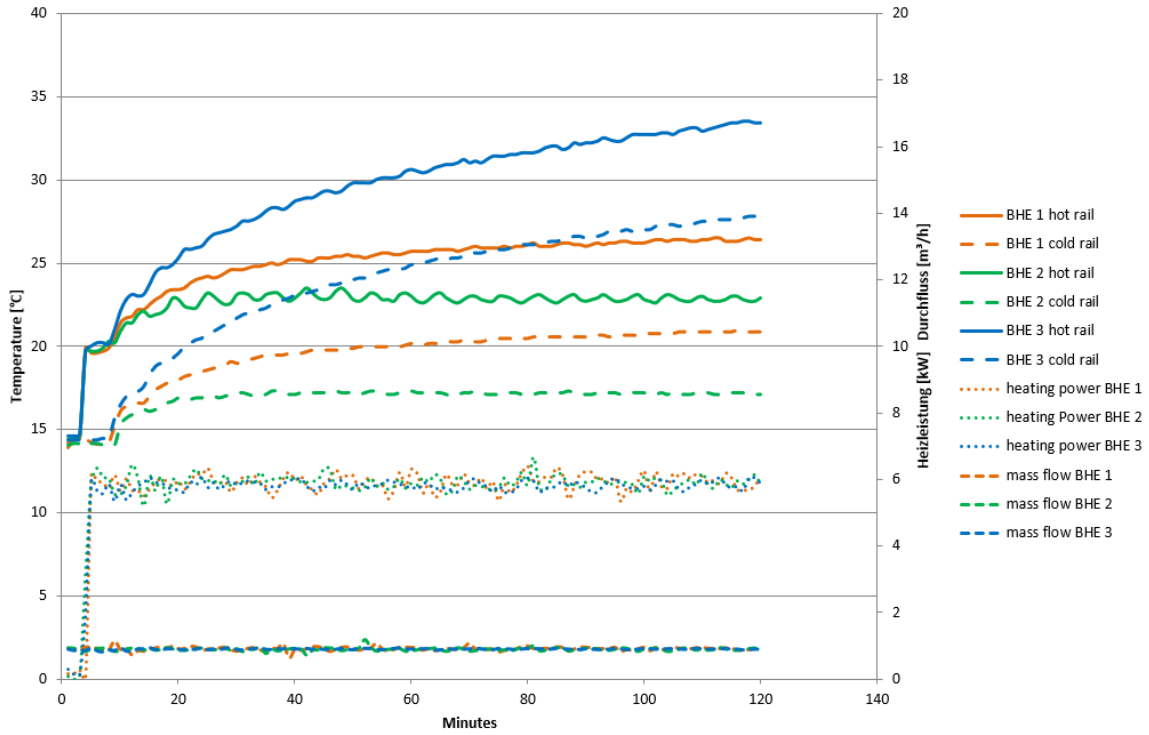


Figure 6. Measuring data while heating up probes

The following illustrations clearly show the influence of groundwater flow on the probe. The backfill is intact in probe 3. Three groundwater horizons are short-circuited in probe 1 and all four groundwater horizons are short-circuited in probe 2.

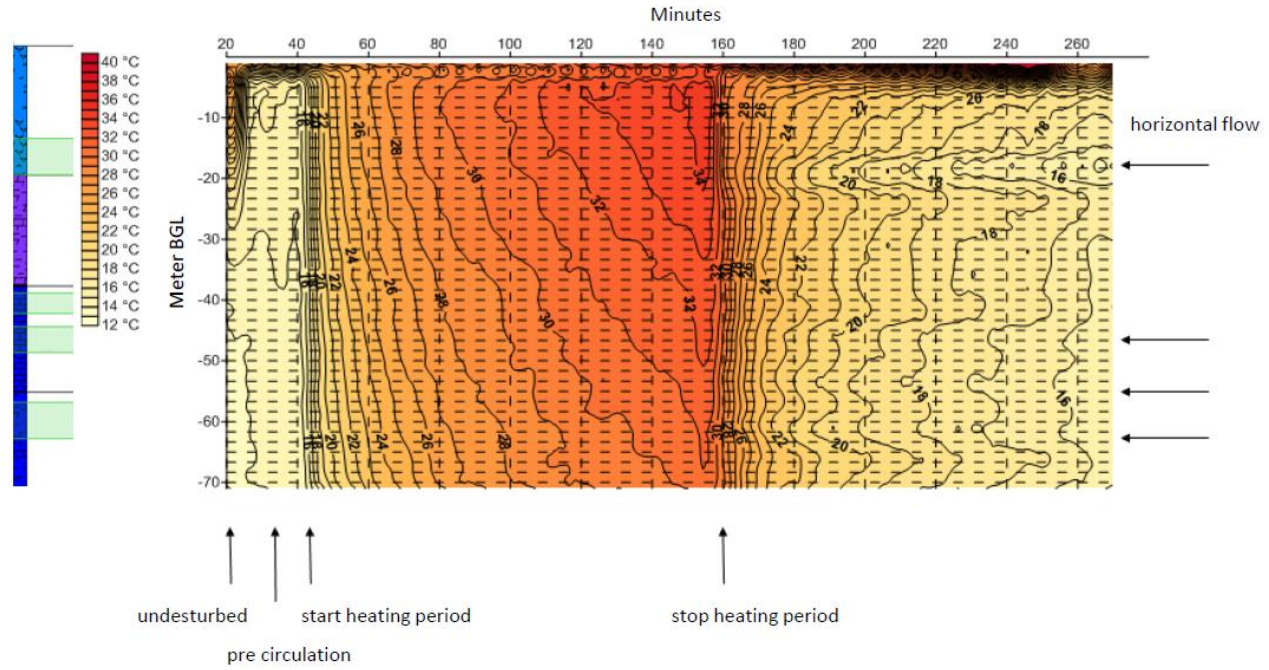


Figure 7a. Chrono-Thermography BHE on BHE 3 shows an intact backfill

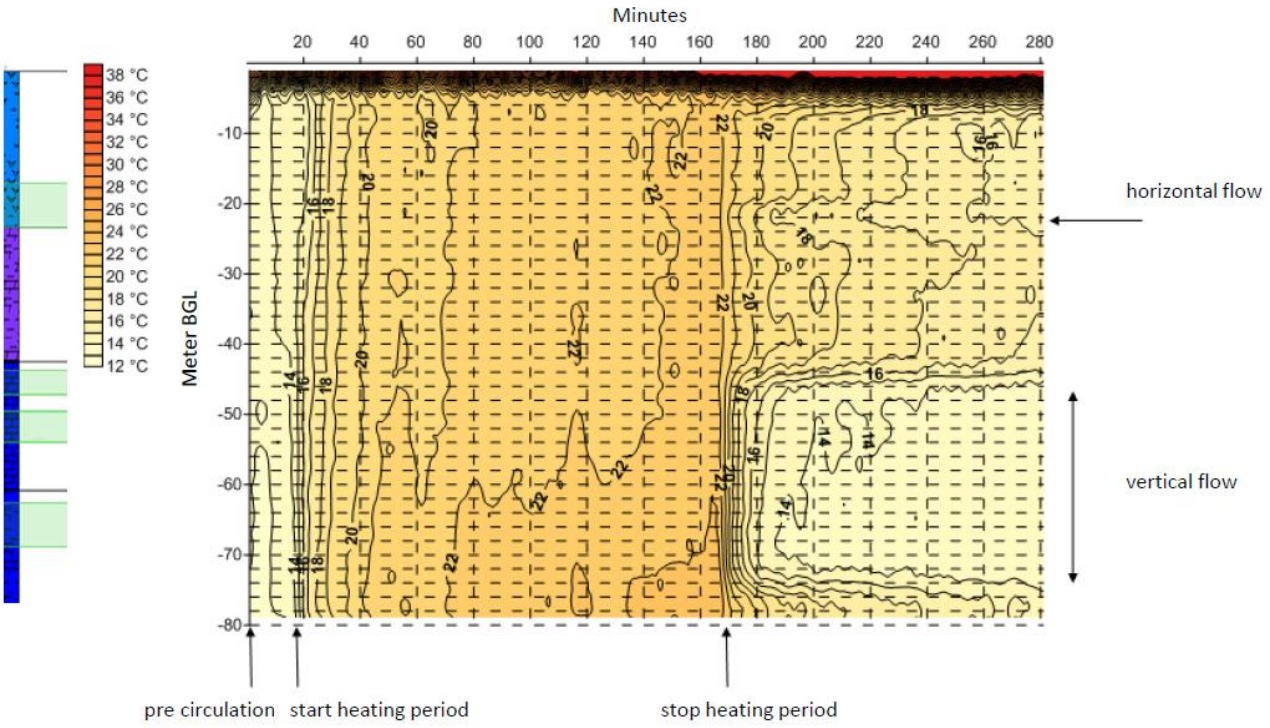


Figure 7b. Chrono-Thermography on BHE 1 short-circuit over three aquifers

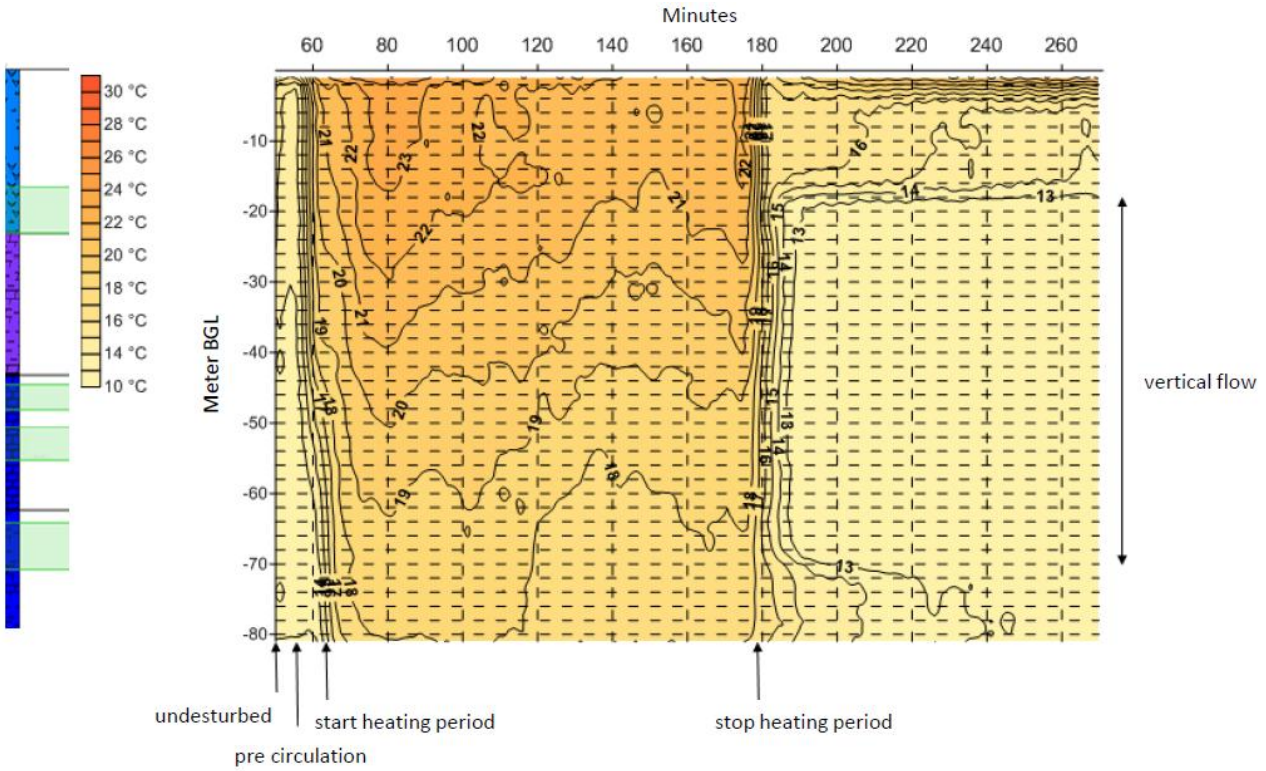


Figure 7c. Chrono-Thermography on BHE 2 short-circuit over all aquifers

Technically, a geothermal probe corresponds to a tube bundle heat exchanger. Since the borehole diameter, probe geometry, energy loss, and temperatures in the subsurface are known, the flowing mass can be estimated based on the short-circuited distance known from the measurement. The calculation is performed in the same way as for a technical tube bundle heat exchanger. In this case for BHE 2 was calculated a flow amount of 12 m^3/h. A measurement by flow meter showed similar dimensions.

4 CONCLUSION

Incorrect or missing backfilling causes groundwater horizons to be short-circuited. This results in flow in the unsealed borehole. This can lead to various consequential damages. The outflow of groundwater can cause subsidence of the subsoil and damage to buildings. In areas with water-soluble minerals (e.g., gypsum), this can also lead to leaching and mass loss. This also leads to subsidence, which can cause damage to buildings. It can also cause swellable rock (e.g., anhydrite) to come into contact with water and cause uplift. Environmental pollution can enter several groundwater levels as a result of faulty backfilling and the associated groundwater flow.

The method presented here makes it possible to test existing probes and assess their structural integrity. Detailed knowledge of the subsoil allows causes of damage to be identified or ruled out. This knowledge is also valuable for developing remediation concepts in the event of damage.

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