BEDROCK TEMPERATURE MEASUREMENTS IN MYNÄMÄKI

Geological Survey of Finland (GTK) conducted a thermal response test in Mynämäki. Special fiber optic measurement cables were installed inside the collector pipes in order to measure the temperature profile of the brine fluid from top to bottom of the borehole.

The temperature data collected from fiber optic measurement will be presented in a separate report. This report presents the initial temperature data of the borehole and results of the TRT-test.

The test was conducted in a 350 meters deep borehole 20.- 23.5.2016. The initial temperature profile of the bedrock was measured 19.5. Heating and circulation of the brine was stopped at 23.5. and recovery (cooling) period was monitored with fiber optic cables until 30.5.

GEOPHYSICAL MEASUREMENTS AT THE SITE

The 350 meter deep borehole (diameter 114 mm) was drilled by Rototec Ltd at the beginning of april. The installed collector was also 350 meters.

Drilling increases the temperature of the bedrock significantly so a nominal cooling period of two weeks must be waited before the TRT-test. No rock samples were collected during drilling but the dominant rock type at the site is biotite paragneiss. TRT- measurements have been made nearby before.

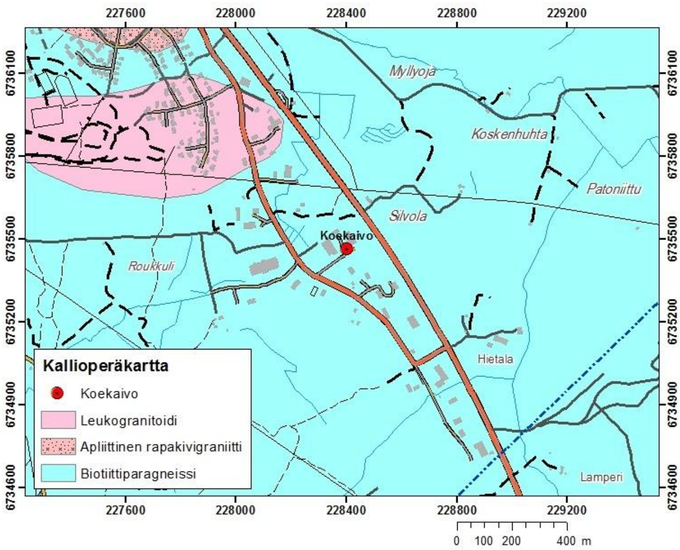

Figure 1. *Location of the test borehole. Maps: © National Land Survey of Finland & Geological Survey of Finland.*

Temperature profile of the borehole

Temperature profile of the borehole was measured before the TRT-test. Temperature measurements were conducted inside the collector pipes filled with brine (Altia Naturet). Measurement was done by accurate temperature probe. Because of the annual temperature variation near surface, the first 60 meters must be measured more precisely. Temperature profile is provided in figure 2 and overall results in table 1.

In Finland the annual temperature variation near ground surface caused by weather conditions is quite vast. It has been inspected that the variation affects temperature levels up to 15 meters below surface. At that level the temperature level of the bedrock is not affected by weather conditions and is almost the same as the average annual temperature of the surface, which in Mynämäki area is typically 6–7 °C. The measured temperature of the bedrock at 15 meter level was now 7,1 °C.

Temperature of the bedrock at the site is high. The coldest point (6,2 °C) was detected at 50 meters. Temperature starts to rise linearly after at 125 meters. Geothermal gradient is typically in Finland 8-15°C/km. Thermal gradient in the borehole was 1,43 °C/100 m which is a very good value. The weighted average temperature of the bedrock is 7,8 °C.

The ground water level was 1,32 meters below the ground surface during the measurements.

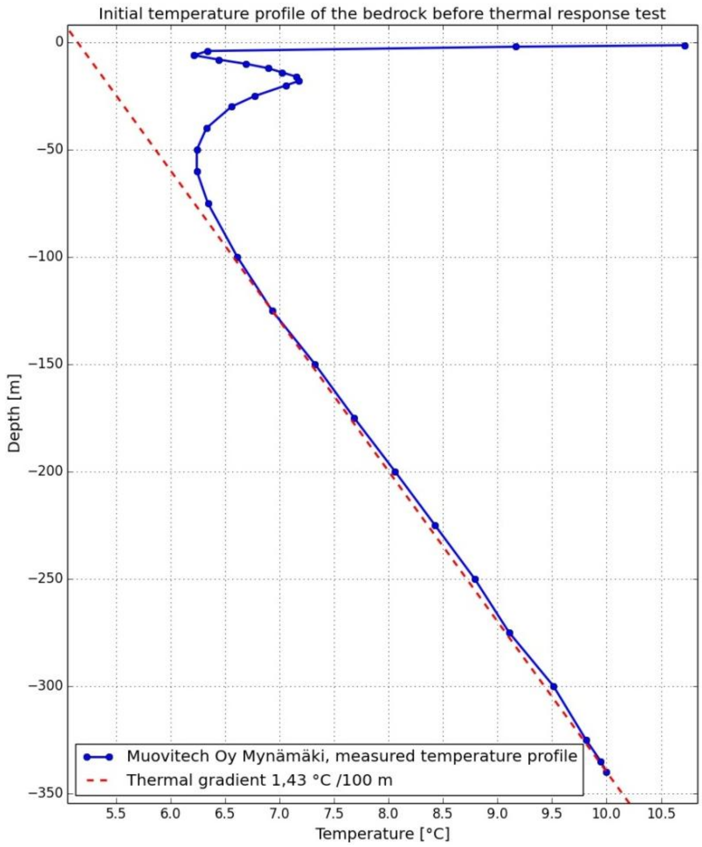

Figure 2. *Bedrock temperature profile measured in the borehole*

***Table 1**. Initial temperature measurements.*

Measuring date	19.5.2016
Temperature at the ground water level [°C]	10,71
Temperature at the bottom of the borehole [°C]	10,00
Weighted average [°C]	7,81
Weighted average below annual temperature variation zone, 15–300 m [°C]	7,84
Geothermal gradient (125 m – 300 m) [°C/100 m]	1,43

Results of the TRT-test

Essential temperature and power profiles are presented in figures 3, 4 and 5. The brine was heated by average power of 11 kW (figure 5). Measured temperature difference between in- and outlet is in figure 4. The average difference was 4,1 °C.

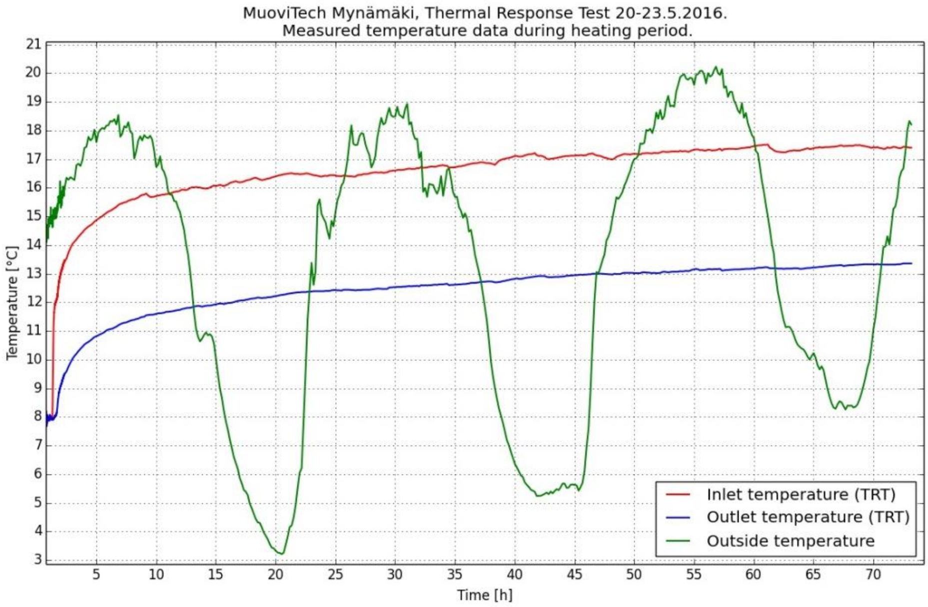

***Figure 3.** Temperature data of the TRT-test.*

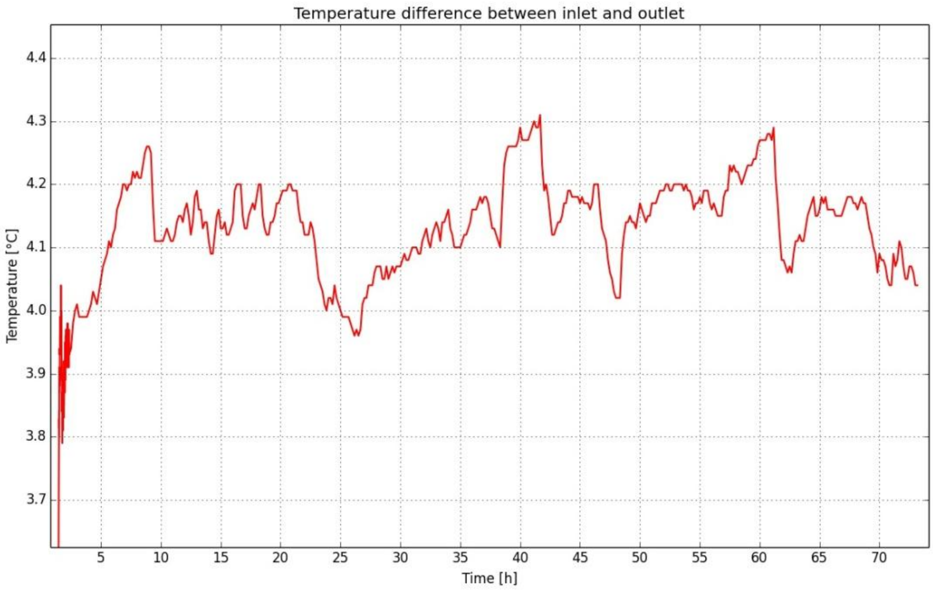

Figure 4. *Temperature difference between inlet and outlet flows.*

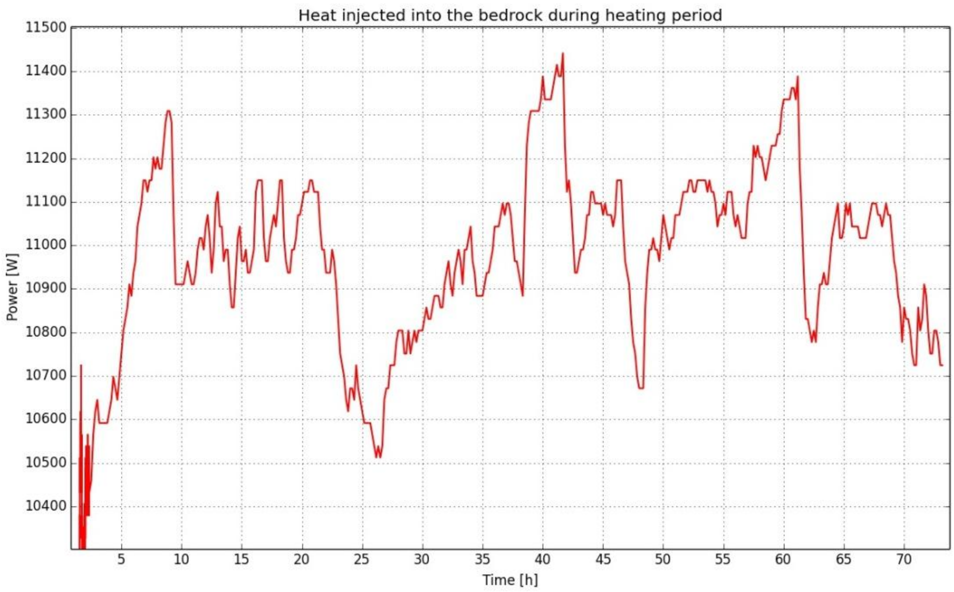

Figure 5. *Heat injected during the TRT-test.*

From figure 5 one can see that the outside temperature variation causes little variation into power too. This variation has been taken into account in data interpretation. During the first 10- 15 hours of the TRT-test, injected heat mainly rises the temperature of the groundwater. That's why one should not use data from that period of time in interpretation

The analytical interpretation was made on the time period 15 hours – end of the heating period. Figure 6 shows that the effective bedrock thermal conductivity is 2,90 W/(m·K) whether fitting is done by using constant or variable heating power.

Effective thermal resistance of the borehole (R_b) 0,087 m·K/W is slightly lower than in other non-grouted boreholes with the same diameter (114 mm) measured by GTK.

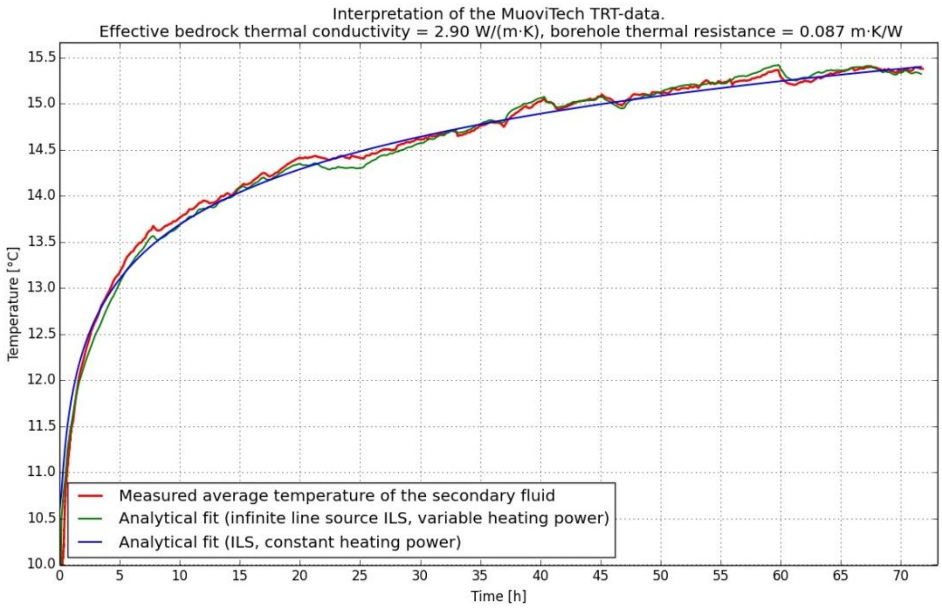

Figure 6. *Interpretation of the the TRT-data.*

Flow rate during the TRT-test was 41,695 l/min, so flow speed in 45 mm pipe (2,8 mm wall thickness), was 0,57 m/s. Flow was clearly turbulent (Reynolds number > 10 000). By using Reynold's and Nusselt´s number and the friction coefficient of the flow, one can calculate the convective heat transfer coefficient of the fluid which affects the thermal resistance of the fluid.

The local theoretical thermal resistance of the borehole R_b can be presented in equation

$$R_b = R_g + R_p + R_f,$$

where R_g is resistance of groundwater, R_p is resistance of the pipe material and R_f is convective resistance of the brine fluid. Resistance of the groundwater depends on the distance between collector pipes and their location in the borehole so analytically R_g can't be determined precisely. Instead the theoretical values for R_p and R_f can be calculated. Figure 7 shows how thickness of the pipe walls affects R_p and how R_f decreases as the turbulence/convective heat transfer coefficient rises. Thermal conductivity of pipe material is assumed to be 0,43 W/(m·K).

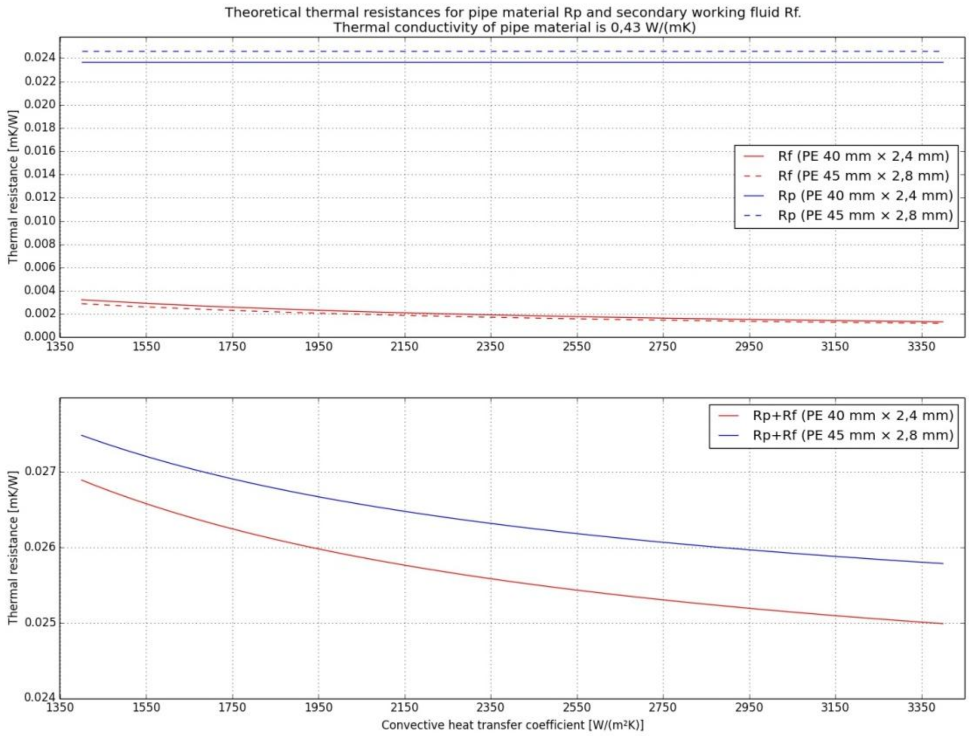

Figure 7. *Theoretical thermal resistances for pipe material and working fluid.*

By theoretical calculation (figure 7), the convective thermal resistance of the fluid is smaller in 45 mm pipe compared to 40 mm pipe. On the other hand, pipe material´s thermal resistance in the 45 mm pipe is bigger because of thicker walls.

COMSOL Multiphysics – program was used to calculate the results in figure 8. 45 mm collector reduces the ground water volume and also the thermal resistance of the borehole. The distance between collector pipes was assumed to be 60 mm. Despite how the pipe shanks are located inside the borehole, the local thermal resistance of the borehole is better when 45 mm pipe is used. The heating power used in simulations was 11 kW. The local borehole thermal resistance for 45 mm pipe was 0,087 m·K/W and corresponding resistance for 40 mm pipe 0,098 m·K/W.

Other constants used in COMSOL simulation:

- Thermal conductivity of pipe material: 0,43 W/(m·K)
- Volumetric heat capacity of pipe material: 1,83e6 J/(m^3·K)
- Volumetric heat capacity of brine fluid: 3,82e6 J/(m^3·K)
- Effective thermal conductivity of ground water: 0,96 W/(m·K).

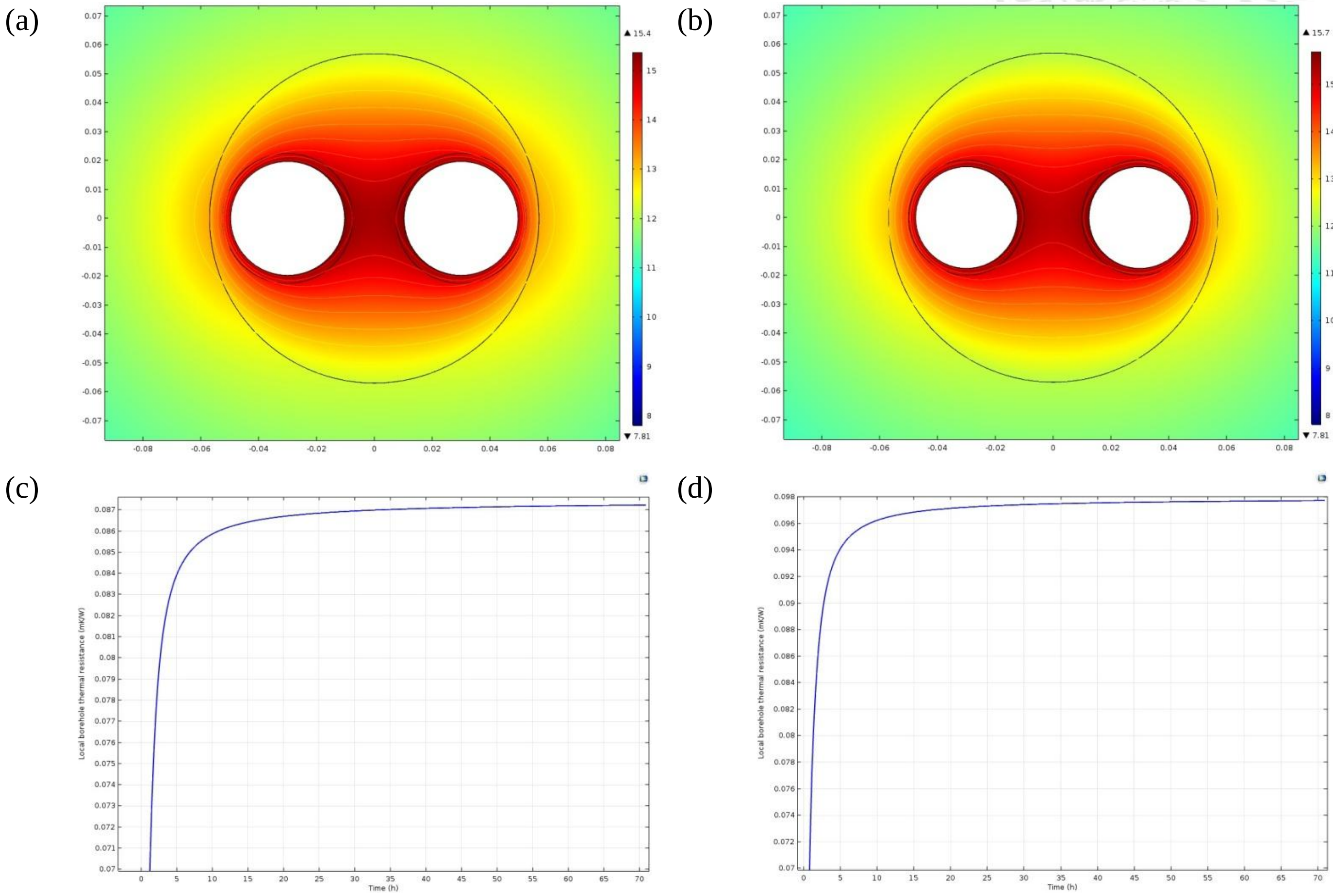

Figure 8. *Simulated local thermal resistance of the borehole with a) 45 mm and b) 40 mm collector pipe. With 45 mm pipe the thermal resistance was c) 0,087 m·K/W and with 40 mm pipe d) 0,098 m·K/W*

DTS-measurements

Fiber optic cables inside the collector pipes measured temperature in 5 minute intervals. This data can be used to determine the distributed (”layered”) bedrock thermal conductivity and thermal resistance of the borehole. It’s also possible to evaluate how location of the pipes and variation of ground water temperature affects the thermal resistance in certain depths.

The borehole can be dived for example in layers of 20 meters with characteristical values for thermal conductivity and thermal resistance. DTS- data and data interpretation can be presented in own report.

Temperature at the bottom of the borehole was 10,0 °C. Lower picture in figure 9 shows that the initial temperature was nearly the same after 7 days of recovery. Upper picture in figure 9 show that the temperature data from the ground water level (approximately 2 meters deep in descending and ascending shanks) is similar to temperature data collected from TRT-rig’s temperature probes.

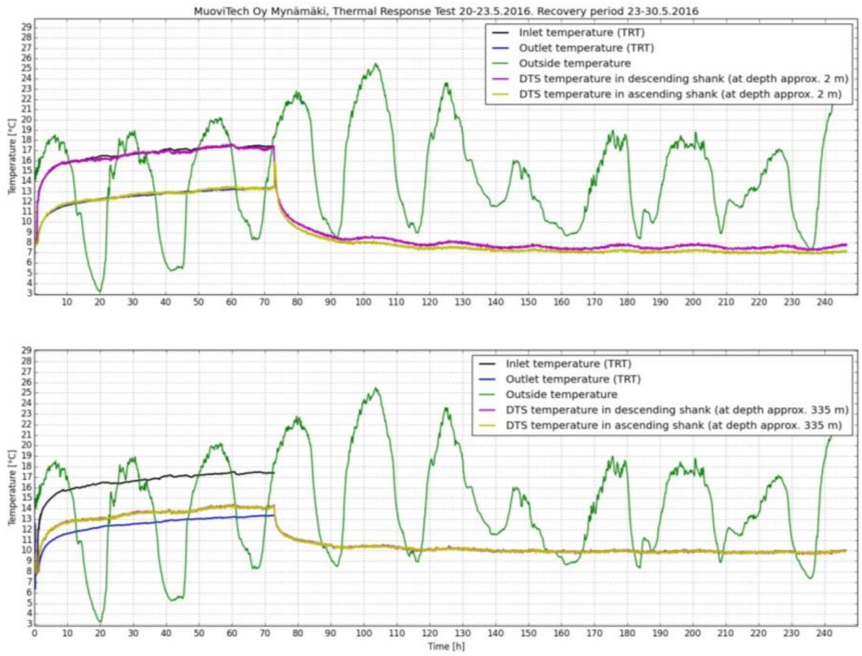

Figure 9. *The temperature of the fluid during TRT-measurement and temperatures obtained with DTS-measurement (from depths 2 and 335 meters). DTS-device was measuring the temperature in both pipe shanks during the TRT- test and recovery period 20-30.5.2016.*

Figure 10 shows that the full recovery back to initial temperature levels was not reached within a week after heating. At depths approximately from 125 to 150 meters recovery seemed to be slower.

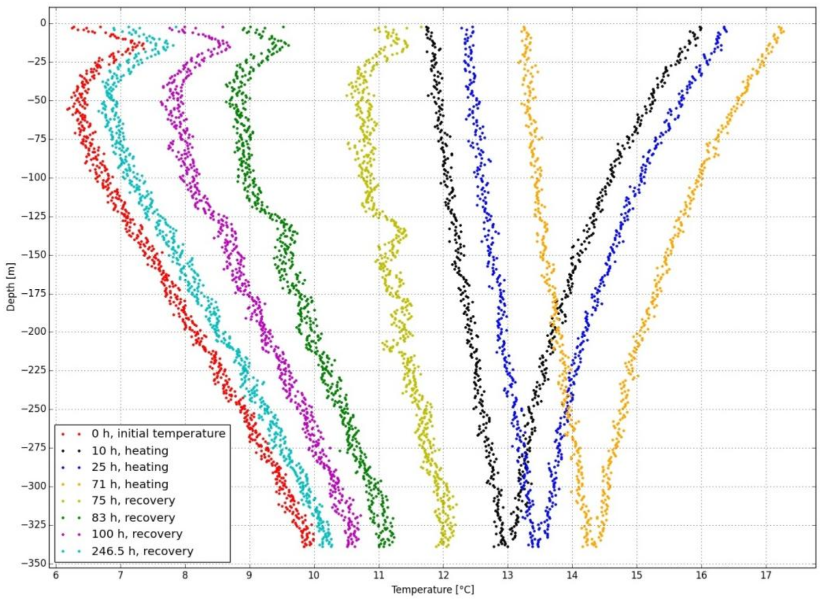

Figure10. *Temperature profiles of the fluid in both pipe shanks as a function of depth in different moments of time (before heating, during heating period and during recovery).*

SUMMARY

Measurements were done in a borehole drilled at Muovitech Finland site at Mynämäki. The interpretation of the TRT-data showed that the effective thermal conductivity of the bedrock was 2,90 W/(m·K) which is typical value for gneiss-type rock. Thermal resistance of the borehole with the 45 mm pipe (0,087 m·K/W) was slightly lower compared to GTK's other measurements done in a 114 diameter non-grouted borehole.

Numerical simulation was used to compare 45 mm and 40 mm pipes. Although there was no significant difference between these pipes in case of pipe material's and fluid's thermal resistance, the overall theoretical thermal resistance of the borehole is smaller when 45 mm pipe is used. The main reason for that is the smaller ground water volume inside the borehole when using 45 mm pipe.

Data collected from DTS- measurement can be used for interpretation of distributed local borehole thermal resistances. It shows the local temperatures of the brine fluid in different depths as a function of time. Position of the pipes compared to borehole walls affects the results more than the diameter of the pipes. Data shows how local differences in thermal conductivity of the bedrock affect the temperature recovery after heating.