Optimum waiting duration between Thermal Response Tests in borehole heat exchangers

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Abstract

In large scale applications of ground source heat pump (GSHP) systems, multiple Borehole Heat Exchangers (BHE) are used and thermal properties of ground (thermal conductivity and diffusivity) becomes important parameters to design a BHE field. Therefore, Thermal Response Test (TRT) methods are commonly used to determine these parameters. A conventional TRT takes around two days, and during these two days generally constant heat flux is injected to a borehole heat exchanger (BHE). This given heat flux is usually generated from electrical source, therefore, costs of tests are too high. In some applications there is a need to make a new test after a finished TRT to verify the results. Furthermore, some tests may be interrupted due to problems such as electric cut-off or fault in data acquisition etc. In these cases, it is required to start a new test. ASHRAE advised that waiting period for a new test after completed test should be 14 days. This period is very long time for academic studies and last user projects. Therefore, waiting long period of time for a newer test after a finished test in the same borehole is one of the important problem in TRTs. In this study, borehole's temperature behaviour in TRT and optimum waiting period are investigated experimentally and numerically. In solutions of waiting period for a BHE, boundary and initial conditions are changed and solved numerically in a modelling program. Solutions are validated each other with numerical and experimental results. After validation, numerical solution is used further investigations. Undisturbed ground temperature is taken as a reference point for comparisons. After a TRT (for injection or extraction heat flux), BHE needs very long time to come the same conditions at the beginning. Different cases are considered and the results are discussed in this study. Moreover, effects of different TRT types (constant heat flux, constant temperature) are investigated. The effect of heat flux amount for constant heat flux TRT method and the effect of test temperature for constant temperature TRTs as well as test duration for both types are investigated. In addition to these, depth of BHE is another important parameter in the renovation process. At deep depths, regeneration is too different than the shallow regions because of different temperatures of these layers. Based on this works, some possible actions are discussed to shorten this duration. If the undisturbed ground temperature is measured sensitively and this new data is used for evaluation of newer test, in this case, may not need to wait long time for renovation. If the new value has too much effect to the final solution, then it is required to wait a period of time. One of the possible action is to extract the some amount of heat energy after a heat injection test for a new test. Economic analysis of these actions are also examined. In the light of the results, it is obtained that 14 days waiting period is very long time to start a new test. By applying some possible actions like extracting some amount of heat energy after a heat injection test, this duration can be shortened. Besides, with using new borehole average temperature in the solution same results may be achieved. These results could be useful for academic studies and last customers to achieve more reliable results in limited time.

Keywords:

Thermal response tests, borehole heat exchanger, ground source heat pumps

1. Introduction

Thermal Response Test (TRT) is one of the important process before the application of Ground Source Heat Pumps (GSHP) especially in larger projects. Sometimes more than one test is needed for a borehole and sometimes the test is needed to be repeated because of the problems during the testing. Especially in the research studies there are always requirement to test a borehole more than once. For a newer test after an interrupting or completed test, a period of time has to be waited for recovering of the ground. Information about the optimum recovery period of borehole is not enough. Only for ASHRAE (Ashrae, 2011) waiting duration must be at least 14 days.

After a heat injection TRT or immediately after the drilling process vertical temperature distribution of the borehole is changed. Furthermore, temperature distribution in radial distance also changed after the test. Effected radial distance around the borehole depends on the test duration and given heat energy to the borehole, more heat energy is caused more effected area. Immediately after a test stops, the recovery of the ground temperature starts. Recovery process of a borehole after a TRT is investigated by Raymond (Raymond et al., 2011). They also build a test system depends on the evaluations on recovery period (Raymond and Lamarche, 2014). In the recovery period, important amount of renovation happens in the first hours. Then decreasing rate of temperature decreases and coming back of the first undisturbed temperature takes very long time.

In this study, thermal behavior of a borehole is investigated during TRT and recovery period. For a normal heat injection Thermal Response Test, minimum recovery time is calculated and effect of test duration and the amount of heat injected to ground is also investigated. Furthermore, possible actions for reducing recovery time are also discussed.

2. Problem Definition

A sample borehole with a single U-tube is given in Fig.1. In this figure, grout, ground and inlet and outlet pipes sections are shown.

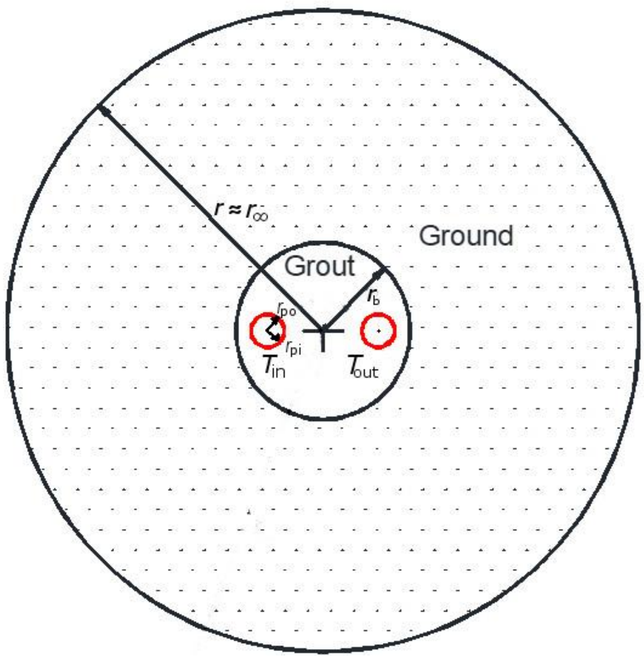

Figure 1: Sketch of a single U-tube borehole cross section.

Governing Equations 1D-cylindrical heat conduction equation:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

Boundary conditions for testing process

In the periphery of inlet pipe : T_{in} and in the periphery of outlet pipe : T_{out}

Far field temperature in radial distance where is not effected thermally from the test $T(r_\infty, t) = T_\infty$

Initial Condition

$T(r, t = 0) = T_\infty$

Boundary conditions in recovery process

$T(r_\infty, t) = T_\infty$

Initial condition of recovery process is last temperature distribution around the borehole after testing process. This temperature distribution is calculated in COMSOL Multiphysics and it is used in solution of recovery period as initial condition.

3. Modeling and Validation

In the validation process of TRT, experimental inlet and outlet temperatures are imported to the model. In the model domain size of ground is chosen large enough to ensure that temperature changings not effect to boundaries considerably in the duration of test. Grout and ground properties are chosen as isotropic and homogeneous. Figure 2 shows temperature records in a sensor located on pipe in borehole during in a sample test and recovery process. In the figure continuous line represents results from the COMSOL model.

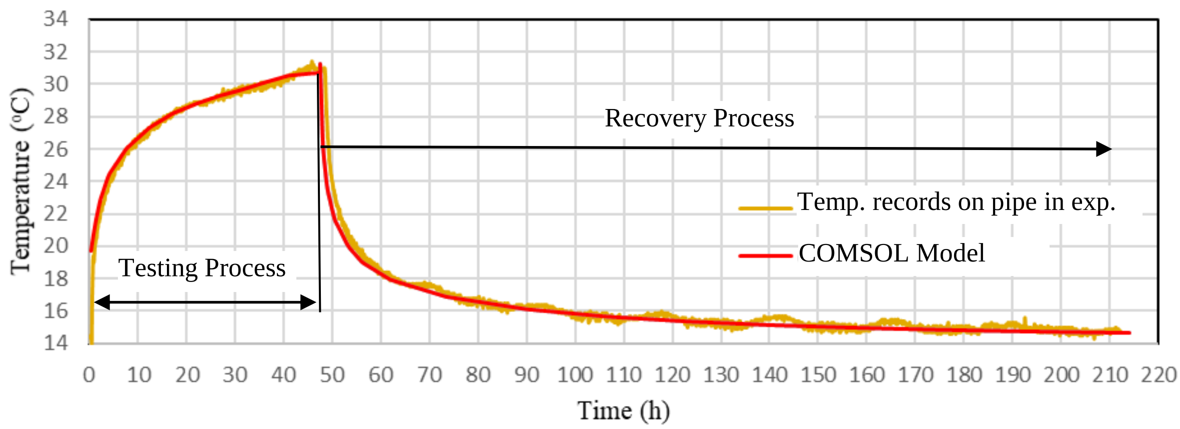

Figure 2: Temperature recordings in a sensor located on pipe during a sample test and recovery period.

Figure 3 shows variation of temperature distribution around the borehole during testing process. It can be seen from the figure, after 50 hour test operation, thermally effected region around of the borehole is smaller than 2 m.

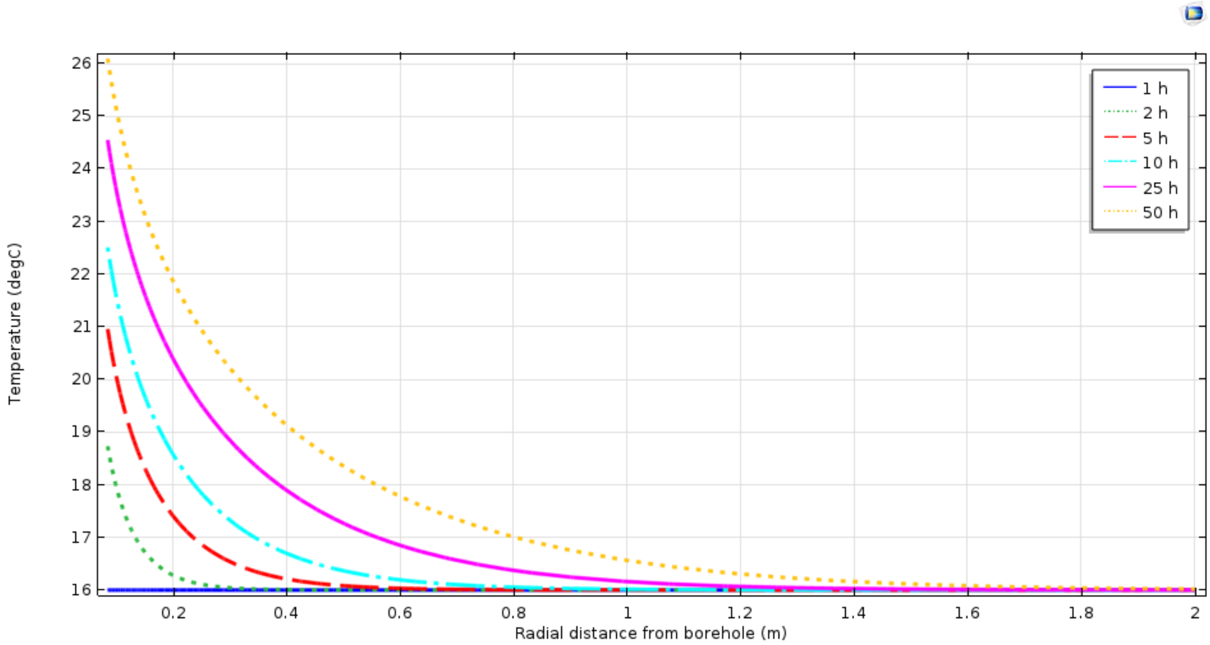

Figure 3: Variations of temperature around the borehole during the 50-hour 80 W/m test.

After performing a test, recovery process starts immediately as it can be seen from Figure 4. After 14 days there is very small residual heat left inside ground. Comparing with first undisturbed ground temperature, the temperature difference is lower than 0.5 °C. However, it is needed to wait very long time to come ground temperature in the first condition. Nevertheless, this residual heat cannot effect the results so much, therefore, it is generally omitted.

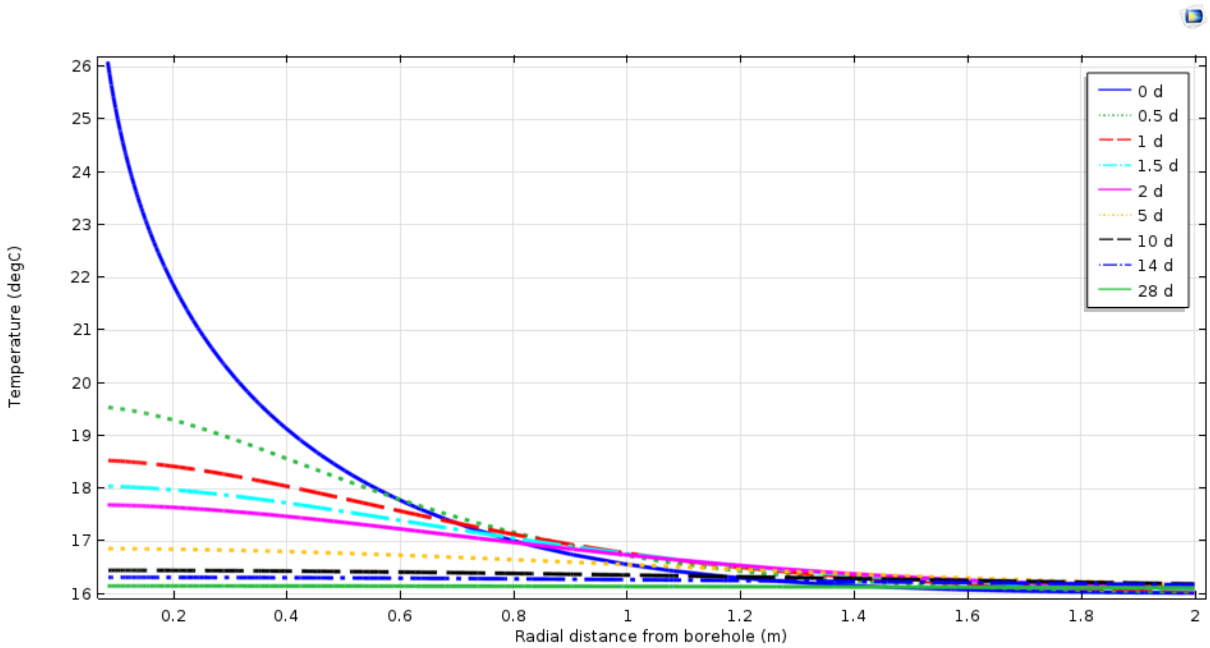

Figure 4: Variations of temperature around the borehole during recovery period.

Decreasing of temperature in the borehole also can be seen from Figure 5, by records in temperature sensor located on pipe inside borehole. Here tolerance between the first borehole temperature and temperature end of the test is chosen as 0.5 °C, if the tolerance is chosen lower than this value, optimum recovery time will be longer than the values given here.

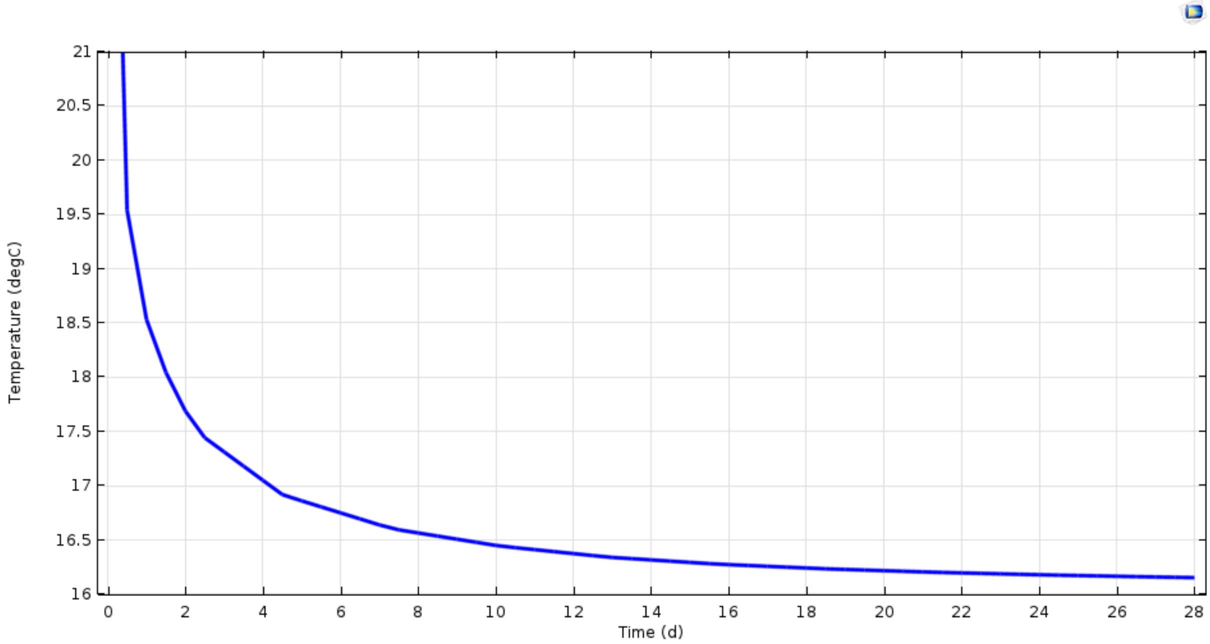

Figure 5: Temperature variations on the pipe during the recovery period.

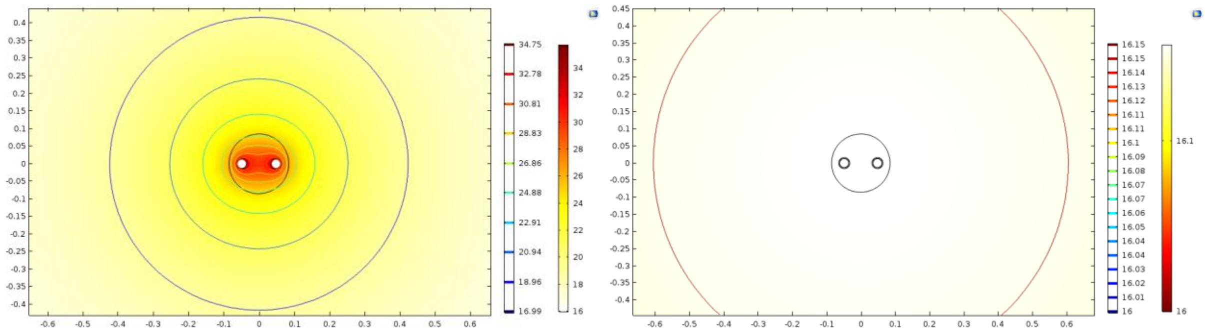

Figure 6: a) Temperature distribution after 50h-80W/m TRT and **b)**temperature distribution after the 14 days recovery period.

3.1. Effect of Test Duration

However, duration of the test and heating power in the test are important parameters in the recovery process. Figure 7 shows variation of temperature distribution in a line around the borehole with after different durations. It can be seen from the figure, after 200 h test operation closer regions to the borehole have higher temperatures than 50 h test operation.

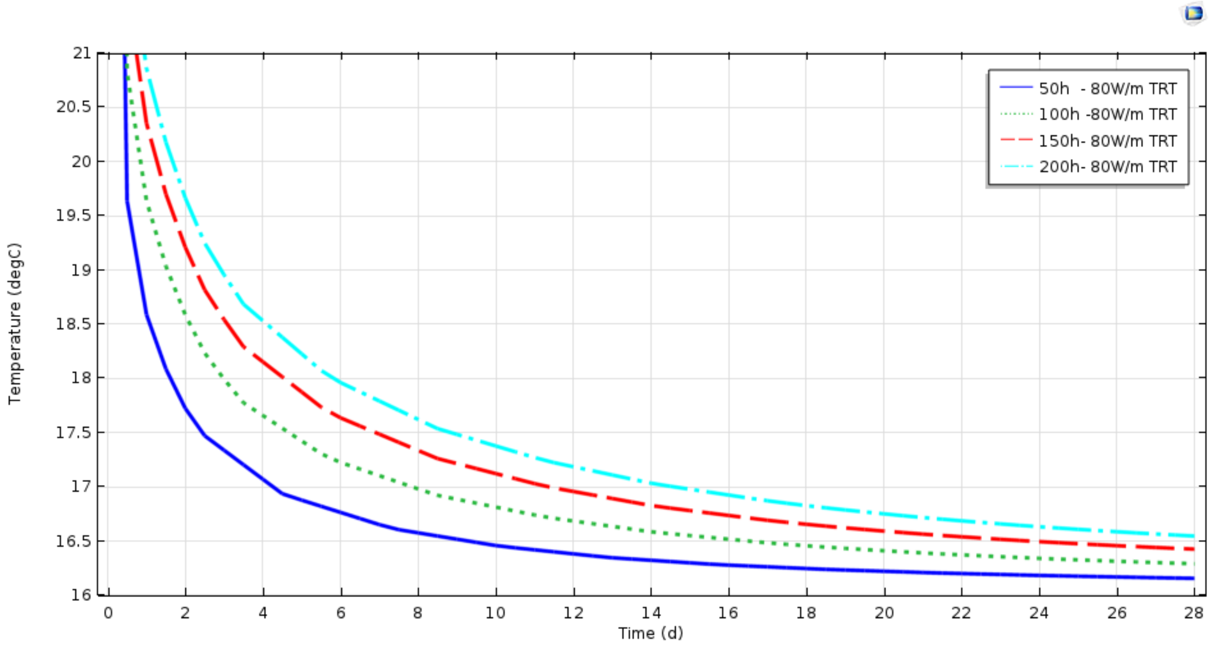

Figure 7 : Temperature changings on the pipe during the recovery period for different test durations.

Furthermore, as it can be seen from Figure 7 after 200 h test approximately 28 days are needed for ground to become 0.5 ^{o}C closer to initial temperature condition. Optimum recovery times depending on testing duration are given in Table 1.

Table 1 : Minimum recovery time depending on test duration for constant heat flux TRTs.

Test Duration	Min. Recovery Time for 80W/m Constant Heat Flux TRT
50	9
100	16
150	24
200	30

3.2. Effect of Testing Power

As we know, the determination indicate of the TRT is the temperature change by the reason of the heat injection or extraction. It does not matter if heat is injected or not. In other words, thermal conductivity or diffusivity are not dependent on the direction of heat flow. Apart from this, testing power is another important parameter in the recovery process, more heating power caused to more effected area around the borehole. Therefore, for high testing power recovery process must be longer.

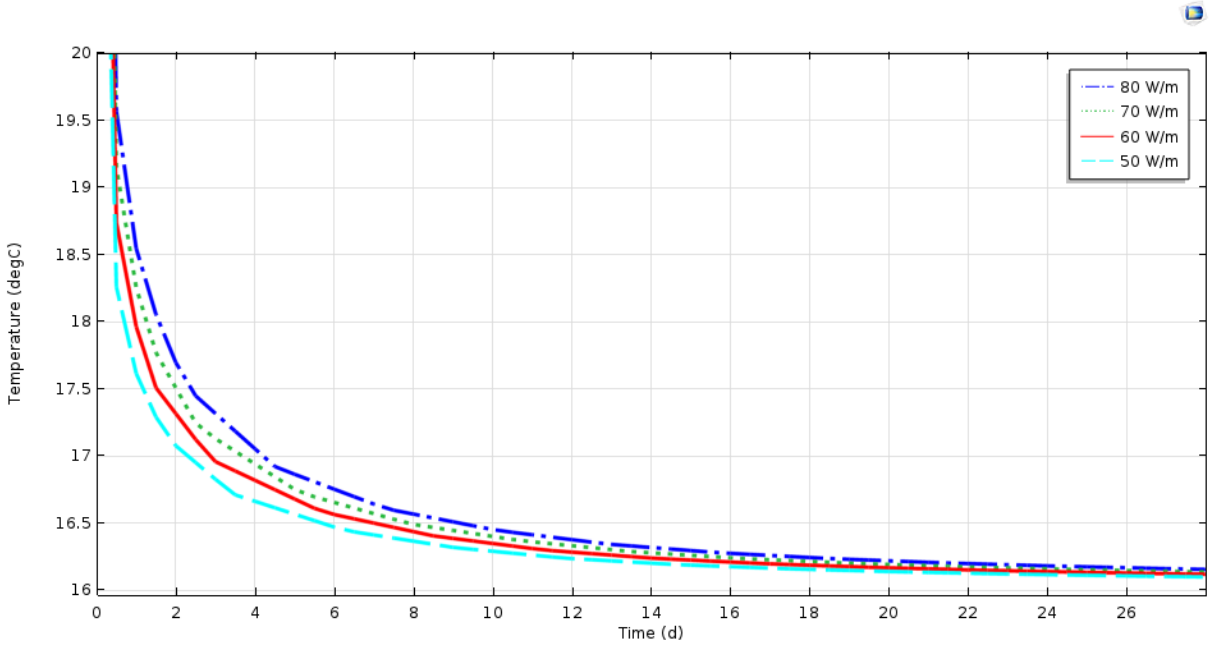

Figure 8 : Temperature changings on the outer side of pipe during the recovery period after 50h tests for different heat injection rates.

As it can be seen from Figure 8 minimum optimum recovery time for 50 W/m test is 4 days, for 80 W/m test it is 7 days. However as it can be seen from Table 2 effect of testing power to recovery time is not high like test duration.

Table 2 : Minimum recovery time depending on testing power for constant heat flux TRTs.

Test Power (W/m)	**Min. Recovery Time**
50	4
60	5
70	6
80	7

3.4. Recovery Times in Constant Temperature TRT

Same modeling process can be repeated for constant temperature TRTs, too. If we repeat all modeling processes for constant temperature TRTs it will be like in Figure 9. This figure shows different recovery times for different testing temperatures for same test duration.

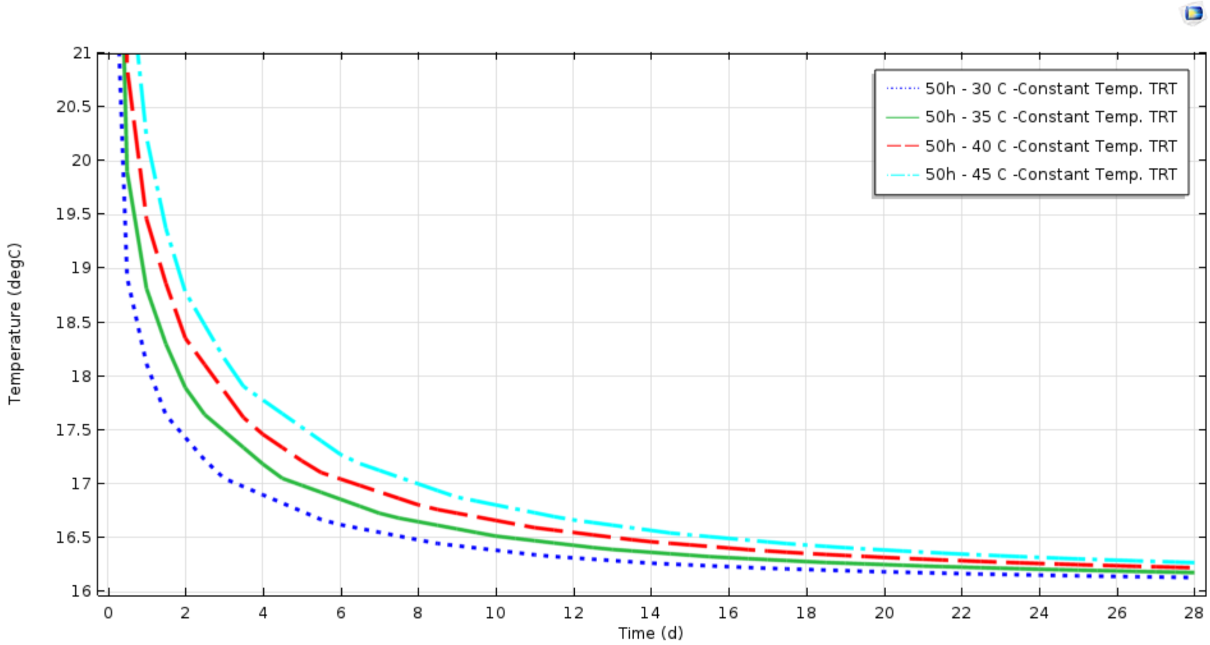

Figure 9 : Temperature changings on the outer side of pipe during the recovery period after for different testing temperatures.

Also it is seen that recovery times in constant temperature TRT are longer than constant heat flux TRTs. Minimum recovery times for different testing temperatures are given in Table 3.

Table 3 : Minimum recovery time depending on testing temperature for constant temperature TRTs.

Test Temperature (°C)	Min. Recovery Time
30	7
35	10
40	12
45	15

4. Reducing the Recovery Time

If it is needed test a borehole immediately after a completed test some actions can be applied. Because of injecting an amount of heat to the ground, after the test extracting an amount of heat from the borehole may be applied. For 50 hour 80 W/m TRT, 4kWh/m heat energy is injected in borehole. For a sample 100m borehole, injected total heat energy is 400 kWh. If this energy is produced by electrical resistances total cost is about 120 € (0.3€/kWh). If heat energy is produced with a heat pump total cost will be between 27-40€ depending on COP (3-4.5) of heat pump. For extracting heat from borehole cold fluid has to be send to the borehole, by using a heat pump this cost will be like heating cost with heat pump, 27-40€.

Furthermore, if the temperature distribution along the borehole and around the borehole is known well, these values can be taken as initial conditions in the calculations of newer test. However, these actions should be investigated deeply. Examination of these actions is out of scope of this manuscript.

5. Conclusion

In this study temperature behavior of borehole is investigated during TRT testing and recovery period immediately after the test. It is seen that recovery period of borehole strongly depends on test durations and test powers. To start a new test after a completed or interrupted test, required recovery time must be taken in account. According to the results, it is obtained that 14 days waiting period is not same for all tests. Recovery period can be different on testing duration, testing power etc. The results of this study can be instructive for determining optimum waiting duration between two thermal response tests in borehole heat exchangers. Furthermore, they could be useful for academic studies and last customers to achieve more reliable results in limited time.

References

ASHRAE. (2011). *ASHRAE handbook: HVAC applications.* Atlanta, GA, USA: ASHRAE; 2011.

Raymond, J., Therrien, R., Gosselin, L. (2011). Borehole temperature evolution during thermal response tests. *Geothermics*, 40, 69–78.

Raymond, J. ve Lamarche, L. (2014). Development and numerical validation of a novel thermal response test with a low power source. *Geothermics*, 51, 434-444.

Nomenclature

k	[W/(mK)]	Thermal conductivity
r	[m]	Diameter
r_b	[m]	Borehole diameter
r_∞	[m]	Far field temperature
r_{p_in}	[m]	Inner pipe diameter
r_{p_out}	[m]	Outer pipe diameter
t	[sec]	Time
T	[°C]	Temperature
T_∞	[°C]	Undisturbed ground temperature
T_{in}	[°C]	Inlet fluid temperature to the borehole
T_{out}	[°C]	Outlet fluid temperature from the borehole
α	[m²/s]	Thermal diffusivity coefficient