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# INSTALLATION FOR THERMAL RESPONSE TEST IMPLEMENTATION

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**Abstract:** *Nowadays, development of efficient thermal energy storage systems is becoming very important since they assist in storing gained energy from renewable energy sources at medium or large scales in an effective way with the purpose of balancing demand and supply for the energy. One of the technologies which allows storing thermal energy in a large-scale, is Borehole Thermal Energy Storage (BTES). Such technology gives opportunity to store heat into the ground and/or groundwater in the summer, and extract it during winter. To evaluate the performance of BTES, thermal properties of the ground must be known. One of the in situ methods for this purpose is to conduct thermal response test (TRT). In order to carry out TRT, special installation must be developed. In the current paper, we will discuss about the TRT installation and its parts developed by the authors. While developing the installation, special attention is paid to the compactness of its size, performance and order of its parts sequentially located in the installation since carefully built installation allows to measure borehole thermal resistance and effective thermal conductivity of the ground around a borehole in a proper way.*

**Key words:** *Borehole thermal energy storage, installation, thermal response test*

## 1. Introduction

Technologies for harnessing thermal energy from renewable energy sources are being developed and improved at a good pace worldwide. Consequently, the improved efficiency of such technologies gives opportunity to gain thermal energy at a large amount in a short time. But, in order to effectively use the harnessed energy, energy storages are needed.

There are several types of thermal energy storage techniques are developed and storage types vary with storage capacities. Storages, capable of storing thermal energy in a large amount, are usually underground thermal energy storage (UTES) systems. One of the most common systems among UTES is borehole thermal energy storage (BTES). BTES is attractive since: (i) construction costs are less compared to other UTES systems, (ii) can be installed almost everywhere except in locations where in the underground there are emptied caverns or high pressure geysers; and (iii) it is long-term system if borehole heat exchanger is installed by carefully following the installation rules [1, 2].

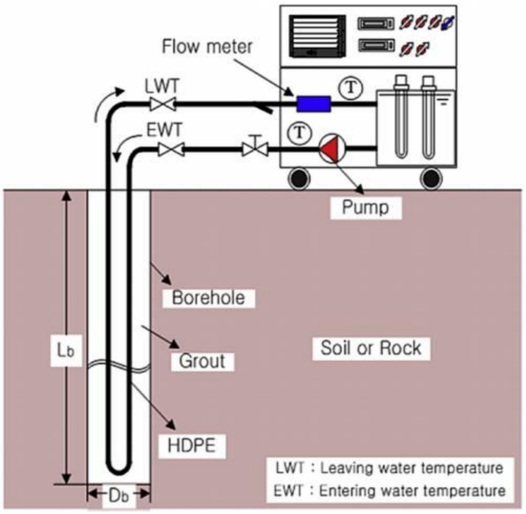

***Fig. 1.*** *Schematic diagram of TRT installation*

Accurate estimation of a thermal performance of BHE is obtained if knowledge of thermal properties of the ground and borehole are evaluated in a correct way. One of the well known experimental methods for evaluating the thermal properties of the ground is thermal response test (TRT). During the TRT, a constant amount of thermal energy is transferred into the ground by using TRT installation (Fig.1) connected to BHE and the temperatures of the circulating heat carrier fluid is recorded at the inlet and outlet sections of the BHE [4]. After the temperature measurements which usually last around 7 to 10 days, analysing the recorded data by means of the line source theory, effective thermal conductivity of the ground $\lambda_{eff}$ and borehole resistance $R_b$ are evaluated. Thus, the formula developed based on the line source theory is [5]:

$$T_f(t) \cong m + k \ln t \tag{1}$$

where

$$k = \frac{q_0}{4\pi\alpha} \tag{2}$$

and

$$m = T_0 + \frac{q_0}{4\pi\alpha}\left[\ln\left(\frac{4\alpha}{r_b^2}\right) - \gamma\right] + \frac{R_b}{q_0} \tag{3}$$

With the purpose of developing and experimentally studying the performance of BTES, partner universities, Al-Farabi Kazakh National University and Technical University of Sofia, branch Plovdiv, installed 50 meter BTES with single U-pipe borehole heat exchanger (BHE) in order to understand the performance of the BTES and evaluate thermal properties of the ground. Moreover, to carry out TRT, special installation developed too.

Thus, in the current paper, developed TRT installation is described in detail including its parts. The developed installation will be used to evaluate the performance of the BTES constructed in the campus of Al-Farabi Kazakh National University, Almaty, Kazakhstan.

## 2. Installation

Schematic diagram of the in-situ thermal response test installation designed to evaluate thermal properties of a borehole and a subsurface is illustrated in Fig.2. Developed installation is relatively simple and includes basic equipments such as water pump, water heater, expansion tank, pressure measuring device-manometer, air remover, valves and connecting pipes. But, the order of the devices in the installation is very important in terms of proper operation of the whole system during TRT, and carrying out the measurement process. Therefore, in the following indents, parts of the installation and their order in the system are discussed in detail.

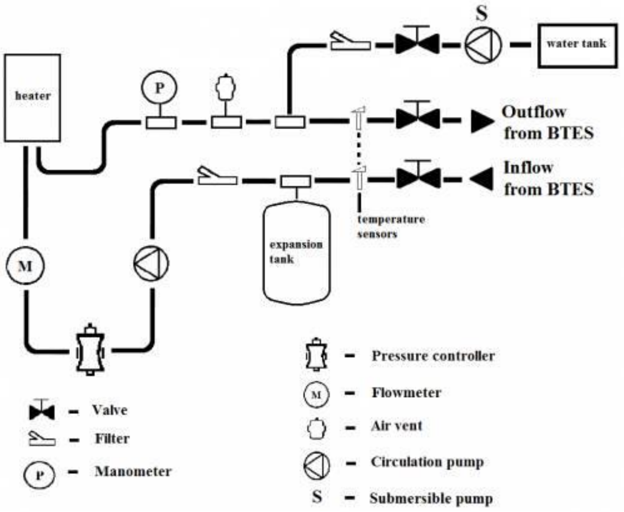

***Fig. 2.*** *Schematic diagram of the thermal response test installation.*

There are three ball valves (Fig.3) were included in the installation: (i) one along the pipe used to charge the loop with the necessary amount of water from an external water source (e.g. a water tank) by means of submersible pump (Fig.4), and (ii) other two were used at the inlet and outlet sections of the pipes which were made to integrate the installation with a borehole heat exchanger (BHE), as illustrated in Fig.1.

***Fig. 3.*** *Ball valve used to control water flow thought the pipes of the installation*

*Fig. 4. Submersible pump (Leo XKS) for chagrining the loop with water.*

Two screen filters (Fig.5) are installed in the TRT equipment. One of them is set up along the pipe which is used to charge the loop with the purpose of cleaning the charging water from unnecessary particles or debris if they are absent in the water. Second filter is established just after the ball valve which controls the water flow from BHE. It helps to clean the water in the loop while circulating it throughout the system. Indeed, such filters must be presented in the TRT installation, otherwise, devices such as heater, air remover, manometer and pump might stop functioning properly because of the particles in the water of the system.

***Fig. 5.*** *Screen filter used to clean the water from particles.*

Right after the ball valves at the inlet and outlet section of the system, **temperature sensors - Pt100** are installed to measure inlet and outlet temperatures of circulating water during TRT process. These three wire temperature sensors are connected to a data logger, iDAQ PT-08 WiFi Data Acquisition Unit (Fig.7), in order to record the temperature development over the TRT process. The data logger is a WiFi based, 8 channel PT100 type thermometer input data-logger. It incorporates a built-in web-server showing data in both tabular and chart formats and requires no PC application software to function. Moreover, it includes 256Kb of internal memory for stand-alone operation. With the help of this type of data logger, it possible to remotely control temperature readings of TRT process. Besides that, the data logger can be configured in a way that it sends a daily or weekly summary email.

***Fig. 6.*** *Temperature sensors – Pt100, for measuring inlet and outlet temperatures of BHE*

***Fig. 7.*** *Data logger used to record temperature changes during TRT process.*

***Fig. 8.*** *a) 8-liter expansion tank and b) circulation pump which are installed in the TRT equipment.*

Expansion tank (Fig.8, a) also plays important role in the system because it assists in managing density changes (or volume changes) of water caused by heat supply from the heater to the loop during TRT process. With the help of the tank, it possible to create fluid circulation in the installation with preferable pressure which is very important for normal functioning of other devices of the system. Otherwise, density changes of water might lead to leakage problems during working modes of the installation. Actually, the expansion tank could be installed almost anywhere along the system but we located it after the inlet ball valve though which water flows from BHE. Proper size of the expansion tank depends on desired system pressure and changes in volume of water from ambient temperature to the maximum operating temperature of the system. Therefore, in order to design the expansion tank, we need to know the total volume of water in the installation as well as in the BHE. Volume change can be calculated using following formula:

$$\rho_1 = \rho_0 /(1 + \beta (T_1 - T_0)) \qquad (4)$$

where $\rho_1$ - final density (kg/m$^3$), $\rho_0$ - initial density (kg/m$^3$), $\beta$ - volumetric temperature expansion coefficient (m$^3$/ m$^3$ $^0$C), $T_1$ - final temperature, and $T_0$ - initial temperature. During the calculation of the volumetric change, it was assumed that the installation is connected to 50 m borehole heat exchanger with initial pipe diameter of 32. Thus, the volumetric change of water when temperature changes from 20 $^{0}$C up to 60 $^{0}$C is 1.5 liter. Thus, the size of the expansion tank is enough to handle water volume changes.

One of the main devices in the system is a circulation pump, and in our case it is Grundfos ALPHA2 L 25-60 (Fig.8, b). This type of pump is specially designed for circulating liquids in heating systems; therefore, it is suitable to carry out thermal response test. Performance range of the pump is shown in Fig.10, where volumetric rate can be increased up to around 0.7 l/s. But, the flow rate is limited by the flow meter performance.

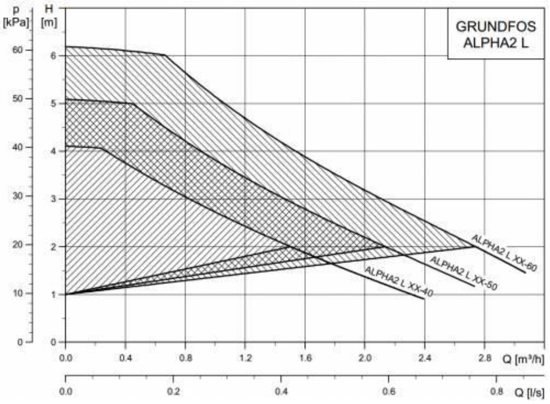

***Fig. 9.*** *Performance range of the circulation pump ALPHA2 L [6].*

Once water circulation is launched by the pump, its flow rate can be monitored with the help of variable area flow meter (rotameter). Maximum amount of water that can flow thought the flow meter in a second is 0.4 liter. Therefore, pump must initiate fluid flow maximum up to 0.4 l/s only, otherwise, leakage problems might arise around the rotameter. Moreover, between the pump and rotameter there is a pressure regulating device was installed to control the pressure in the system during TRT.

*Fig.10. Rotameter, emis-meta 025A, used in the TRT equipment to measure average flow velocity.*

After the rotameter, electrical flow heater, thermex stream 300 (Fig.11, a), was installed and its function as a part of the installation is to provide constant amount of thermal energy to the circulating fluid while carrying out TRT. But, the flow heater is not directly plugged into power socket but through voltage regulator, AVR-5000-W (Fig.11, b). Indeed, automatic single-phase voltage regulator AVR-5000-W is used to stabilize the output voltage in a network with single-phase alternating current frequency of 50 Hz. Therefore, it prevents failure of the electrical equipment, as a result of probable fluctuations in voltage AC. In our case, it also helps to supply constant amount of thermal energy (kJ/sec) to the circulating fluid by means of the flow heater since it receives stabilized 220 V electrical energy from the regulator AVR-5000-W. Keeping the amount of thermal energy supplied to the working fluid by the heater is very important because in the line source model, it was assumed that the BHE receives fixed amount of thermal energy per length of BHE (Eqns. (1)-(3)).

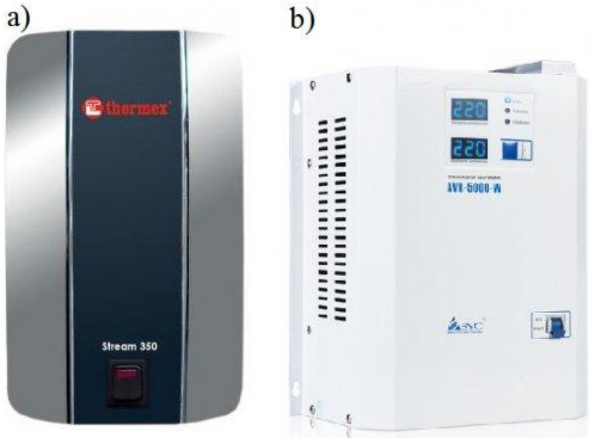

***Fig. 11.*** *a) Flow heater, thermex 350, installed in the TRT equipment as the thermal energy supplier; b) automatic voltage regulator AVR-5000-W.*

Pressure measuring device - manometer (Fig.12, a) was installed after the heater to monitor the pressure during the test. Error of the device is 1.5% which shows its high accuracy. Moreover, it can be installed to a system where temperature of working fluids might raise up to 150 $^{0}$C and it can work at ambient temperatures starting from -70 $^{0}$C till 50 $^{0}$C; therefore, it is appropriate to the TRT equipment where working fluid temperature might go up to 40-50 $^{0}$C and climate of Kazakhstan with temperature change from -20 $^{0}$C till 40 $^{0}$C.

On the left side of the manometer, automatic air vent (Fig.12, b) was installed to the installation with the purpose of removing air bubbles present in the circulating fluid.

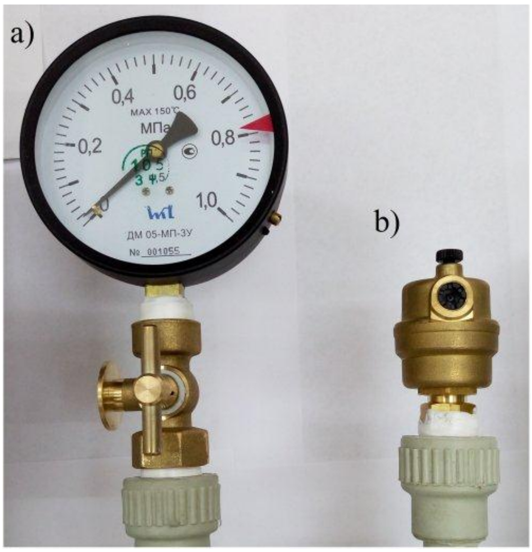

***Fig. 12.*** *a) Manometer for measuring fluid pressure during TRT process and b) Automatic air vent (Hertz).*

Assembled parts of the installation are illustrated in Fig.13. All the parts were connected with polyethylene pipe with external diameter of 32 mm by means of a soldering iron for plastic pipes.

***Fig. 13.*** *Assembled installation parts.*

In order to ensure that piping connections and other connections related to the devices are well established, a leakage test under pressure must be carried out. The leakage test was conducted with the help of the pressure testing pump, Rothenberger RP 50-S (Fig.14). The leakage test was conducted in a following way: First, necessary amount of water charged into the installation thought the top ball valve. Then, additional water is poured into the tank of the testing pump (Parts of the pump are listed in Fig.14) to charge additional amount of water into the installation, thus creating internally pressurized environment. Indeed, the pressure was increased up to 2 bar, and possible leakage problems in the system was monitored. During the first leakage test, there were little water discharged from the connections between piping and the manometer, around the circulation pump. These leakage problems are eliminated by tightening those connections by means of appropriate wrenches. During the second leakage test, water discharges were absent and pressurized installation kept around 24 hours to make sure if there are any other leakage problems in the installation.

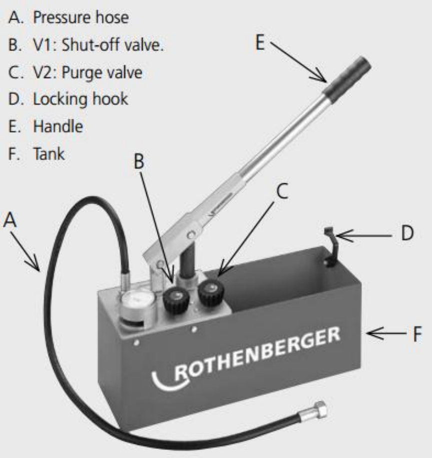

***Fig. 14.*** *Pressure testing pump, Rothenberger RP 50-S [7].*

## 3. Conclusion

BTES is one of the efficient systems which help to manage thermal energy for space heating/cooling and air-conditioning. In order to design appropriate BTES system, it is very important to know the thermal properties of the ground around BHE. One of the in-situ methods for assessing the thermal properties of the ground as well as a borehole is thermal response test. In order to conduct TRT special equipment is needed. In this paper, we discussed such equipment developed by the authors in detail. All the devices of the installation were illustrated and their important as the part of the installation were discussed. Main aim during the development of the installation was to make it mobile and compact with the dimensions of $1m \times 1m \times 0.5m$ (height× length× width), and expectations are achieved. The developed installation will be used to conduct TRT in Almaty at first towards mid of May, 2016.

## 4. Acknowledgments

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consisting of latent heat storage and borehole thermal energy storage, designed to accumulate solar thermal energy”.

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