Experimental facility to perform Thermal Response Tests and study the thermal behaviour of the ground

Borja Badenes[1, *], Miguel A. Mateo Pla[2], Teresa Magraner[1], Lenin Lemus[1], Javier F. Urchueguía[1]

[1] ITACA Institute - Universitat Politècnica de València. Camino de Vera s/n. 46022 Valencia (Spain)
[2] Departamento de Informática de Sistemas y Computadores. Universitat Politècnica de València. Camino de Vera s/n. 46022 Valencia (Spain)

* borbaba@upv.es

Keywords: geothermal precast pile, thermal characterization, thermal response tests, ground coupled heat pump.

ABSTRACT

The technology of soil characterisation or thermal response test is a method to evaluate the key parameters of the ground for the design of geothermal systems, such as the ground conductivity, the thermal resistivity of the borehole and other thermal conditions of the undisturbed ground. Both the collection data during the test and its subsequent interpretation are of paramount importance to avoid erroneous or uncertain results.

At the Polytechnic University of Valencia (UPV) there is an equipped geothermal borehole conceived as a test site to be able to design, assess, analyse and implement any interesting measure to allow a better understanding of the processes underlying TRT activity. The test site includes the monitoring of all involved variables and allows a fine-tuned control of heat injection into the soil.

This paper describes the development of this experimental facility. The implementation of this technology will allow a more correct analysis of the obtained information without the need to change substantially the established basics of TRT methodology. At the end of the article, there is an example of use and relevant conclusions.

1. INTRODUCTION

In 2010 it was installed at the Polytechnic University of Valencia a geothermal borehole heat exchanger facility with the original purpose of verifying the research to improve the procedures for ground thermal characterization (Montero et al 2013).

Although the main components and basic functionality of such facility has not changed, it has been necessary to change some components and improve mechanisms for its use. But not only components and mechanisms have changed, also objectives have evolved and the data obtained from different experiments have contributed to this.

In this article we consider, firstly, make an exhaustive description of the current components of the installation. This description will allow us to describe the strengths of the facility and identify opportunities for future improvement.

In addition to the hardware, software developed for the control and monitoring it is of great importance in any such facility. One of the strength of current system is the use of a WEB interface for experiment definition and data collection.

After facility and its control software description the results obtained from a typical experiment are presented.

A further objective of this paper is to describe the actions we are going to take on the facility in the coming years. The first we plan to do is to develop a system to test and calibrate thermal response mobile labs based on the known and fixed facility we already have. Additionally, we want to make easier to use the facility for conducting geothermal energy related experiments for teaching and research purposes.

2. BOREHOLE HEAT EXCHANGER FACILITY DESCRIPTION

Thermal response test basic equipment is formed by a heat source, a hydraulic system that circulates water through the borehole, a set of sensors and a basic control system. In Figure 1 these elements are shown. Generally, this equipment is installed on a mobile laboratory to transport to the building site where, in most cases, it is very difficult to connect it to the test borehole in optimum conditions in terms of pipes distances and sensor cable length.

A distinguishing feature of our fixed experimental facility is that has been designed to minimize the distances between the elements to reduce possible of noise, both the hydraulic system and the control system data acquisition.

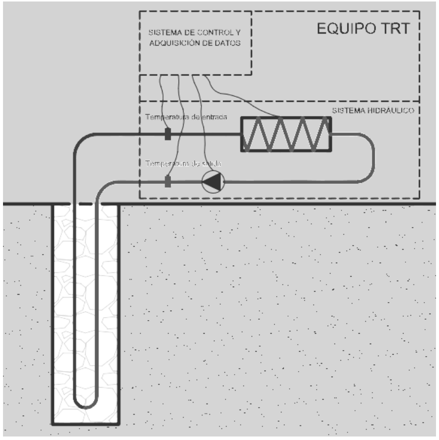

Figure 1: Basic TRT installation.

The facility is located in the Polytechnic University of Valencia campus, specifically at 39°28'46.4"N and 0°20'14.8"W and at 0 m above the sea level, not to far from the Mediterranean Sea (1230 m.)

The experimental facility is in a lawn area, away from buildings, the nearest is a two heights building located 15 m east, and the walking and cycling path is more than 3 meters of the borehole. The Figure 2 shows the outside installation.

Figure 2: Location of borehole and control cabinet at UPV campus.

The following sections describe in detail the various components of the installation.

2.1 Borehole

The borehole heat exchanger (BHE) facility was built in early May 2010. It is composed of two independents U-pipes inserted in a 40 meter-borehole. First U-pipe depth is 29,5 meters and second U-pipe depth is 39,5 meters. Although two pipes were installed, only the longest one is used.

The borehole is filled with a mixture of one part of bentonite and twelve parts of cement (CEMEX 32.5 raff). This mixture and the type of cement was chosen because is particularly appropriate for grounds with a considerable amount of ground water flows, as is the case of the Valencia coastal floodplain.

Samples of ground components were stored while drilling, giving a first idea of ground layer structure. Figure 3 shows this vertical layer structure together with the vertical layout of both independent U-pipes.

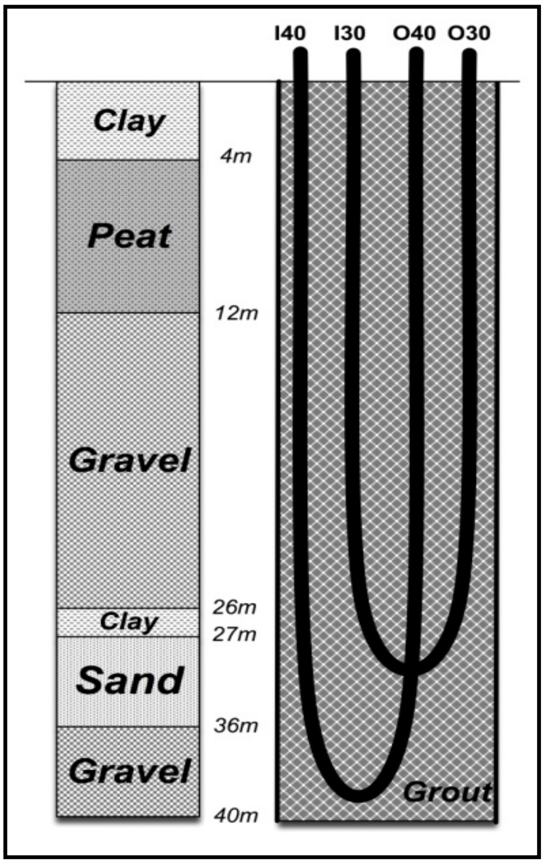

Figure 3: Diagram showing the vertical layout of the borehole, indicating the different strata of the ground

From ground samples, six layers can be identified along the 40 meters drilled. First one, from 0 to 4 m., is a clay layer. Second one, from 4 to 12 m., is a peat layer. Third one, from 12 to 26 m., is a gravel layer, with many small round stones. Fourth one is another clay layer; from 26 to 27 meters. Fifth one is a sand layer, from 27 to 36 meters. And sixth one is another gravel layer, from 36 to 40 meters, also with many small round stones. During drilling a considerable amount of ground water was observed.

2.2 Hydraulic components and sensors

The main components of the hydraulic system and the location of the sensors can be seen in Figure 4. Note that this is a basic scheme and there are other components that do not appear in this figure and facilitate the use of the system, such as valves, filters or expansion tank.

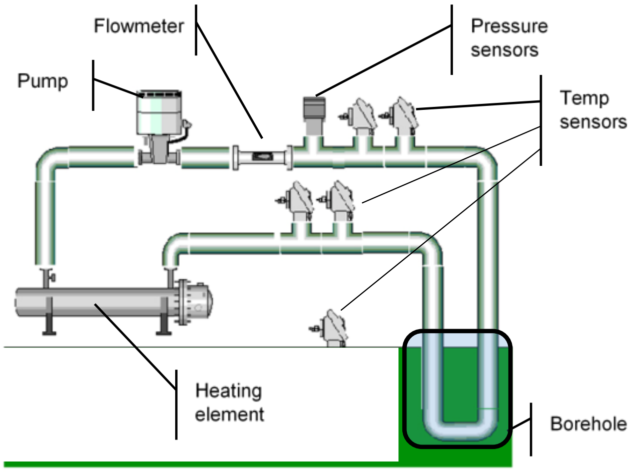

Figure 4: Basic diagram of hydraulic system.

A connexion to the city water network is used for filling the installation and emptying does not have a drain connected to sewers. Being in a garden the water is drained directly into the ground to serve as exceptional irrigation.

In order to generate the heat rate required to inject during the test, there is a resistant immersion heater with a maximum power of 3kW. For water circulation is installed the impulsion pump GRUNDFOS_MAGNA_25-60-180.

The following sensors are installed in the hydraulic circuit: a flowmeter, a press meter and six temperature sensors. The Table 1 resumes these sensors and their main characteristics.

In a thermal response test installation, the critical measures corresponding to the inlet and outlet borehole temperatures. Therefore, to increase the accuracy, the system has doubled the temperature probes at the inlet and outlet.

When a digital interface is not provided, a current loop is preferred over direct voltage measurements in order to minimize electromagnetic noise due to the used cables lengths (several meters) and environment (not controlled).

Figure 5: Experimental facility hydraulic system.

Table 1: Sensor List and Main Characteristics.

Sensor name	Measure unit and description	Specification
Tin1	ºC Temp. at borehole input	IFM Model TA3130 PT100, class A Range 0…140ºC Output 4…20 mA Res. < 0.02mA Accuracy ±0.5ºC
Tin2		
Tout1	ºC Temperature at borehole output	
Tout2		
Tund	ºC Terrain temperature	
Tamb	ºC Ambient temperature	DeltaOhm HD2008TV Range -20…80ºC Output 4…20 mA ±0.1°C ±0.1% of reading
Pressure	bar System Pressure	Osaka PP10 Range 0…10 bar Output 4…20 mA

		Linearity: 0.3% Stability: 0.2%
Flow	m^3/h Water flow	IFM efector300 SM8000 Range 0,010...6.000 m^3/h Output 4…20 mA Res: 0,005 m^3/h ± (2% MW + 0,5% MEW)

2.3 System control and data acquisition

The system control and data acquisition is based on a PLC Siemens Simatic S7-1200. This PLC have been added several analogue input / output modules to receive and interpret signals from the sensors. The outputs of these modules are used for controlling the heater and the pump impulsion (Figure 6).

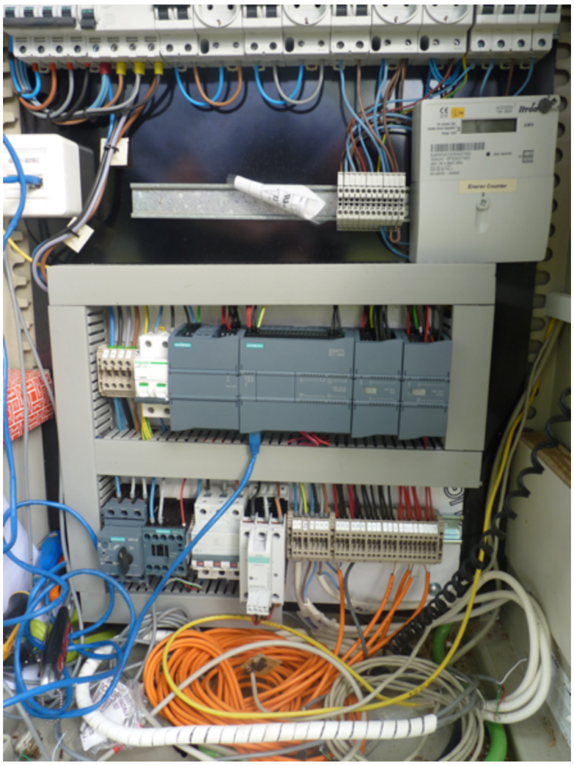

Figure 6: System control and data acquisition.

This PLC has an Ethernet connexion that enables programming and remote monitoring, i.e. it is possible to change the PLC program without having to scroll to the installation of the TRT, depurate the program or access and modify the state of the different variables and signals that the PLC handles.

The PC additional functionality is the inclusion of a web server. Pages this web server offers are divided into two categories: management and user PLC. The first allowed to modify the operation of the PLC and check their status, but would not allow to change its program. User pages are most important in our facility because they allow a read and write access to the PLC variables; allowing to configure boxes advanced remote control.

In our case we have defined two websites: the first provides an interface monitoring the current status of the sensors and the second allows you to set the operating parameters of the experiments (see Figure 11).

The configurable parameters to perform an experiment are: i) state of the pump (on or off), ii) the kind of control for heating element: PID or a manual fixed pre-setting, ii) the reference for internal PID heating control or manual setting and iii) the sample period for data acquisition in milliseconds.

When an experiment has started, the sensor data and date is logged inside the PLC. This log can be downloaded using any web browser or web downloading tool, e.g. curl or wget. The PLC storage capacity limits the size of log to 2048 entries, so when an experiment reaches this number of cycles the PLC overwrites old entries with new ones so the last 2048 values are always present. A log download can be performed any time and it is not a destructive operation i.e. the data remains stores in PLC.

The pump control drive is an on / off control, the only decision is whether the pump is running or not. PLC signal that activates the pump is directed to a three-phase contactor that is finally starts the pump. The response time of these elements is orders of magnitude smaller than the response time of the entire system so it has opted for the generic solution.

However, for the heat generator it has opted for a PID controller implemented in the PLC. The PID block PLC generates a control signal between 0 and 100 % that is sent to an external element which performs a PWM modulation to actuate a three-phase heater 3kW.

In different experiments PID is configured in two possible setups. In the first configuration it is used as PID input the difference between the readings of the borehole inlet and outlet temperature sensors. In the second setup, the reference introduced is the power to be injected into the borehole, taking into account in this case the temperature difference and the system flow.

3. AN EASY EXAMPLE OF TRT ANALYSIS

To truly understand the operation of this facility, an easy example of a Thermal Response Test performed with this installation is detailed below. The main parameters applied during the test are presented in Table 2.

Table 2: Thermal response test parameters

	TRT
Temperature step	3,6 ºC
Flow rate	0,48 m^3/h (8 l/min).
Fluid	Tap water
Heat transfer	1996±1% W
Heat injection rate	50,55 W/m
Duration	5-6 days

The temperatures of the heat exchange fluid entering and exiting the borehole during the operation were monitored and all other variables were monitored with the equipment described in paragraph 2.

Here you can see the evolution of the injected heat.

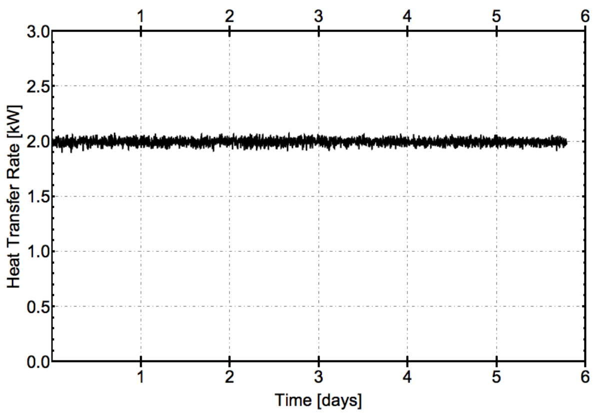

Figure 7: Evolution of the injected heat over time

The evolution of the average temperature of the borehole is shown below.

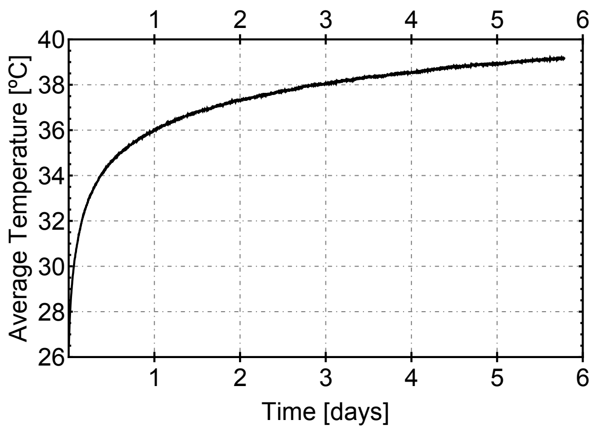

Figure 8: Evolution of the average temperature over time

It is important to note that due to both the design of the facility and its programming, no influence of the outside ambient temperature is observed during the the performance of the Thermal Response Test. From Figure 9, the difference between the test performed in the installation (red line) and a test performed with a mobile laboratory (standard TRT), which is influenced by external ambient temperature (blue line) can be observed.

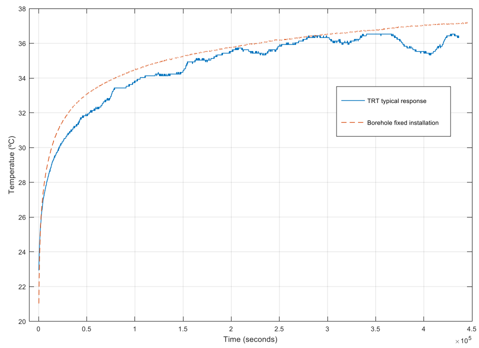

Figure 9: Difference between a test performed with this installation (red line) and a standard TRT performed with a mobile laboratory, which is influenced by external ambient temperature (blue line).

Considering the duration of the test, the borehole can be approximated by a line source in a homogeneous medium as a first approximation for the thermal assessment. By the line source approximation, the evolution of the mean fluid temperature $T_f(t)$ follow the trend described by the following equation (1) [Eskilson 1987]:

$$T_f(t) - T_0 = \frac{Q_Z}{4\pi\lambda}\left(\ln\left(\frac{4\alpha t}{r_b^2}\right) - \gamma\right) + Q_z \cdot R_b = \frac{Q_Z}{4\pi\lambda}\ln(t) + Q_Z\left[R_b + \frac{1}{4\pi\lambda}\left(\ln\left(\frac{4\alpha}{r_b^2}\right) - \gamma\right)\right] \qquad [1]$$

Where Q_z represents the constant heat injection rate used for the response test (W/m), T_0 the undisturbed ground temperature (ºC), t denotes the duration of the heat injection (s), r_b the borehole radius and γ is Euler's constant (0.5772).

Adjusting this model to the experimental data, the following parameters are obtained:

Table 3: Theoretical model parameters

Thermal diffusivity (α)	$6.0 *10^{7}$ m/s
Heat injection rate (Q_Z)	50.55 W/m
Undisturbed ground temperature (T_0)	20º C

Borehole Thermal Resistance (R_b)	0,204 mK/W
Ground Conductivity (λ)	2.08 W/mK
Borehole radius (r_b)	0.08 m

Finally, we can see the adjustment of the theoretical curve with previous data and the curve obtained during the test.

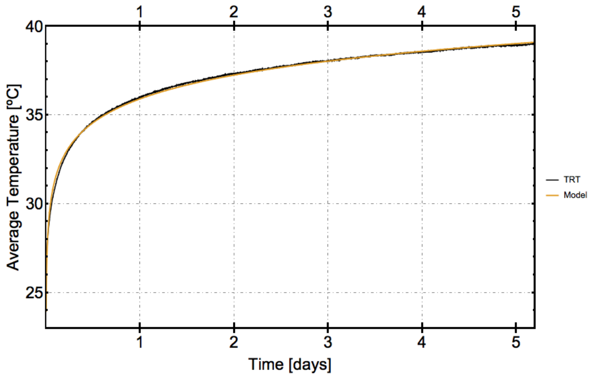

Figure 10: Difference between the test performed in the installation (black line) and the theoretical curve (yellow line)

3. CONCLUSIONS

This article describes in detail the main elements making up this installation (borehole, hydraulic components, sensors, etc.), its system control and data collection. An easy example of operation has also been given.

One of the strategic advantages of this instrumented installation with a controlled heat injection system is its use as a fundamental tool where further research on numerical modelling systems of heat transfer to the ground can be developed and the use of it as a testbed for new technologies in the field of geothermal energy.

Other potential use is as external calibration system for mobile or portable laboratories of Thermal Response Test for geothermal installations.

Finally, this monitored facility has a huge educational value, allowing the realization of academic courses which illustrate the techniques for measuring the thermal properties of the ground.

REFERENCES

Montero, Álvaro; Urchueguía, Javier F.; Martos, Julio; Badenes, Borja; Picard, Miguel Á.: Ground temperature profile while thermal response testing. European Geothermal Congress (EGC 2013) (ISSN 978-2-8052-0226-1).

GEHLIN, S., 1998. Thermal Response Test, In-Situ Measurements of Thermal Properties in Hard Rock. Licentiate Thesis, Luleå University of Technology, Department of Environmental Engineering, Division of Water Resources Engineering.

ACKNOWLEDGEMENTS (OPTIONAL)

Part of the work developed here has been financed by PAID-05-12 UPPTE/2012/351 of Universidad Politécnica de Valencia.

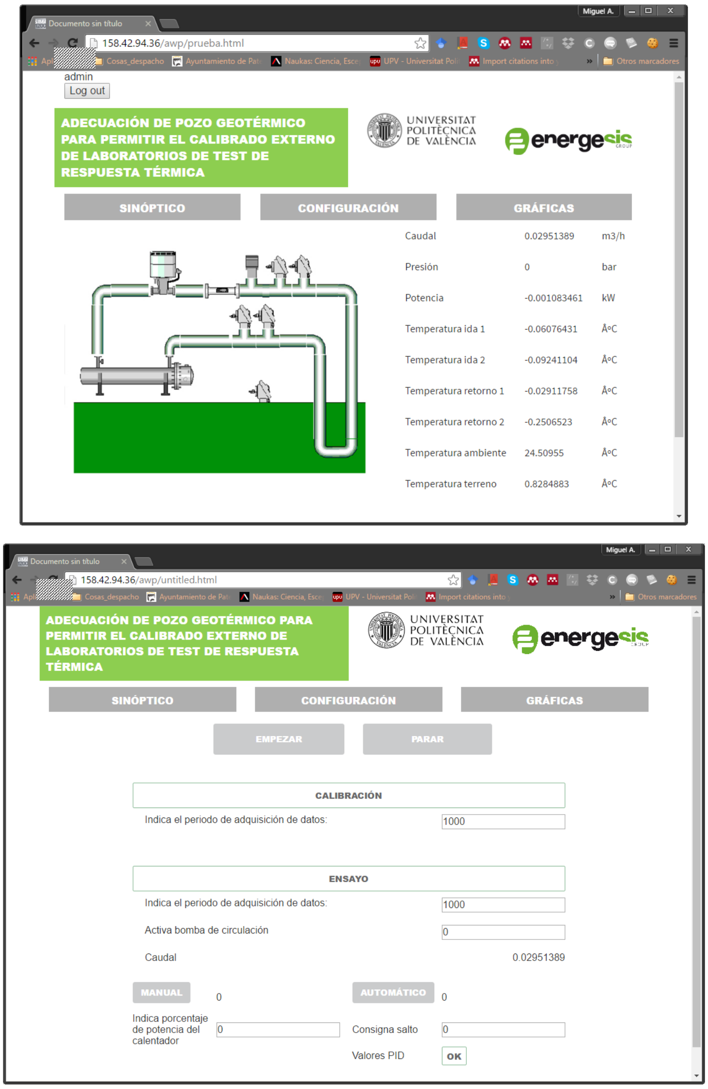

Figure 11: Web pages: monitoring the status of facility (up) and experiment setup (down). Nowadays only Spanish versions of these pages is available and are only accessible from institution network.