Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Operating Experience with Vertical Borehole Heat Exchanger for Underground Thermal Energy Storage Applications in Chile and Argentina

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Keywords: Borehole Thermal Energy Storage; Solar Collectors; Natural Experiment; Charging; Discharging .

ABSTRACT

The possible heat sources for seasonal Underground Thermal Energy Storage (UTES) can be divided in two main groups - renewable energy (solar thermal, hydrogeothermal, biofuels and others) and waste heat (heat and power co-generation, industrial process heat, waste incineration and others). Chile is a country possessing solar energy in large amounts which can be stored in the ground by means of UTES during the summer and used 3 to 6 months later during the winter. The same seasonal storage could be used to produce cold in the summer. Large cities, like Santiago with a population of more than 5 million inhabitants, requires heating in the winter (minimum temperature about -5°C) and cold in the summer (maximum temperature about 35°C). A setup for testing this type of storages was realized at the "Solar Energy Laboratory" of the Technical University Federico Santa Maria, Valparaiso, Chile. Research groups of Chile and Argentina performed and analyzed a charging – discharging cycle test with this installation. During the first phase the store was charged during 29 days (18.08 - 16.09.2003) with solar energy by means of 4.4 m^2 of solar collectors. Discharging followed during 13 days (17.09 - 30.09.2003) using a water-water heat exchanger. One loop was connected to the BHE the other loop was supplied with tap water. The experiments made prove the possibility of using underground seasonal storage for heating and cooling in different regions of Chile and Latin America (Argentina, Brazil) and to apply the BTES technology in the same region.

1. INTRODUCTION

The application of long-term (>3 months) seasonal thermal energy storage is uncommon. This is not due to a lack of energetic potential. On the contrary, depending of the geographical region, there is a large amount of ambient heat in summer and cold in winter that can be collected and used for different purposes.

Long term storage of huge amounts of thermal energy for heating and even more important for cooling can give a significant contribution in energy saving and rational use of energy. Underground thermal energy storage (UTES) is a favorable technology from both the technical and the economical point of view. Depending on the local geology, hydrogeology and geochemistry either aquifer thermal energy storage (ATES) or borehole thermal energy storage (BTES) are applied. BTES has because of its smaller size and less hydro-geological restrictions, a bigger potential for application.

Mainly eight countries (Sweden (Reuss et al, 2000; Dikici et al, 2000), Canada, Germany (Reuss et al, 2000), Netherlands, Norway, Turkey (Paksoy et al, 2002) , United Kingdom and the U.S.A (Austin, 1998) have developed the technique. Recently also France and Switzerland have taken up using it.

Some months ago (June - July 2003) an Thermal Response Test (TRT) was realized in Valparaiso, Chile - the first one in Latin America. The object of this work is to present the next steps undertaken to develop this success - laboratory investigation of ground charging and discharging implemented by the same installation.

2. EXPERIMENTL SETUP

Prof. Pedro Roth was the first one in Chile who tried, some 20 years ago, to use the ground as a heat storage using a BHE. After preparing the perforation some problems mounting of the sensors arouse and the result of the first attempt was unsuccessful.

A working installation of this type was recently realized (about two year ago) at the "Solar Energy Laboratory" of the Technical University Federico Santa Maria (UTFSM) in Valparaiso, Chile (Georgiev et al). The shallow BHE was used to carry out an in situ determination of ground thermal conductivity λ, borehole thermal resistance Rb and undisturbed soil temperature, technique commonly known as Thermal Response Test -TRT . The TRT lasted 9 days (from 24th of June to 3rd of July 2003) being the first of its kind in Latin America (Roth et al). Fig.1 presents a schematic diagram of the setup.

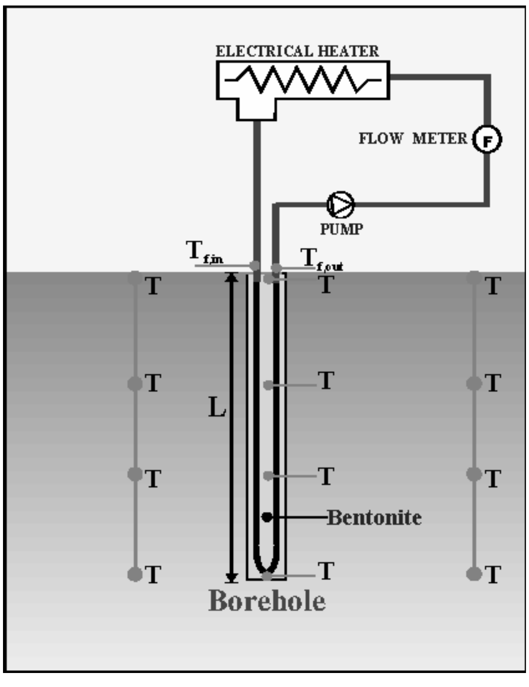

Figure 1: Scheme of the experimental installation

This far two main experiments were performed with the new setup; the TRT - to determine the soil and BHE thermal properties, and the charging / discharging cycle - to submit the system to different heat flow conditions over a period of time that could allow deeper characterization and understanding the store. This study was also aided by TRNSYS simulations.

2.1 First stage of setup preparation

For the drilling the truck of the Laboratory of Material Testing of the Department of Civil Works of the UTFSM was used. Three perforations were done along a line to a depth of about 22 m. The drilling works showed the soil at the site as consisting of 3 main layers.

The central perforation is a borehole with a depth of 16,9 m and a diameter of 0.15 m. Prior to refilling it with a 12% bentonite mixture (commercial name Max Gel, produced in Federal Summit, Houston, Texas), a U-loop BHE made of High Density Polyethylene (3/4 " SDR 11) along with a temperature probe comprising 4 thermocouples type K (Chromel / Alumel) at depths of 16,9m, 10,7m, 3,24m and 0,25m were inserted into this well. The temperature probe was located at the axis of the well.. The other two perforations were one 0,4 m to the left of the BHE, the other 0,8m to its right. Temperature probes with thermocouples type K at depths of 20,5m, 13,67m, 6,84m and 0,25m were also installed in this perforations being subsequently replenished with the same soil.

3/4"copper pipes join the U-loop BHE to the heating system above the soil surface. An electric heater with power of 2 kW was mounted in the installation. The circulation pump is of the type PKM 60-1, made by Pedrollo, Italy. It has a nominal electrical power of 370 W, working at 2900 rpm with a flow rate between 5 - 40 l/min to a max height of 40m. The entire pipe length was thermally insulated to reduce heat loss to the surroundings. A plastic liner was put on top of the entire installation to reduce sun’s influence during the test.

2.2 Second stage of setup preparation

Remodeling of the installation started just after completion of the TRT. Three solar collectors were connected to the BTES. Their total active area is about 4,4 m^2 (the collector size is 1,05 m x 1,40 m). The distance between the collectors and the storage is about 2 m. Two additional by pass valves were mounted to allow the installation be ran in two different modes according to the type of power source in used. TRT mode - if power is supplied purely by electric heater, solar mode - if the BTES is to be charged by the help of a solar energy. All the pipes were carefully insulated.

After the modification works the pump was left on for 10 days and different variables were monitored.

To further reduce ambient influence on the system a surface area of about 4 m^2 on top of the store was insulated with a layer of 0.1m of high density polystyrene covered with aluminum folio (Fig. 2).

2.3 Third stage of setup preparation

After the charging cycle a new modification was introduced to the hydraulic system. One loop of a cross-flow water-water heat exchanger was connected to the BHE circuit instead of the collectors with the other loop fed with tap water.

Figure 2: View of the insulated installation

An old automobile radiator was adapted to work as the cross-flow water-water heat exchanger. The radiator was placed inside a metal casing 0.24m height, 0.30m wide and 0.08m, thick. Provisions for inlet and outlet connections to the radiator and casing were taken.

Tap water circulated through the radiator becoming the cold loop of the heat exchanger and water from the BHE circulated between the radiator and casing walls thus becoming the warm loop. The entire heat exchanger was thermally insulated on its outside to prevent ambient coupling.

3. MEASURING INSTRUMENTATION

As mentioned before 12 Chromel / Alumel thermocouples (8 in the ground and 4 in the bentonite) were available for monitoring temperature of the ground. The idea was to gather information about the temperature field at different distances from the BHE under the ground surfaceElectrical and communication cables between the installation and the PC situated in the Laboratory were installed in metallic pipes buried 30cm under the ground surface in a trench running from the installation to the main switch board inside the laboratory house (about 25m away).The influence of the near by AM radio transmitting antenna made it impossible to use this instrumentation at this stage of the work.

Figure 3: Outlet collector temperatures measurement.

3.1 Instrumentation used during the charging phase

A manual rotameter "Blue White industries 9509" with maximal flow rate of 7,5 l/min was used. The installed flow meter (aided by a differential pressure gage), which send the data to a PC not worked by reason of the mentioned antenna. Four Gemini Data Loggers TGP-0020 with sensor of the type Standard Temperature Probe PB-4724 shown in were used for monitoring the inlet and outlet borehole temperatures and the inlet and outlet collector temperatures (Fig. 3). Ambient temperature was measured with a Gemini Data Logger TGP – 0017 with a case-integrated sensor. The global solar radiation was measured with Gemini Data Logger TGPR – 1001 using Kipp & Zonen SP-LITE Silicon Pyranometer shown in Fig. 4. The Data loggers were programmed by means of the software GLM v2.8. Measurements were recorded at 1 min. frequency in the memory of the logger and downloaded to the PC using the same software. The circulating pump was turned on/off by means of a differential controller STR 1 with safety-fuse (Fig. 5). All the equipment was calibrated prior to the test.

Figure 4: Kipp & Zonen SP-LITE Silicon Pyranometer.

3.2 Instrumentation used during the discharging phase

The same measurement equipment (without the pyranometer) was used during discharging. Additionally a rotameter (ROTA Apparate- und Maschinenbau, Öfingen, Germany) was installed to measure the flow rate on the other hydraulic circuit of the heat exchanger connected to the tap water line.

4. EXPERIMENT

4.1 Charging phase

The installation was remodeled after realizing the TRT and was used to charge the ground my means of solar energy (natural experiment). The test was implemented during 29 days (from 18th of August to 16th of September 2003).Borehole inlet and outlet temperatures, collector inlet and outlet temperatures and ambient temperature were measured and recorded at a 1min. frequency during the length of the experiment. Although the flow rate was fixed at the constant value of 3,17 l/min it was periodically measured and controlled Temperature probes of the differential controller were located to sense collector outlet and borehole inlet temperatures. Set up points were 5°C and 2°C for Pump-On / Off respectively.

Figure 5: Temperature- Difference- Regulator STR 1 with safety-fuse.

4.2 Discharging phase

After the charging cycle a heat exchanger was installed to extract heat from the ground in a discharging mode. The experiment started on the 17th of September and ended on the 30th of September 2003. Ambient temperature, borehole inlet and outlet temperature (connected to the warm loop of the heat exchanger) and inlet and outlet temperature to the cold loop of the heat exchanger were measured and recorded during this phase. Flow rates measured on the warm and cold circuits of heat exchanger were 3,17 l/min and 1,6 l/min respectively.

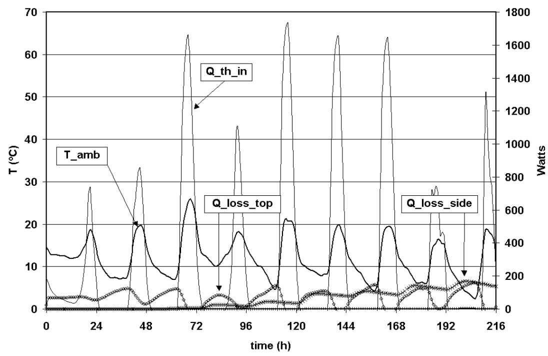

Figure 6: Time evolution of the energy rates before installation of the thermal insulation layer on top of the store.

5. RESULTS

5.1 Charging trial (during the 2 Second stage of setup preparation)

The data gathered during the short charging ran before adding the insulation on top of the store allowed some modelling to assess the impact of such improvements on the system's performance. Fig. 6 present the energy exchange rates before and after the improvements as predicted by TRNSYS for this 9 days trial charging. A sensitive reduction of top energy losses due to the better thermal insulation used is clearly observable.

For the simulations the volume of the store is considered that of a cylinder of radius 1m and length equal to the depth of the BHE (16.9 m.).

5.2 Charging phase

For the charging phase the store was subjected to fluctuating power injection by coupling the BHE to the solar collectors as source of energy. To avoid or diminish heat extraction from the store the pumping operation strategy implemented was Pump-On only during times of high solar energy. In view of the oscillatory behavior exhibited by the differential controller (Fig. 7) during the first days the set points were subsequently readjusted. In spite of this no provisions were taken to record the on/off time pattern for the pump hence in all the calculations and simulations the flow rate was assumed constant and equal to the measured value of 3.13 l/min.

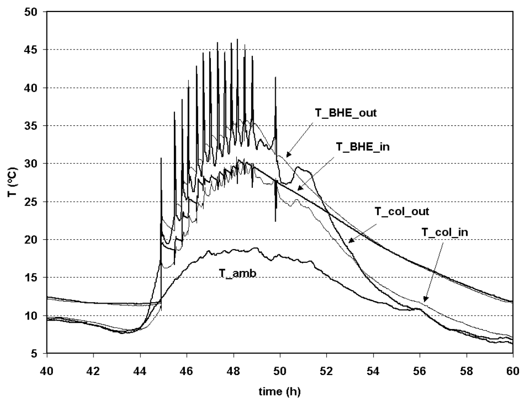

Figure 7: Perturbation imposed on the system by the On/Off oscillatory behavior of the pump due to inappropriate settings of the differential controller.

For the evaluation of the charging process injected thermal energy was calculated from experimental data and compared to results obtained with TRNSYS simulations. This analysis tool provides assessment of losses through storage boundaries and the evolution of near borehole and average storage temperature over time as well. Fig. 8 is a plot of the result so obtained.

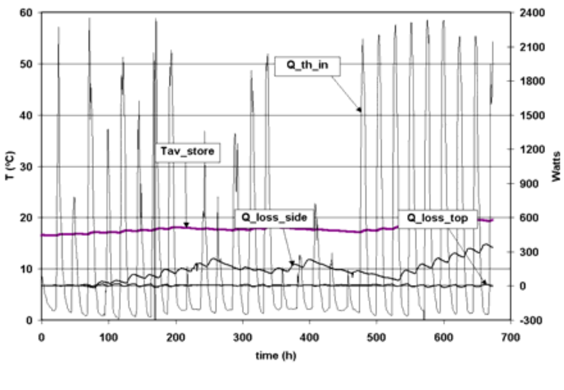

Figure 8: Time evolution experimental and simulated variables characterizing the store; experimental injected energy rate (Q_th_in), predicted losses through store boundaries (Q_loss_side, Q_loss_top) and predicted average store temperature (Tav_store).

According to these results, top and bottom losses are rather minimal with the thermal wave reaching the lateral boundary of the store after approximately 72 h., time after which an outward heat flux begin to show as side losses. It can also be observed from the plot that at the end of the charging phase the average temperature of the store had risen ~3ºC. Similarly, at this point 50% of the ~730 MJ of injected thermal energy has been lost trough the side boundary of the store as depicted on the plot of accumulated thermal energy (Fig. 9), with top and bottom energy losses being minimal.

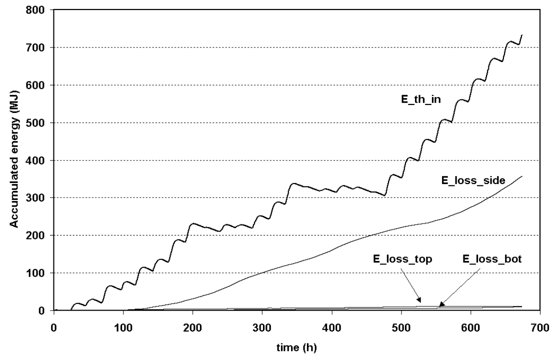

Figure 9: Time evolution of accumulated energies

Given that the store volume is $53m^3$, the volumetric heat capacity of the soil in the store 2200 kJ/m^3K and the increase of the store temperature was 3ºC, a back of the envelope calculation of the energy required to produce such heating effect leads to some 350 MJ in reasonable agreement with previous findings.

It must be bared in mind that this accumulated thermal energy continues flowing outwards from the store even after the charging stops, point this to be considered when analyzing discharging data.

Further analysis of experimental and simulated data is presented in Fig. 10. The lower part of the plot depicts temperature profiles over time for the testing period between days 21 – 25, the upper part being a comparison between simulated and experimental BHE temperature difference for the same time interval. The main feature observable is that at a certain point, assumed to coincide with the Pump-Off point, ΔT_Exp (dotted curve) exhibits a transient response with larger negative values at the beginning, asimpthotically tending to values slightly below zero during night time. In contrast, ΔT_sim shows a smooth profile but becoming more negative during night hours.

A possible explanation to this behavior is the occurrence of an early than expected Pump-Off. The still available solar radiation continues heating the water in the solar collectors inducing a thermosyphon effect in the same direction as the forced circulation. The induced convective flow is accompanied by a small heat extraction which shows up as T_exp_out > T_exp_in as may be observed from the experimental curves in the lower plot. As sun goes down convective flow dies out and inlet and outlet temperatures tend to equal. Contrasting to this, the always-Pump_On assumption used in TRNSYS simulations keeps T_sim_out < T_exp_in during the same period but inducing a higher heat extraction during night hours hence explaining the larger negative values exhibited by ΔT_sim.

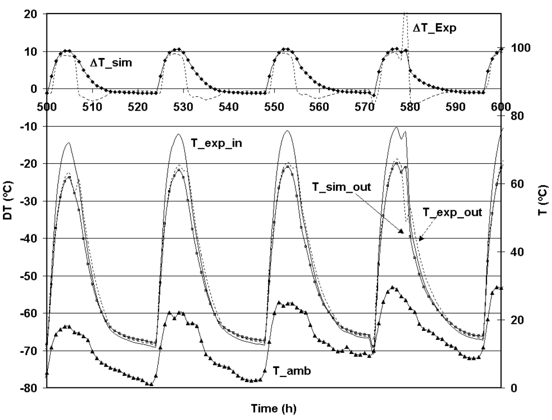

Figure 10: Time evolution of measured and predicted temperatures in the system.

Fig. 11 depicts the time evolution of accumulated energies for the entire length of the charging phase. Solar collectors delivered around 70% of the available solar radiation and in turn only about 50% of this energy was injected to the heat storage. Furthermore, a good agreement it is seen to exist between simulated and experimental accumulated injected energies. The difference being due to the constant pumping condition that makes heat injection cycle more effective as explained in previous paragraphs and observed in the upper curves of Fig. 10.

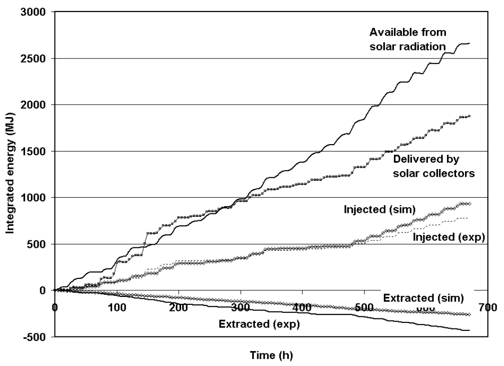

Figure 11: Time evolution of energies in the system; solar available, delivered by collectors, injected and extracted.

5.3 Discharging phase

Two sets of data were used in the analysis of the discharging phase. One data set associated to the BHE/water-water heat exchanger system, the other set associated to the temperature probes installed in the ground. Corresponding plots are presented in Fig. 12 respectively.

For clarity reasons, to avoid many curves superimposed on a single graph ambient temperature (T_amb) on Fig.12 is referred to the secondary axis using a different scaling factor. The inset on the upper right corner shows the correct picture for a given time interval. A considerable ambient influence on the system as exhibited by the temperature curves is clearly visible.

Due to technical problems measurements from the temperature probes in the ground were used as qualitative indicator of the development of the thermal wave in the store and of the trend of the average store temperature over time.

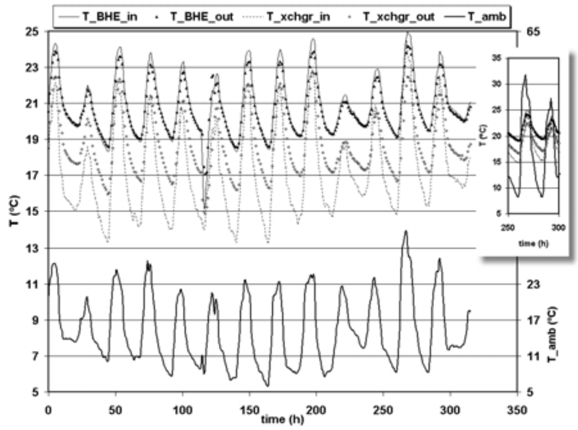

Figure 12: Time evolution of soil and fluid temperatures measured by Gemini probes in direct fluid contact.

In the upper half of Fig.13 time evolution of the energy rates in both loops of the heat exchanger are presented. The ambient temperature curve in the lower half is presented to have the reference pattern of the ambient fluctuation.

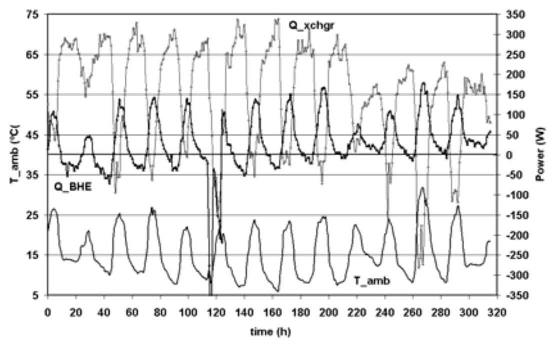

Figure 13: Time evolution of energy exchanged rates in the BHE and in the water-water heat exchanger.

It might be recalled at this point that the fluid in the warm loop of the heat exchanger (water loop linked to the BHE hydraulic circuit) flows outside the radiator in contact with the metal casing thus being more susceptible to be affected by ambient fluctuations than the fluid in the cold loop. This explains the heat injection (Q_BHE > 0) actually observed (T_BHE_in > T_BHE_out in Fig.12). Interestingly enough is also the fact that the energy exchange rate in the cold loop (Q_xchgr) falls below zero for these time intervals indicating heat extraction from the cold side is taking place. Aside from experimental errors we did not succeed finding a reasonable explanation for this effect this far.

During night hours large temperature difference in the cold loop and T_BHE_out > T_BHE_in as observed in Fig.12 are clear sings that heat extraction from the BHE is taking place. This can also be readily seen in the energy exchange rate curves of Fig.13. The puzzling point here is the mismatch between the magnitudes of exchanged powers. Power taken up by the cold loop is approximately 5 times higher than that extracted from the BHE indicating unaccounted energy sources.

According to Fig.12 (see inset), during night hours heat exchanger temperatures always remain higher than ambient temperature thus a cooling effect should be expected instead hence, ambient contribution is ruled out.

Another source of power is the pump. The effect of this device on the system has been assessed in a previous work (Roth et al) to be in the order of 135 W.

According to Fig.13, no heat extraction from the store appears to take place after 200h (day 10), that is, apparently the store has been depleted. In the ideal case under this circumstances the fluid in the warm loop should only be gaining energy from the pump and some from friction in the hydraulic circuit. In turn, this energy should be transferred to the cold loop. The average power for the time interval between 200–315h is estimated to be ~150 W in good agreement with previous finding.

Although the pump has been identified as one energy source and its energy contribution quantified still unidentified the source of another 100 W. This matter is pending further investigation.

It maybe pointed out that after the charging phase ended almost two days past by before discharging started. During this time side and top losses might have produced some cooling of the store. In spite of this fact, to have a more realistic scenario of how the continuous process would look like, charging and discharging data sets were merged into one for the TRNSYS runs. The outcome of one such a simulation is presented in Fig.14.

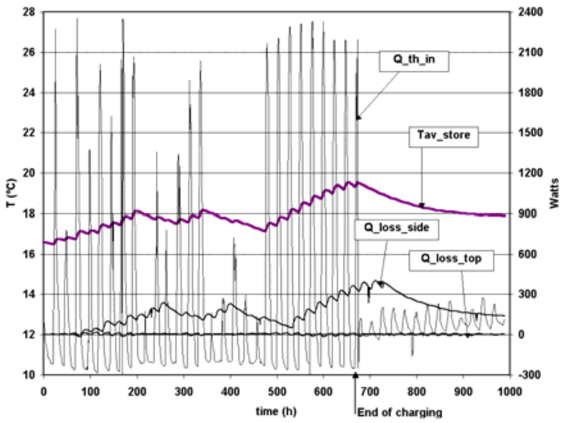

Figure 14: Time evolution experimental and simulated variables characterizing the store during the entire charging/discharging cycle.

The plot shows that as soon as charging reaches the end side losses keep increasing for some time till they start to diminish towards some steady value at long enough times. This is a consequence of the retardation of the traveling thermal front belonging to the charging phase. Contrary to this average store temperature starts decreasing right after the end of charging.

According to TRNSYS predictions the store is expected to cool down ~1.5ºC in agreement with measurements obtained by the temperature probes). The correlation of these curves is functional as well.

Moreover, Fig.14 also shows that heat extraction (Q_th < 0) mainly takes place during night hours (T_amb is lowest) and heat injection occurs throughout daytime. In the latter case injected power includes pump contribution (~135W) and ambient coupling. As time passes heat injection takes over the scene and at long times, when thermal steady state is reached, the only sources of power will be the pump and ambient coupling of a fluctuating nature. Under these circumstances an outgoing energy flux greater than 135W is expected mainly through the store side boundaries in agreement with predictions. A back of the envelope calculation indicates that the energy rate needed to keep the store at an average steady state temperature of ~17.7ºC (~1.2ºC above undisturbed ground temperature) is ~140 W.

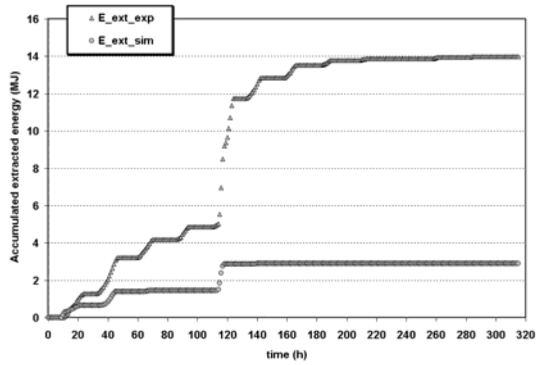

Figure 15: Comparison between experimental accumulated extracted energy and that predicted by simulations.

Finally, Fig.15 shows experimental and predicted accumulated extracted energy. The large deviation between the curves might well possibly be due to the assumption used for the simulations that discharging immediately follows charging. The matter is pending further analysis. The rather low total extracted energy, ~14 MJ, obeys to the testing conditions and it has already been predicted from thermodynamical considerations. At the same time 283 MJ were lost from the store through boundary losses. It may be recalled that by the end of the charging cycle ~350 MJ were accumulated in the store.

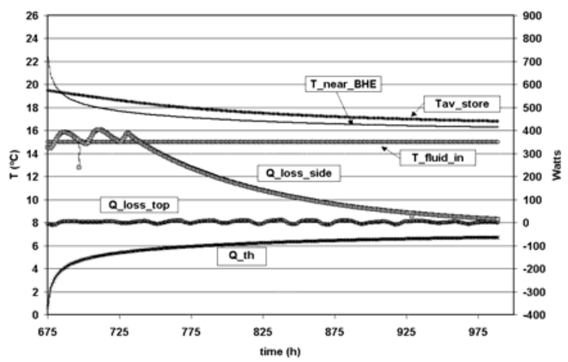

Figure 16: Time evolution of variables characterizing for a case study with constant temperature water source feeding the cold loop of the heat exchanger.

As a small case study to support that a more effective discharging would be attained with lower fluid temperatures let’s assume T_fluid_in is kept constant at 15ºC throughout the discharge. Fig.16 presents what the discharging cycle would look like under these conditions. Condition T_fluid_in < T_near_BHE is clearly fully met making heat extraction from the store possible throughout the cycle. The total accumulated energy that could eventually be extracted is ~113 MJ which represents only 32% of the total thermal energy available in the store at the end of the charging phase. According to predictions the total amount of energy lost from the store in the same interval is ~201 MJ.

6. CONCLUSIONS

In this work the data from a charging/discharging experiment of a shallow BHE has been presented and analyzed. Simulations using TRNSYS Type 141 has been applied as well in order to better understand some of the features exhibited by thermal behavior of the system. The main conclusions drawn from all these work are:

Charging phase:

- Thermal insulation on top of the store proved to cut down heat losses through the upper boundary by ~80%.

- Inappropriate initial settings of the differential controller during early stages of the experiment provoked an oscillatory operation of the pump making the thermal process in the ground unable to reach a steady-flux condition due to the short time power fluctuations imposed on the system.

- The possible explanation to the small heat extraction observed during daytime assumes that, despite correcting the settings of the differential controller, an early than expected Pump_Off occurred and the still available solar radiation continued heating the water in the solar collectors inducing a thermosyphon flow in the same direction as the forced circulation accompanied by heat extraction.

- According to experimental data and assessment of losses aided by TRNSYS simulations, the ~2650 MJ of solar energy received by the collectors during the charging period only 70% has transformed into thermal energy out of this amount 50% (~730 MJ) injected into the ground by the BHE.

- Simulation runs showed that side losses first appear after around 72 h. and are expected to escalate as high as %46 of the total injected thermal energy by end of the charging period.

Charging phase:

- The relatively large ambient coupling detected in the water-water heat exchanger requires better thermal insulation of the device.

- The experimental average store temperature decay during discharging (calculated using temperature measurements from probes in the soil at 0.5m and 1m distance from the BHE) agree in magnitude and shape with simulated average store temperature obtained from TRNSYS simulations.

- The time evolution exhibited by the experimental energy exchange rate curve show that thermal energy is extracted from the store in decreasing amounts only during night hours and injected during daytime. Full heat injection takes over the process near the end.

- Similarly, these curves show that the rate of energy exchange in the water-water heat exchanger is 5 times larger than corresponding rate of extracted energy from the BHE. Approximately 135 W are successfully associated to be caused by pump’s heating contribution with the source of another 100 W still not identified.

- The small amount of total thermal energy (14 MJ or 4% of stored thermal energy at the end of charging) extracted during the discharge is explained aided by TRNSYS simulations and basic thermodynamic concepts. According to the simulations, at the beginning of the cycle near borehole temperature during night time is higher than fluid temperature in the BHE flow channels, hence, heat extraction occurs due to the appearance of a thermal gradient in the direction of the fluid. As time passes the store cools down reversing the direction of this thermal gradient and heat injection takes place.

- Improvement in the heat extraction performance is proposed by a case study in which inlet fluid to the BHE is maintained constant at 15 ºC. The outcome shows 8 times more energy (32% of stored thermal energy at the end of charging) could be extracted under this conditions.

Several points are still pending further improvement and analysis;

- Resetting of the differential controller to avoid any unwanted heat extraction and achieve a more efficient use of the energy supplied by the collectors.

- Register the On/Off time profile of the differential controller. This would help performing more realistic simulation runs.

- Improve thermal insulation of the water-water heat exchanger.

- Use a constant temperature source water supply to the cold loop of the heat exchanger to reduce ambient coupling and improve assessment of extracted energy from the store.

7. REFERENCES

Andersson, O., Hellström, G. and Nordell, B.: Recent UTES development in Sweden. *Proceedings* of Terrastock 2000, 8th Int. Conference on Thermal Energy Storage, Stuttgart, August 28-September 1, vol. 1, 2000. p. 75-80.

Dikici, D., Nordell, B. and Paksoy, H.: Cold extraction from winter air in different climates for seasonal storage. *Proceedings* of Terrastock 2000, 8th Int. Conference on Thermal Energy Storage, Stuttgart, August 28-September 1, vol. 2, 2000. p. 515-520.

Reuss, M. and Müller, J. P.: Solar district heating with seasonal storage in Attenkirchen. *Proceedings* of Terrastock 2000, 8th Int. Conference on Thermal Energy Storage, Stuttgart, August 28-September 1, vol. 1, 2000. p. 221-226.

Paksoy, H., Gurbuz, Z., Turgut, B., Dikici, D. and Evliya, H.: Aquifer thermal storage (ATES) for air-conditioning of a supermarket in Turkey. *Proceedings* of World Renewable Energy Congress-VII 2002, Cologne, Germany, 29 June - 5 July, 2002. 10_n66.pdf.

Austin W. A.: Development of an in-situ system for measuring ground thermal properties. *Master's thesis*. Oklahoma State University, Stillwater, Oklahoma, 1998.

Georgiev, A., Ortiz, A., and Roth P.: Underground Thermal Energy Storage - Chilean experience. *Proceedings* of World Renewable Energy Congress-VII 2002, Cologne, Germany, 29 June - 5 July, 2002. 05_N39.pdf.

Roth P., Georgiev, A., Busso, A. and Barraza,E.: First In-situ Determination of Ground and Borehole Thermal Properties in Latin America. In press *Renewable Energy*.