FREE CONTRIBUTIONS

INTERNATIONAL SUMMER SCHOOL
on Direct Application of Geothermal Energy
POLISH GEOTHERMAL ASSOCIATION
International Geothermal Days
POLAND 2004
EUROPEAN BRANCH
Under the auspice of Division of Earth Sciences

VERTICAL BOREHOLE HEAT EXCHANGER: REPORT ON FIRST EXPERIENCE IN SOUTH AMERICA. COOPERATIVE WORK BETWEEN CHILE AND ARGENTINA.

A. Busso [a,*], A. Georgiev [b, v], P. Roth [b]
[a] *Department of Physics, FaCENA, UNNE, 3400 Corrientes, Argentina*
[b] *Department of Mechanical Engineering, UTFSM, Valparaiso, Chile*
v On leave from Department of Mechanics, Technical University of Sofia, branch Plovdiv, Bulgaria
- *Corresponding author. Fax: +54 3783 473930,*
- *E-mail:* ajbusso@exa.unne.edu.ar

Abstract

Chile and Argentina are countries 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. 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. 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.

***Keywords**:* Underground Thermal Energy Storage; Solar Collectors; Charging; Discharging.

1. Introduction

Long term storage of huge amounts of thermal energy for heating and more importantly 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. Because of its smaller size and less hydro-geological restrictions, BTES has a bigger potential for application.

Mainly eight countries (Sweden [1, 2] , Canada, Germany [3], Netherlands, Norway, Turkey [4] , United Kingdom and the U.S.A [5]) have developed the technique.

Some months ago (June - July 2003) an Thermal Response Test (TRT) was performed in Valparaiso, Chile - the first one in Latin America carried out jointly between research groups of Chile and Argentina.

2. Test Installation

A shallow BHE, 16 m deep, was installed at the experimental grounds of the "Solar Energy Laboratory" - Technical University Federico Santa Maria (UTFSM) in Valparaiso, Chile [6]. This BHE was used to carry out in situ determination of ground thermal conductivity λ, borehole thermal resistance R_b and undisturbed soil temperature, technique commonly known as Thermal Response Test (TRT). The TRT ran for 9 days (from 24th of June to 3rd of July 2003) being the first of its kind in Latin America [7]. Fig. 1 presents a schematic diagram of the setup used.

Two main experiments were performed: TRT - to determine the soil and BHE thermal properties, and a charging / discharging cycle - to subject the system to different heat flow conditions over a period of time. This could allow deeper characterization and understanding of the shallow store. The study was also aided by TRNSYS simulations.

For the drilling phase, the truck of the Laboratory of Material Testing of the Department of Civil Works of the UTFSM was used. Three perforations were made along a line to a depth of about 22 m.

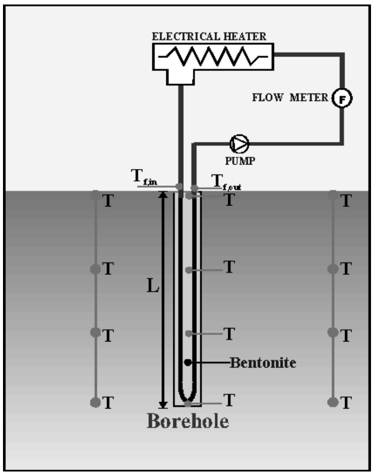


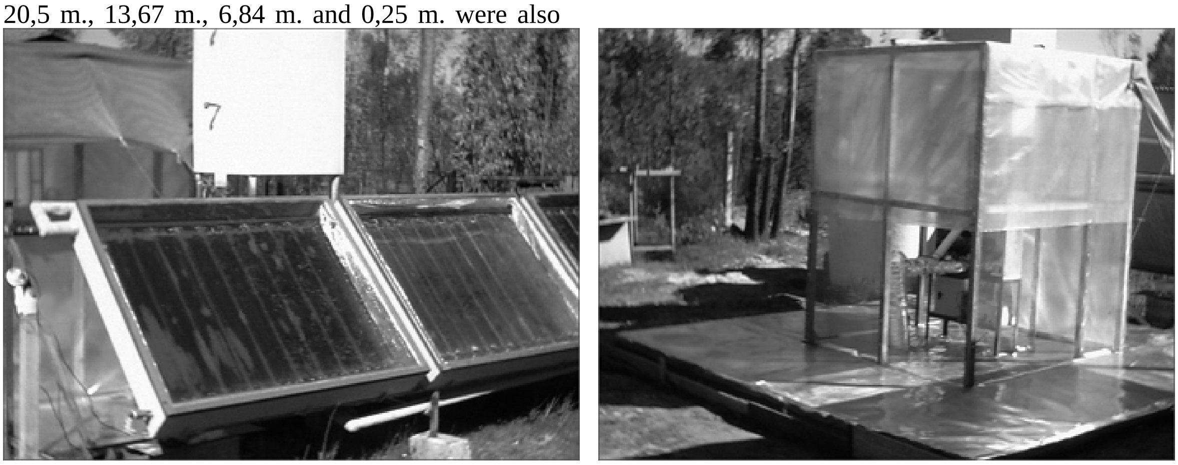
Figure 1. Scheme of the test installation.

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

The BHE is connected to the heating system on the surface by 3/4" copper pipes. A 2 kW electric heater was mounted in the hydraulic circuit of the installation. The circulation pump is a PKM 60-1, made by Pedrollo, Italy. It has a nominal electrical power of 370 W at 2900 rpm and flow rate between 5 - 40 l/min with a maximal head of 40 m. The entire pipe length was thermally insulated to reduce heat losses to the surroundings. The entire installation was cover by a plastic liner to reduce direct sun influence during test.

For the charging experiment three solar collectors were mounted and connected to the BTES (Fig. 2) providing a total active area of 4,4 m^2 (collector size is 1,05 m x 1,40 m). The distance between the collectors and the storage is about 2 m. Additional by pass valves were mounted to allow the system be ran in two different modes according to the type of power source in use. TRT mode - if power is supplied purely by electric heaters; solar mode - if the BTES is to be charged by solar energy. All connecting pipes were carefully insulated. After completing conditioning works the pump remained running for 10 days and different variables were monitored.

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



a) b)

Figure 2.- View of the installation and components.

At the end of the charging cycle a new modification was introduced to the hydraulic system. To release the stored energy the collectors were replaced by one loop of a cross flow water-to-water heat exchanger, the other loop being fed with tap water. To this purpose, an old automobile radiator was adapted by placing it inside a metal casing 0.24 m. height, 0.30 m. wide and 0.08 m. 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 the outside to diminish ambient coupling.

3. Equipment of measurement

With the aim of mapping the underground temperature field around the BHE, 12 Chromel /

Alumel thermocouples (8 in the ground and 4 in the bentonite) were available from the temperature probes mounted in the ground. All electrical and communication cables between the setup and the PC located at the laboratory were tubed in metallic pipes buried in a 0.30 m. deep trench running from the installation to the main switch board inside the laboratory house (some 25 m appart).

A manual rotameter "Blue White industries 9509" with maximal flow rate of 7,5 l/min was used during the charging phase. Four Gemini Data Loggers TGP-0020 with a Standard Temperature Probe PB-4724 monitored inlet and outlet borehole temperatures and the inlet and outlet collector temperatures. 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. Fig.3 and Table 1 present a picture and main technical characteristics of the Gemini Data Loggers. 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. All the measuring equipment was calibrated prior to the test.

Table. 1. Technical data of Gemini Data Sheet: Tinytag Plus Range G for Standard Probe TGP-0020, Tinytag Plus Temperature Range G Internal TGP-0017 and Tinytag Plus Re-ed Millivolt Input TGPR-1001.

Mechanical Data	
Case Style :	IP68 Style
Case Dimensions	
Height :	34mm / 1.34”
Width :	59mm / 2.32”
Depth :	80mm / 3.15”
Weight :	110g / 3.9 oz.
Features	
Memory Size :	16k (Non-volatile)
No. of Readings :	16000 (approx)
Resolution :	8 bit
Trigger Start :	Magnetic reed switch
Delayed Start :	Relative / Actual up to 45 days
Stop Options :	When Full/ After n Readings/ Never (Wrap around)
Reading Types :	Actual, Min, Max.
Logging Interval :	1 sec to 10 days
Offload :	While stopped or when logging in minute multiples
Alarms :	Two, fully Programmable
Functional Range :	- 40°C to + 85°C / -40°F to +185°F
IP Rating :	IP68 waterproof
Battery Life :	Up to 5 Years
Sensor Details (only for TGP-0020)	
Range :	-40°C to + 125°C / -40°F to +257°F
Sensor Type :	Standard Probe with 10k NTC Thermistor
Resolution :	0.4°C at +25°C / 0.72°F at +77°F
Sensor Details (only for TGP-0017)	
Range :	-40°C to + 85°C / -40°F to +185°F
Sensor Type :	10k NTC Thermistor (Encapsulated)
Sensor location :	Internally mounted
Response Time :	1.5 min to 90% (in water); 25 min (in air)
Sensor accuracy :	± 0.2°C / ± 0.36°F; From 32°F to 158°F/ 0°C to 70°C
Resolution:	0.4°C at +25°C / 0.72°F at +77°F
Input Specification (only for TGPR-1001)	
Range :	to 200 mV
Maximum Input :	500mV
Input Impedance :	> 10 Megohms
Resolution :	0,8 mV
Accuracy :	± 1mV ± 0.5% of reading

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

4. Experiment

The TRT was carried out in June - July 2003. The test was implemented during 9 days (from 24th of June to 3rd of July 2003). Temperatures measured were - ambient temperature, inlet and outlet temperature of the borehole. Additionally, although the flow rate was fixed at the constant value of 3,17 l/min it was periodically measured and controlled. The electrical power was regulated and maintained constant at about 1000 W. The electrical power of the circulating pump was about 350 W.

The charging was done by means of solar energy (natural experiment). The test was implemented during 29 days (from 18th of August to 16th of September 2003). Five temperatures measured were - inlet and outlet temperature of the borehole, inlet and outlet collector temperature and ambient temperature. Additionally, the global solar ra-diation was measured. The Temperature- Difference- Regulator was used to turn on (5°C difference) and off (2°C difference) the pump depending on the temperature difference between the outlet collector and the inlet borehole temperatures.

The discharging followed connecting the heat exchanger to the BHE to extract heat from the store. The experiment started on 17th of September and finished on 30 of September 2003. Flow rates measured on the warm and cold circuits of heat exchanger were 3,17 l/min and 1,6 l/min respectively.

5. Results

5.1. Response Test Analysis

The data gathered was analysed and evaluated using the classical "slope determination technique", "two-variable parameter fitting" and with the aid of the GPM (Geothermal Properties Measurements) software. A brief description of each method is presented.

Line Source Model (LSM) problem - the equation for the temperature field as a function of time (t) and radius (r) around a line source with constant heat injection rate ($\dot{Q}$) may be used as an approximation of the heat injection from a BHE:

$$T_f(t) = \frac{\dot{Q}}{4\pi\lambda H}\left[\ln\left(\frac{4at}{r^2}\right) - \gamma\right] + \frac{\dot{Q}}{H}R_b + T_0 \qquad (1)$$

a - Thermal diffusivity (l/C), m^2/s;
t - Time, s;
$\dot{Q}$ - Heat injection rate, W;
T - Temperature, ºC;
r - Borehole radius, m;
l - Thermal conductivity of soil, W/mK;
H - Borehole depth, m;
C – Volumetric heat capacity, MJ/m^3K.
$\gamma = 0.5772$ (Euler´s constant);
T_0 - Undisturbed ground temperature;
R_b - Borehole thermal resistance.

Eq. (1) can be re-written in a linear form as:

$$T_f(t) = k\ln(t) + m \quad \text{with} \quad k = \frac{\dot{Q}}{4\pi\lambda H} \qquad (2)$$

Hence, l can be determined from the slope of the line resulting when plotting T_f against *ln(t)*, therefore the name and basis of the evaluation method.

The need for a more interval-independent evaluation technique led to fit the data using as fitting function Eq. (1) with l and R_b left as the two variable parameters. For the analysis the commercial software "Origin6" was used. The Software used has the capability of performing nonlinear curve fitting to user input functions using a Levenberg-Marquardt iteration algorithm. At each iteration, the fitter computes the Variance-Covariance matrix using its value from the previous iteration.

The GPM is a program developed at the Oak Ridge National Laboratory to determine soil formation thermal properties from short term field test data. The program makes use of a parameter-estimation-based method in combination with a 1-D numerical model developed by Shonder and Beck. The numerical model relies on the cylinder source model considering the two pipes of the U-loop as a single cylinder.

As shown by Eq. (2), the thermal conductivity is related to the slope of the resulting line in a logarithmic time plot of the mean fluid temperature T_f in the BHE. Fig.4. shows such a graphical representation (the first 15 h were ruled out) for the entire time span of the test and the slope of the associated regression line. Resulting values for l and R_b are 1.8 W/mK and 0.3 mK/W respectively.

Fig.5 is a plot of the resulting non-linear fitting curve superimposed to the experimental data. The inset presents the summary of results with the values of the two variable parameters, _ = 1.749 W/mK and *Rb* = 0.299 mK/W.

The results of the analysis using the GPM software are presented in Fig.6. Superimposed is the mean fluid temperature predicted by LSM Eq. (2). Because the transient nature of the model, the entire data set is used in the analysis. The residuals (absolute errors) between predictions and experimental points are shown in the lower part of the graph with GPM values very close to zero. Resulting values for _ and *Rb* are 2.35 W/mK and 0.32 W/mK respectively.

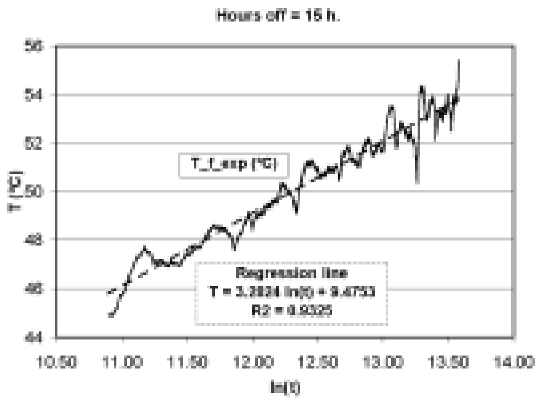


Figure.4. View of evaluation data interval.

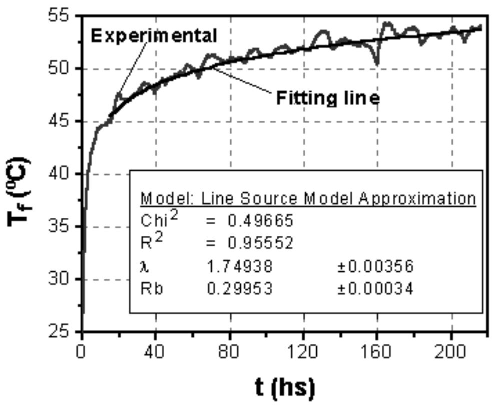


Figure 5. Response test data and fitted curved.

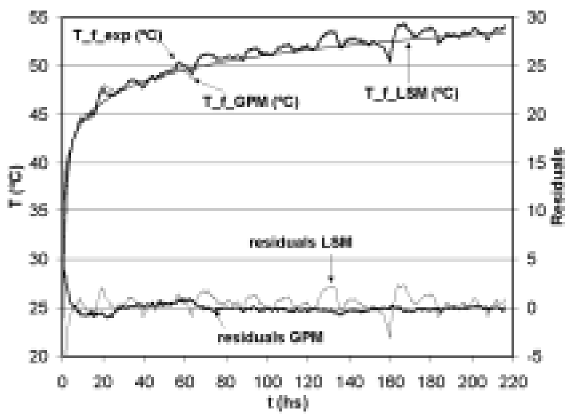


Figure 6. GPM and slope determination method.

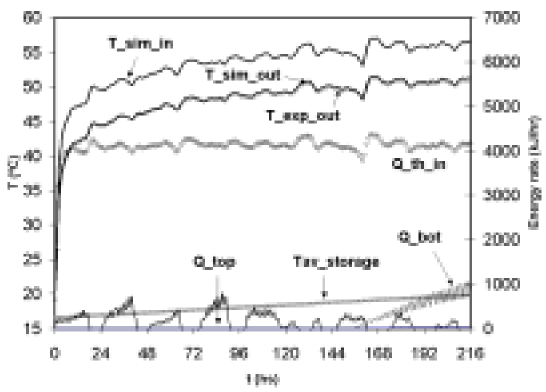


Figure 7. Simulated by TRNSYS type 14

5.1.1 TRNSYS simulation

The response test was further studied using TRNSYS TYPE 141 VERTICAL GROUND HEAT EXCHANGER. This subroutine models a vertical heat exchanger that interacts thermally with the ground. The program was fed with measured data on BHE inlet and outlet fluid temperature as well as ambient temperature. Fig.7 presents the results of the TRNSYS simulation. The agreement between experimental and TRNSYS simulated outlet temperature is remarkable. The graph also shows energy rates through the boundaries of the storage region and the evolution of the mean storage temperature.

With the outputs at user-specified under-ground nodes, mappings at 12 h interval of the evolution of the thermal wave in the soil were constructed for the entire duration of the test. Fig.8. depicts four time instances; 12 h., 84 h.,156 h. and 240 h.; of the thermal field so obtained. The observable feature is that top losses prevent the lower part of the storage to increase temperature significantly affecting long-time performance of the storage.

5.2. Pre-charging trial

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.9a and 9b present 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 addition of thermal insulation 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.).

5.3. Charging phase

The store was subjected to fluctuating power injection by coupling the BHE to the solar collector array 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 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 of the pump hence in all the calculations and simulations flow rate is assumed constant and equal to the measured value of 3.13 l/min.

Given that the store volume is 53m3, the volumetric heat capacity of the soil in the store 2200

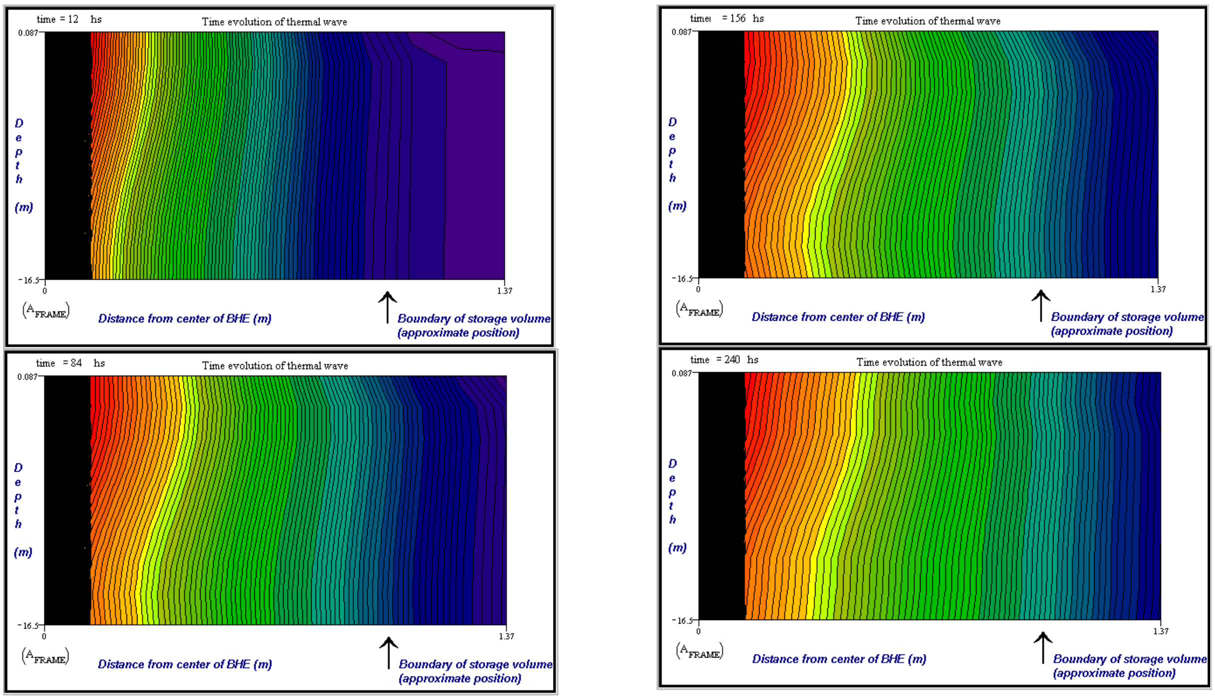
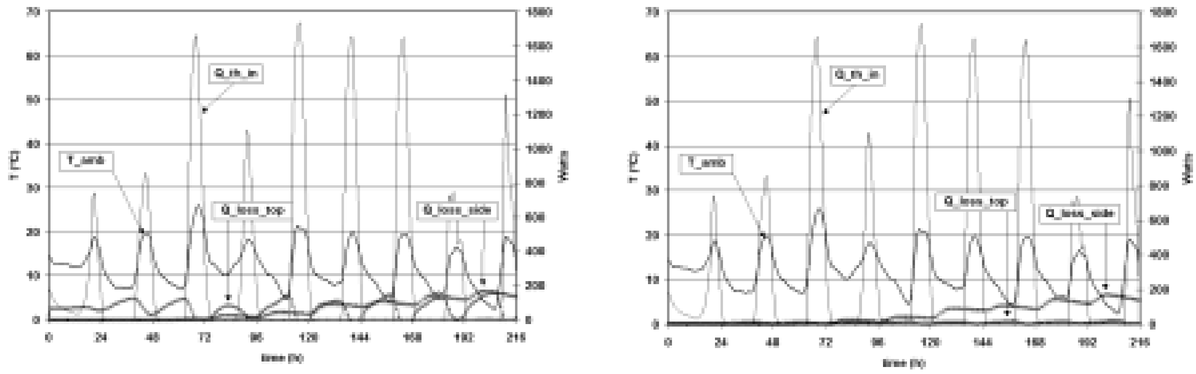


Figure 8. Time evolution of the thermal field in the ground.



a) b)

Figure 9. Time evolution of the energy rates before and after addition of the thermal insulation layer on top of the store.

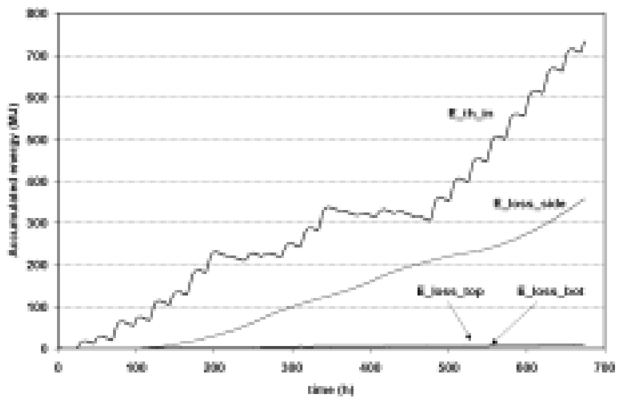
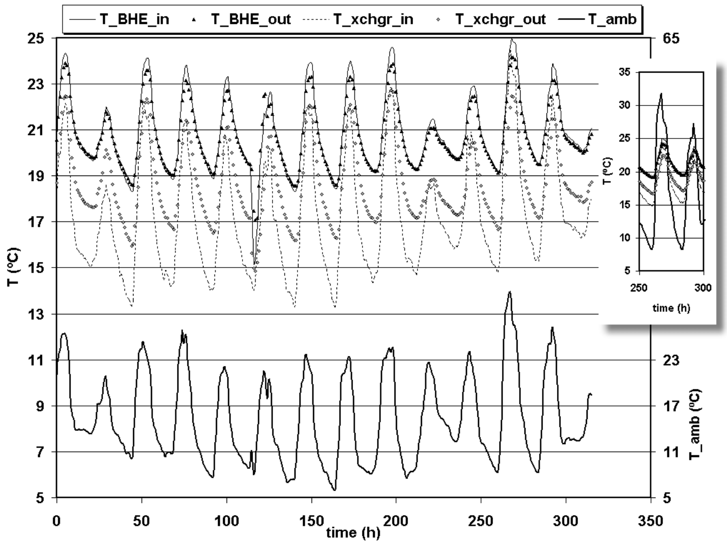
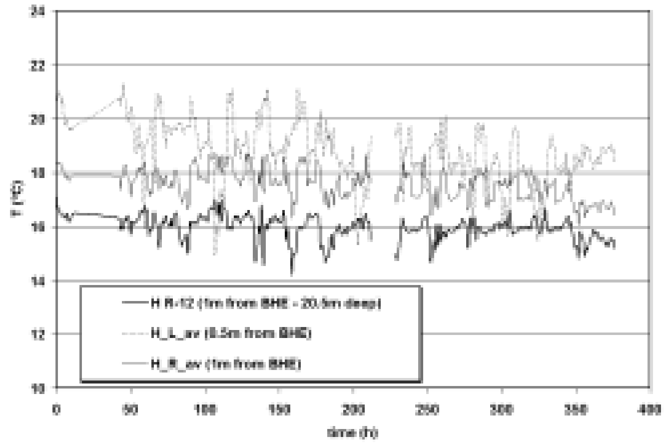


Figure 11.- Time evolution of accumulated energies.

a) Fluid temperatures measured by Gemini probes in direct contact with the fluid (BHE/water-to-water heat exchanger system)



b) Soil temperatures measured by temperature probes in the soil at different depths and distance from the BHE.



c) Decaying trend of the cooling during discharging.

Tav_store - ground probes data

AA_Smoothin – filtered measured data

Exp_decay – fitting curve to bring about possible trends.

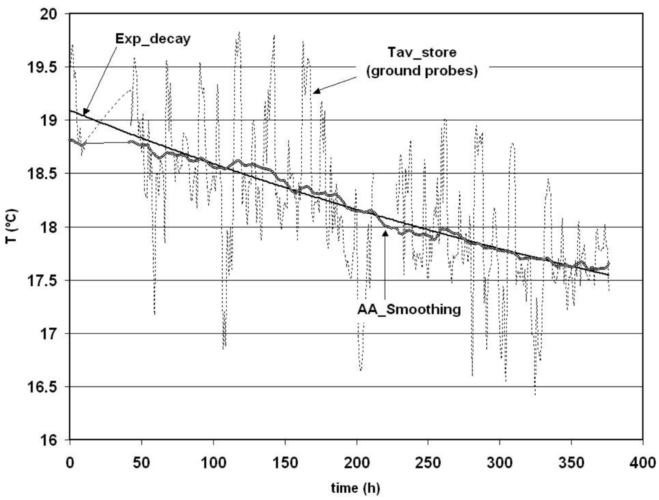


Figure 12. Time evolution of fluid and soil temperatures

kJ/m3K 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.

5.4.Discharging phase

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

For clarity reasons, to avoid many curves superimposed on a single graph ambient tempe-rature (T_amb) on Fig.14a is referred to the se-condary 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.

Fig.12b depicts the variation of soil tempera-ture over time as measured by probes at 0.5m and 1m from the BHE. Additionally, the temperature of a point located on the lateral boundary of the store volume (1m from BHE) some 4m below its bottom (depth of 20.5m) is also shown. The closer to the BHE the higher the temperature.

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

In this regards, Fig.12c depicts the average temperature between H_L_av and H_R_av curves of Fig.12b. Given the sort of noisy nature of the original data set a filtering techniques along with curve fitting was employed in order to visualize possible trends; Adjacent Averaging Smoothing (AA_Smoothing) and curve fitting using a first degree exponential decay function. Resulting curves agree remarkably well indicating that apparently the cooling effect of the discharging follows an exponential decay law.

In the upper part 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 shown as reference pattern of the ambient fluctuation.

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 fluid in the cold loop. This explains the heat injection (Q_BHE > 0) actually observed (T_BHE_in > T_BHE_out in Fig.12a). 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 find-ing a reasonable explanation for this effect this far.

During night hours large temperature differ-ence in the cold loop and T_BHE_out > T_BHE_in as observed in Fig.12a are clear sings that heat ex-traction 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.12a (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 thus ruled out.

Another source of power is the pump. The effect of this device on the system has been assessed in a previous work [7] to be in the order of 135 W.

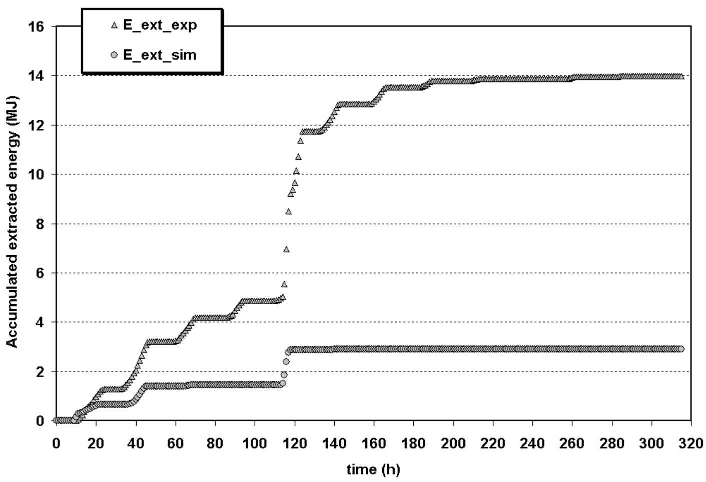


Fig. 14. comparison between experimental accumulated extracted energy and that predicted by simulations.

One immediately recognizes heat injection to the store (Q_BHE > 0) during day time hours and heat extraction from the store (Q_BHE < 0) during night hours.

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 an energy source and its energy contribution quantified still unidentified the source of another 100 W. This matter is pending further investigation.

Finally, Fig.14 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 at the end of the charging cycle ~350 MJ were accumulated in the store (Fig.11).

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 in order to better understand some of the features exhibited by the thermal behavior of the system. The main conclusions drawn from all these work are:

TRT:

- The effective values of 1.8 W/mK and 0.3 mK/W were determined for the thermal conductivity l and borehole thermal resistance R_b respectively.
- Application of the classical slope determination and/or two-variable parameter fitting can be used as a fast and reliable tool for data evaluation
- This first experience represents a step towards a more detailed study on thermal properties of the soil in different sites in Chile and Argentina with eyes set on possible practical applications of underground thermal energy storage in the region

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, from the ~2650 MJ of solar energy received by the collectors during the charging period only 70% was transformed into thermal energy and, 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.

Discharging phase:

- The relatively large ambient coupling detected in the water-to-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-to-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.

Presently, the installation of a BHE is under way in the Northeastern region of Argentina to perform a similar study but in a water saturated type of underground.

7. References

[1] Andersson O, Hellström G, 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.

[2] Dikici D, Nordell B, Paksoy HO. 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.

[3] Reuss M, Müller JP. 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.

[4] Paksoy H, Gurbuz Z, Turgut B, Dikici D, 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.

[5] Austin WA. Development of an in-situ system for measuring ground thermal properties. Master's thesis. Oklahoma State University, Stillwater, Oklahoma, 1998.

[6] Georgiev A, Ortiz A, 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.

[7] P. Roth, A. Georgiev, A. Busso, E. Barraza. First In-situ Determination of Ground and Borehole Thermal Properties in Latin America. Submitted to "Renewable Energy" Vol 29/12 pp 1947-1963. 2004.

[8] A. Busso, M. Reuss. Almacenamiento Térmico Subterráneo: Acoplamiento Térmico Ambiental en Ensayos de Respuesta Térmica. Proceedings of the XXVII Semana Nacional de Energía Solar, ANES. México, 2003.