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# Experimental performance of horizontal ground heat exchanger for space cooling

Nabiha NAILI*, Majdi HAZAMI, Issam ATTAR, Abdelhamid FARHAT
*Laboratoire des Procédés Thermiques, Centre de Recherches et des Technologies de l'Energie (CRTEn), PB 95, Hammam Lif 2050, Tunisia*
**Corresponding author: Tel 71430044 / 71430215, Fax:71430934.*
*E-mail:* ***nabiha.naili@crten.rnrt.tn***

**Résumé:** The ground heat exchanger (GHE) consists of a length of pipe buried at reasonable depth below the ground surface, it uses the earth as a heat source (in the winter) or a heat sink (in the summer). This design takes advantage of the moderate temperatures in the ground to boost efficiency and reduce the operational costs of heating and cooling systems. The aim of this study is to test the thermal performance of horizontal ground heat exchanger (GHE) for space cooling. An experimental set-up has been constructed for climatic condition of Borj Cedria localized in the north of Tunisia. Results obtained during experience were presented and discussed. The ground temperature at several depths was measured, the overall heat transfer coefficient (U) was determined. To evaluate the system efficiency the energy analysis was applied, the energy efficiency was found to range from 14 to 28%. The heat exchange rate was quantified, the pressure losses were calculated.

**Mots clés** :
Horizontal Ground heat exchanger; Experimental study; Thermal analysis; energy efficiency.

## 1. Introduction

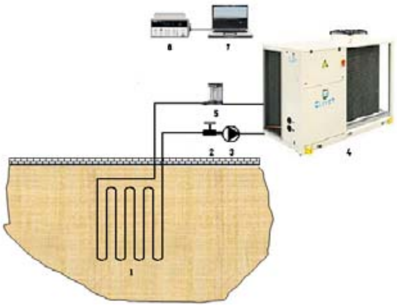
The ground heat exchanger (GHE) consists of a length of pipe buried at reasonable depth below the ground surface, it uses the earth as a heat source (in the winter) or a heat sink (in the summer). This design takes advantage of the moderate temperatures in the ground to boost efficiency and reduce the operational costs of heating and cooling systems. Ground-source heat exchangers provide a new and clean way of heating buildings in the world. They make use of renewable energy stored in the ground, providing one of the most energy-efficient ways of heating buildings. They are suitable for a wide variety of building types and are particularly appropriate for low environmental impact projects. They do not require hot rocks (geothermal energy) and can be installed in most of the world, using a borehole or shallow trenches or, less commonly, by extracting heat from a pond or lake. Heat collecting pipes in a closed loop, containing water (with a little antifreeze) are used to extract this stored energy, which can then be used to provide space heating and domestic hot water [1].

In the open literature, many researches works have been conducted, modeling and testing of ground coupled heat pump systems [2-13]. Esen and al. [2], have tested the performance of an air-conditioning system formed by a ground coupled heat pump with two different depths for ground heat exchanger: 1m and 2m. Their experience showed that the ground exchanger performance increases with the depth (2.5 for 1m and 2.8 for 2m). They have also carried out a comparative economic evaluation. Zhao and al. [4] indicate that heat transfer mainly happens near the outer wall of coaxial GHE and inclines to stabilization at far-field, they also have concluded that the inlet temperature, initial temperature of porous medium and the flow rate are major factors affecting heat transfer. Cui and al. [7] have developed a finite element numerical model to simulate hybrid ground-coupled heat pump with domestic hot water heating (DHW). Authors have concluded that The horizontal GSHP can offer almost 95% of total DHW demand in this case study along with about 70% energy saving compared to the electric heater. Bi et al. [12] have employed a two-dimensional cylindrical coordinate system to model a ground heat exchanger. A CFD simulations have been carried out by Congedo et al.[13] to analyses three main geometries of horizontal ground heat exchangers: linear, helical and slinky. In their study, the authors have concluded that the most important parameter for the heat transfer performance of the system is the thermal conductivity of the ground around the heat exchanger, they have also showed that the choice of the velocity of the heat transfer fluid inside the tubes is a key factor for heat transfer performance for all the arrangements.

In this paper, an experimental set-up was constructed for climatic condition of Borj Cedria localized in the north of Tunisia. The aim of this study is to test the thermal performance of horizontal ground heat exchanger with 25m of length buried at 1m depth.

## 2. Experimental set-up

The schematic arrangement of the experimental system is given in Fig. 1. The experimental set-up consists mainly of two units: the ground heat exchanger (GHE) and the thermal response test equipment. The GHE consists of a polyethylene tube, 0.016 m in internal diameter, buried at 1 m depth. The distance between tubes is 0.3 m to minimize the interference between them. An air-liquid Clivet type heat pump was used to design tests.



1 GHE
2 Valve
3 Circulating pump
4 Heat pump
5 Flow meter
6 Data acquisition chart
7 PC

Fig. 1. Schematic of the experimental system

In the present study, the temperatures and mass flow rates, were measured by appropriate instruments explained below:

- The water entering and leaving the GHE were measured by a copper-constantan thermocouples mounted on the unit water inlet and outlet lines.
- The ground temperatures at several depths were measured by a copper-constantan thermocouples
- The water mass flow rate was measured by a Rotameter.

## 3. Thermal analysis

In this study we will consider only the heat exchange which is making in stationary regime. The heat transfer inside a pipe is makes by forced convection. When we consider an infinitesimal element dx of a tube in the coolant flow direction, the heat exchange rate $Q_e$ is given by the following expression:

$$dQ_{e_{anal}} = \dot{m}\, C_p\, dT_f(x) = U(x)\,(T_g - T_f)\,\pi D\, dx \qquad (1)$$

By admitting that the overall heat transfer coefficient remains constant all along the exchanger, (U(x)=U), after integration, the preceding equation gives

$$\dot{m}\, C_p\, Ln\left\{\frac{(T_o - T_g)}{(T_{in} - T_g)}\right\} = U\,S \qquad (2)$$

Where $T_i$ and $T_o$ are the exchanger inlet and outlet temperature respectively.

The heat exchange rate $Q_e$ was calculated from the following equation $Q_e = \dot{m}\, C_p\,(T_o - T_{in})$

(1) and (2) gives

$$Q_{e_{\exp}} = \frac{U\,S\Delta T}{Ln\left(\frac{(T_o - T_g)}{(T_{in} - T_g)}\right)} \qquad (3)$$

Where $\frac{\Delta T}{Ln\left(\frac{(T_o - T_g)}{(T_{in} - T_g)}\right)}$ represents a log mean temperature difference *DTLM*, so the heat exchange rate can be puts as follows

$$Q_{e_{\exp}} = U\,S\,LMTD \qquad (4)$$

To evaluate the thermal performance of the GHE, we often use the energy efficiency concept. It is defined by the ratio of the really heat exchange rate ($Q_e$) and the theoretically possible of maximum heat exchange rate ($Q_{Max}$), it is expressed by:

$$\varepsilon = \frac{Q_e}{Q_{(Max)}} \qquad (5)$$

With

$$Q_{(Max)} = \dot{m}\, C_p\, \Delta T' \qquad (6)$$

The exchanger energy efficiency is written then:

$$\varepsilon = \frac{\Delta T}{\Delta T'} \qquad (7)$$

The pressure losses must be calculated in order to be able to balance the various criteria the ones compared to the others. For the calculation of the pressure losses, we must calculate the linear and singular pressure losses

$$\Delta p_{total} = \Delta p_{lin} + \Delta p_{sin} \quad (8)$$

The linear pressure loss for a flow in a rectilinear control is determined in the following way [14]:

$$\Delta p = \frac{\Lambda \rho u^2}{2D} L \quad (9)$$

The singular pressure loss is defined by [15]: $\Delta p = \xi \rho \frac{u^2}{2}$ (10)

## 4. Results and discussions

The ground temperature constitutes an essential data in the installation of GHEs. The ground temperature results at various depths (d) measured in summer (21-23 June 2011) is shown in Fig. 2, we can note that the ground sees its temperature changes decreased exponentially with depth. This decrease diminished as the ground depth increases because the high thermal inertia of the ground.

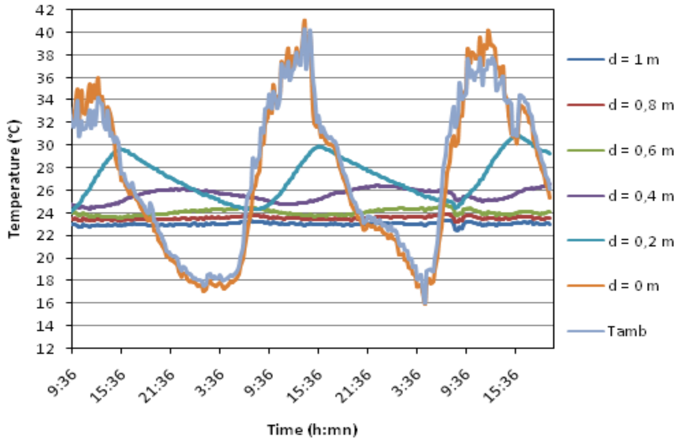



Fig. 2. Soil temperature at several depths 21-23 June 2011

Measurements show that the ground temperature below a certain depth remains relatively constant. The temperature at 1m depth is about 23°C while the outdoor temperature is about 37°C. When the temperature at 1m depth was compared with the outdoor temperature, we established that Tunisia benefits from an important natural geothermal source.

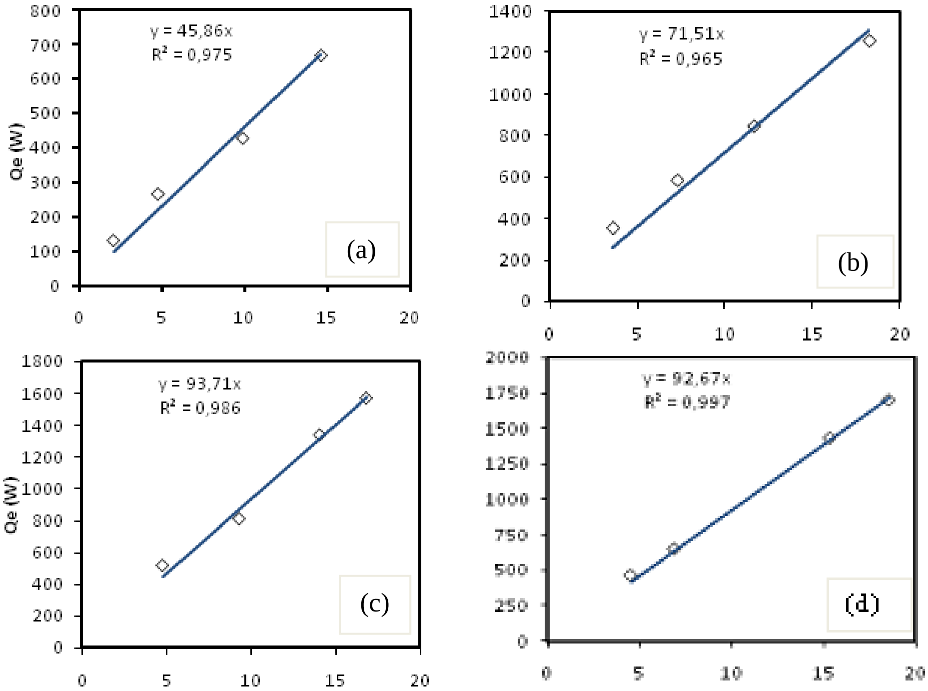



Fig. 4. Heat exchange rate versus log mean temperature difference
for the following flow rates a) 0.06 $kg.s^{-1}$; b) 0.08 $kg.s^{-1}$; c) 0.1 $kg.s^{-1}$; d) 0.12 $kg.s^{-1}$.

Fig. 4 shows the curves of the heat exchange rate versus the log mean temperature difference (DTLM) for the following flows rate : 0.06; 0.08 ; 0.1, 0.12 and 0.16 $kg.s^{-1}$ and for a variety of inlet temperature ranging between 30 °C and 50 °C.

The experimental variation of the heat exchange rate ($Q_e$) versus the log mean temperature difference (DTLM), is linear. The respective slopes of these lines brought back to the unit of surface are, in steady state, the overall heat transfer coefficient, U, of the exchanger.

The overall heat transfer coefficient values are regrouped in Table. 1. We can conclude from table.1 that the overall heat transfer coefficient, U, increases versus the mass flow rate. This increase is not linear. It is slowed down by the pressure losses. The overall heat exchange coefficient reached, during experiments, a maximum value of 59,02 W $m^{-2}$ $°C^{-1}$ for a 25 m of exchanger length and mass flow rate about 0,12 $Kg.s^{-1}$ .The use of the exchanger with lower flows decreases notably the overall heat transfer coefficient.

Table 1: The overall heat transfer coefficient

| Mass flow rate ($kg.s^{-1}$) | 0.06 | 0.08 | 0.1 | 0.12 |
|---|---|---|---|---|
| U($W.m^{-2}.°C$) | 29.15 | 45.04 | 58.41 | 59.02 |

The use of the ground coupled heat exchanger aims essentially to have the maximum of the heat exchange rate, this quantity depends from many parameters. In our study we try to test the effect of the water coolant flow rate on this quantity, so we represent in fig 5 the heat exchange rate Qe variation versus mass flow rate.

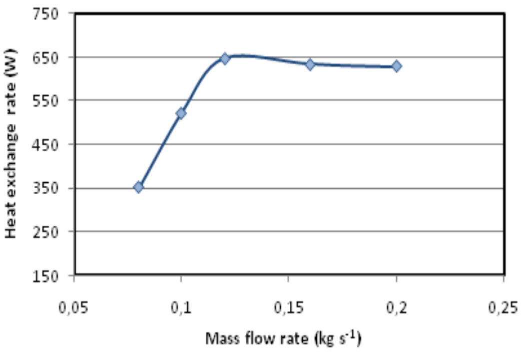



Fig. 5. Heat exchange rate versus mass flow rate

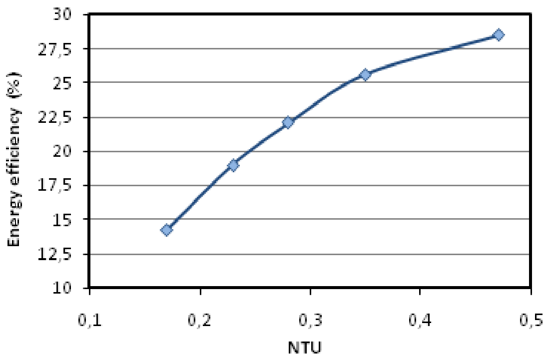



Fig. 6: Energy efficiency versus NTU

It is noted that the heat exchange rate tends towards a limiting value about 650 W obtained for a water mass flow rate about 0.12 $kg.s^{-1}$. Thus 0.12 $Kg.s^{-1}$ is the optimal mass flow rate. Indeed, any increase in the flow of water coolant beyond this value, does not affect the heat exchange rate. We can also concluded from this figure that the heat exchange rate, when the temperature in the outlet side of the exchanger is stabilized (steady-state) and for the masse flow rate about 0.12 $kg.s^{-1}$, is about 26 W/m witch reflects the importance of geothermal energy in Tunisia.

The energy efficiency of the ground heat exchanger is determined by the NTU, the results are shown in Fig. 6. It is noticed from this figure that the energy efficiency increases with NTU, which ranging from 14.3% to 28.4%. Indeed, the NTU determines the residence time of the water on the heat exchanger surface and thus also the amount of heat that it can absorbs by the ground. Consequently when the NTU increases the residence time of the water in the heat exchanger increases, thus the outlet temperature increases witch increase the energy efficiency. In fig.7 we represent the variation of the pressure loss versus mass flow rate. It is noticed that more the mass flow rate increases more the pressure loss increases too (Eq 9,10). This is due to the several accidents met by the liquid coolant inside the exchanger. For the experimental masse flow rate (0.12 kg $s^{-1}$) the pressure loss is about 8.43 kPa.

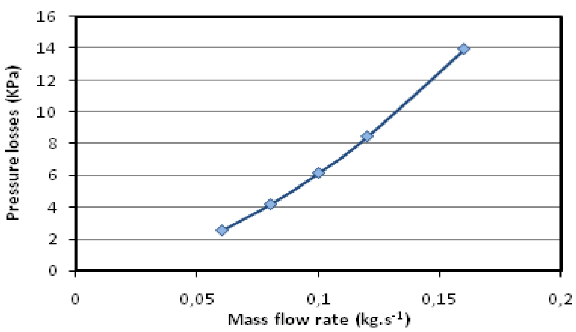



Fig.7: Pressure loss versus mass flow rate

This result is compatible with the experimental and numerical study published in the literature (Missirlis an al [16]).

## 4. Conclusions

In the present study horizontal ground heat exchanger was buried at 1m and tested in the Research and Technology Center of Energy, Tunisia. The following conclusions can be drawn from this study:

∗ Thermal potential in Tunisia offers a good exploitation of horizontal ground source heat exchanger (HGSHE),

∗ The overall heat exchange coefficient reached, during experiments, a maximum value of 59,02 W $m^{-2}$°$C^{-1}$ for a 25 m of exchanger length and mass flow rate about 0,12 Kg.$s^{-1}$

∗ The energy efficiency for the GSHE system considered are found to range from 14.3% to 28.4%

∗ The heat exchange rate, when the temperature in the outlet side of the exchanger is stabilized (steady-state), is about 26 W/m witch reflects the importance of surface geothermal energy in Tunisia.

∗ The pressure loss increase with the mass flow rate, for the optimal mass flow rate obtained (0.12 kg s-1) the pressure loss is about 8.43 kPa.

**Nomenclature**

| | |
|---|---|
| $\dot{m}$ | mass flow rate kg $s^{-1}$ |
| Cp | specific heat of water at constant pressure, kj $kg^{-1}$ °$C^{-1}$ |
| ΔT | temperature difference between the inlet and outlet GHE of circulated water, °C |
| ΔT’ | temperature difference between the inlet GHE of circulated water and the ground at 1m depth, °C |
| L | exchanger lengths, m |
| D | exchanger diameter, m |
| Δp | pressure loss, kPa |
| $Q_e$ | heat exchange rate, W |
| T | temperature, °C |
| u | velocity, m $s^{-1}$ |
| d | depths, m |
| NTU | heat transfer units number, $\frac{US}{\dot{m}\,Cp}$ |

Greek letters

| | |
|---|---|
| ρ | water density, kg.$m^{-3}$ |
| Λ | linear loss ratio of load |
| ξ | singular loss ratio of load |

Subscripts

| | |
|---|---|
| in | inlet |
| o | outlet |
| f | fluid |
| g | ground |
| lin | linear |
| sin | singular |

Abbreviations

| | |
|---|---|
| GHE | ground heat exchanger |
| GSHP | ground source heat pump |

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