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Development of geothermal energy: utilization of a new conic basket geothermal heat exchanger in Tunisia.

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***Abstract*. This paper presents an experimental analysis to test the performance of a new conic basket ground heat exchanger used for geothermal energy application. This system has never been used or exploited in Tunisia for any research or industrial purposes. An experimental setup was designed, constructed, installed, and tested in the Research and Technology Center of Energy of Borj Cedria located in the north of Tunisia. During the experimental period, the temperature of the soil at different depths, the overall heat transfer coefficient, and the heat exchange rate are evaluated. The energy efficiency varies between 17% and 62%. The CBGHE system can be used in the Mediterranean regions such as Tunisia for greenhouses cooling. This study showed that Tunisia has an important thermal potential and that the CBGHE is a promising solution for greenhouse cooling.**

Keywords: Ground Heat Exchanger; Geothermal energy; Energy Efficiency

I. INTRODUCTION

Surface geothermal involves taking energy from the ground using a heat pump. She has energy, economic and environmental performance for air conditioning and domestic hot water. Many research works have been conducted.
Michopoulos and Kyriakis [1] present an energy analysis of geothermal heat pump. They stated that 0.03% of the exchanged energy in the ground heat exchanger and 1.13% of the electricity consumption are consistent and independent of the chosen operation time. Esen et al. [2] have tested the performance of an air-conditioning system formed by a ground-coupled heat pump with two different depths (1 m and 2 m) for ground exchanger. Their experience showed that the ground exchanger performance increases with the depth (2.5 for 1 m and 2.8 for 2 m). They have also carried out a comparative economic evaluation [3].
According to Philippe [4]. The vertical heat exchangers are widespread over the world. Geothermal horizontal exchangers are quite common in France: The installation costs are reduced since they are buried at around one meter depth on large surfaces (typically between once and twice the area to be heated or cooled).

Few thermal models are presented [5-6]. The main work was done for energy storage in arid zones. In another study, Ahmet et al. [7] evaluated the exergetic performance of an air-earth heat exchanger (EAHE) coupled with a photovoltaic cell (PV) for reducing electric power consumption. Rabin et al [8] studied a system of exchanger with 6 m of height, which the upper part is buried at 4 m depth.
In this study a Conic Basket Geothermal Heat Exchanger (CBGHE) designed, and realized in the Thermal Processes Laboratory. This heat exchanger is installed vertically at 3 m of depth in the ground. Its characteristics are given in Table 1.
An experimental set-up was constructed for climatic condition of Borj Cedria localized in the north of Tunisia. The purposes of this study are to estimate the Tunisian geothermal energy and test the performance of the Conic Baskets Geothermal Heat Exchanger buried.

II. EXPERIMENTAL SET-UP.

A. Description of the System

The experimental setup has been installed at the Research and Technology Center of Energy in Borj Cedria, northern Tunisia, located at 36◦N latitude and 10◦E. The experimental system consists of two units: LAUDA T7000 type Heat pump was used to test the conic basket geothermal heat exchanger. The schematic arrangement of the experimental system is given in Fig. 1.

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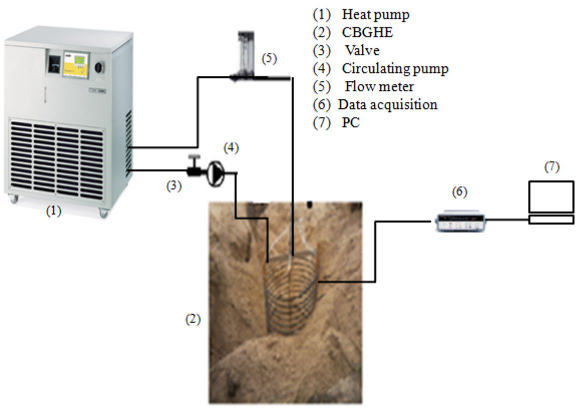

Fig.1. Schematic of the experimental system

The heat pump HP unit LAUDA T7000 type their characteristics are given in Table 2.

TABLE.1 Characteristics of Polyethylene High Density heat exchanger

Material	PEHD
Diameter (cm)	2,5
Length (m)	100
Thickness (cm)	0,230
Conductivity($Wm^{-1}k^{-1}$)	0,48

Fig. 2. Dimension and Schematic diagram of the CBGHE

TABLE.II Technical data of LAUDA T 7000

Ambient temperature range (°C)	[5, 40]
Working temperature range (°C)	[-30 , 120]
Temperature control (°C)	± 0,3
Heater power (KW)	6
Cooling capacity at 20°C (KW)	7
Pump flow max (L/min)	60
Filling volume max (L)	20
Pump pressure max (bar)	6
Overall Dimensions (W*D*H) (mm)	850*670*970

B. *Measurement Procedure*

The experimental approach consists to fix the water temperature and mass flow rates at the inlet of the exchanger. When the temperature in the outlet side of the exchanger is stabilized, we note the outlet temperature, which used to accurate the experimental analysis. Various tests were carried out in a range of mass flow rate between 0.1 and 0.3 $kg \cdot s^{-1}$. Appropriate instruments explained below measured the temperature and masse flow rates:

The inlet, outlet temperatures of CBGHE and the ground temperature were measured by using thermocouples.

The water mass flow rate was measured by a flow meter.

All measured temperatures were recorded by using a multi-channel data-logger type HP. The experimental results were obtained from the ground-source heat pump-system in the cooling season of 2015.

C. *Uncertainty Analysis*

Uncertainty analysis is needed to prove the accuracy of the experiments. In this study, errors came from the sensitiveness of equipment and measurements explained previously. First; errors due to measurement of temperature are: 1) sensitiveness of data acquisition system, about ± 0.1%°C, 2) measurement error is ±0.2% and 3) sensitiveness of the thermocouple is ±0.1%°C. The sensitiveness was obtained from a catalog of the instruments. Second, errors came from the measurement of the flow rate: 1) the sensitiveness of the flow meter is about ±0.1% and 2) errors due to measurement are about ±0.1%. In total, errors of measurement of the flow rate are about ±0.2%.

III. THEORETICAL MODEL

Since the geometry of the conical exchanger is complex we will consider the case of a cylinder with an inner radius ri and outer radius re. The analytical model was initially used to determine the outlet fluid temperature under the soil. We consider an infinitesimal element dz of a pipe in the coolant flow direction (Fig.3).

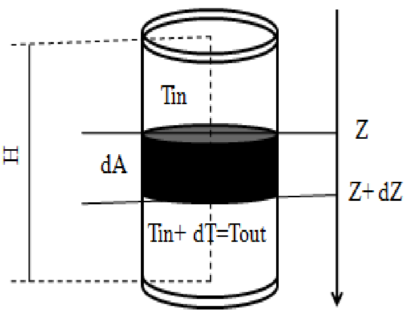

Fig.3. Longitudinal trench of the cylinder

The analytical heat exchange rate dQ is given:

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$$dQ = U(T_g - T_{out})dA \quad (1)$$

$$dQ = \dot{m} C_p dT_{out} = \dot{m} C_p (T_{out}(z+dz) - T_{out}(z)) \quad (2)$$

We suppose that there is no phase change.

$$dQ = \dot{m} C_p dT_{out} \quad (3)$$

$$dQ = U(T_g - T_{out})dA = \dot{m} C_p dT_{out} \quad (4)$$

After, rearranging Eq. (4)

$$\frac{dT_{out}}{T_g - T_{out}} = \frac{U}{\dot{m} C_p} dA \quad (5)$$

The integration of the equation (5) gives

$$\int_{T_{in}}^{T_{out}} \frac{dT_{out}}{T_{out} - T_g} = -\frac{U}{\dot{m} C_p} \int_0^z dA \quad (6)$$

$$\frac{T_{out} - T_g}{T_{in} - T_g} = \exp(-\frac{U}{\dot{m} C_p} A) \quad (7)$$

With $A = 2\pi r L$

The outlet temperature has a following expression:

$$T_{out} = (T_{in} - T_g)\exp(-\frac{h}{\dot{m} C_p} 2\pi r L) + T_g \quad (8)$$

The heat exchange rate Q_{GHE} was calculated from the following equation:

$$Q_{GHE} = \dot{m} C_p (1 - \exp(-\frac{h}{\dot{m} C_p} 2\pi r L)(T_g - T_{in,s}) \quad (9)$$

$$Q_{GHE} = UA\Delta TLM \quad (10)$$

Where $\Delta TLM = \frac{T_{out} - T_{in}}{\ln\left(\frac{T_{out} - T_g}{T_{in} - T_g}\right)}$ represents a log mean temperature difference

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

$$Q_{GHE} = \dot{m} C_p (T_{out,s} - T_{in,s}) \quad (11)$$

The thermal efficiency is calculated by the relationship:

$$\varepsilon = \frac{Q_{GHE}}{Q_{MAX}} \quad (12)$$

Or the maximum exchanged flux is $Q_{MAX} = \dot{m} C_p \Delta T_{MAX}$

$\Delta T_{MAX} = T_p - T_{in,s}$

So

$$\varepsilon = \frac{T_{out,s} - T_{in,s}}{T_p - T_{in,s}} \quad (13)$$

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

$$\Delta P = \Delta P_{lin} + \Delta P_{\sin} \quad (14)$$

The linear pressure loss for a flow in a rectilinear control is determined by the following expression [24]:

$$\Delta P = \frac{\rho L V^2}{2D} \Lambda \quad (15)$$

The calculation of the loss ratio of load (Λ) depends on the nature of the flow, laminar or turbulent. This last gives place to more significant pressure losses.

The singular pressure loss is defined by [9]:

$$\Delta p = \xi \rho \frac{V^2}{2} \quad (16)$$

IV. Results and Discussions

The ground temperature constitutes an essential data in the installation of CBGHE. To determine the ground temperature, we installed in different ground levels, thermocouples that are connected to an acquisition system data. The ground temperature results at various depths measured in summer (29/8 – 1/9 2015) is shown in Fig.4. We can note that the ground temperature decreased exponentially with depth. This decrease diminished as the ground depth increases because the high thermal inertia of the ground.

Measurements show that the ground temperature below a certain depth remains relatively constant. The temperature at 3m of depth is about 20°C while the outdoor temperature is about 39°C. When the temperature at 3m depth was compared with the outdoor temperature, we established that Tunisia benefits from an important natural geothermal source.

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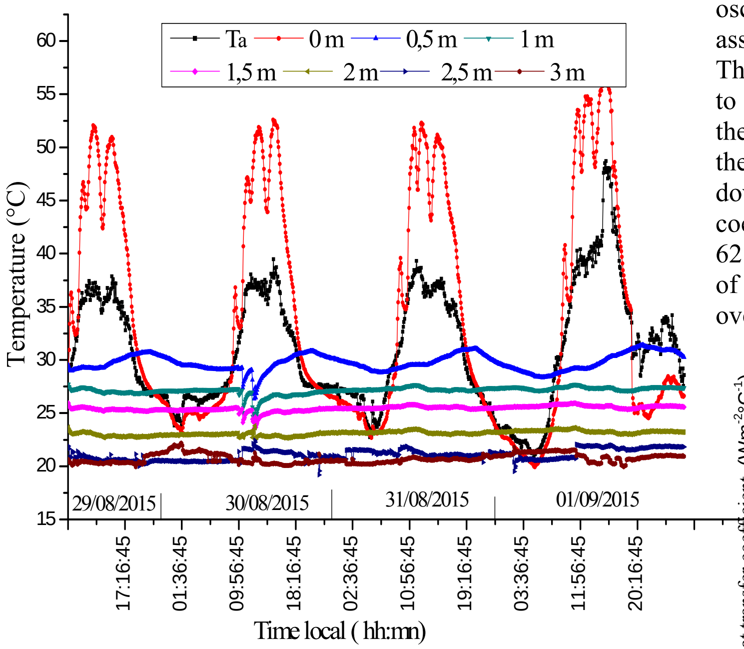

Fig.4. Experimental soil temperature profile at different depths

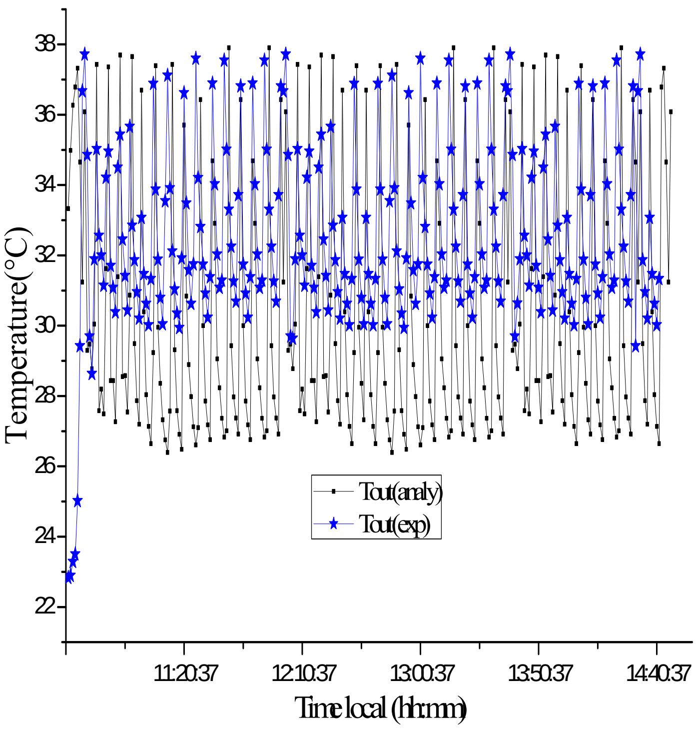

Fig.5. Experimental and analytical variation of outlet water temperature in the CBGHE

Fig. 5 gives the comparison between experimental and analytical outlet water temperature. This figure shows that there is an acceptable agreement between the analytical and the experimental outlet temperature. The outlet temperatures oscillations at the exchanger level are confirmed with our assumption.

The variation of the overall heat transfer coefficient according to the mass flow rate is show in Fig. 6. We can conclude that the overall heat transfer coefficient, U, increases according to 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 62 W m^{-2}°C^{-1} for a mass flow rate about 0.3 kg·s^{-1}. The use of the exchanger with lower flows decreases notably the overall heat transfer coefficient.

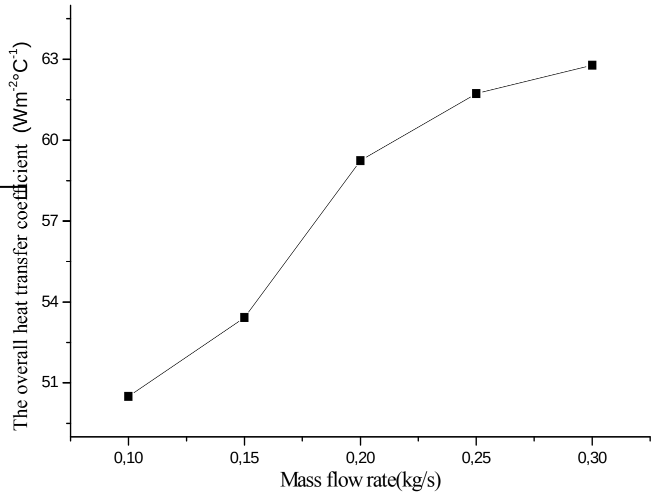

Fig.6. The overall heat transfer coefficient versus mass flow rate

The fig.7 shows the energy efficiency curve of the ground heat exchangers (CBGHE). It is observed that the energy efficiency decreases with increasing the rate mass flow. The maximum energy was 62% with 0,1 kg.s^{-1} and the minimum was 17% with 0.3 kg.s^{-1}. The energy efficiency in the CBGHE reached the maximum performance (E < 25%) for a rate greater than 0,2 kg.s^{-1}. The used of lower flow rates this exchanger (CBGHE) reduces the energy efficiency.

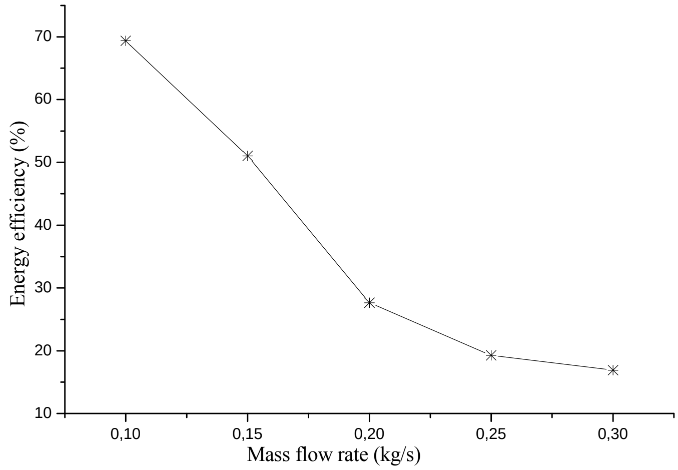

Fig.7. Energy efficiency versus mass flow rate

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Fig.8. present the heat exchange rate of the CBGHE according to the mass flow rate. We notice that the heat exchange rate increases with the rate flow mass from. Indeed, when the mass flow rate value vary from 0,1 to 0,3 kg/s, the heat exchange quantity varied from 26 to 32 W/m

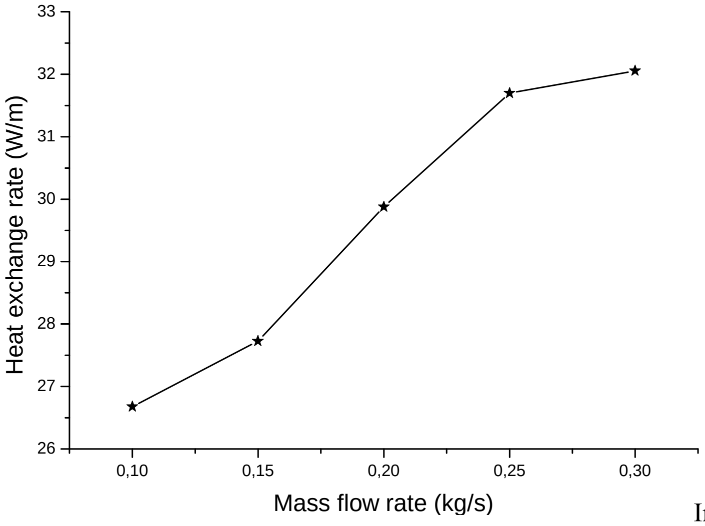

Fig.8. Heat exchange rate versus mass flow rate.

To calculate the pressure loss we must first calculate the Reynolds number *Re* (Table 3). Table III shows that for the range of the flows, which we considered in our experimental study, it is difficult to obtain a laminar flow. We will thus consider for the continuation the pressure loss for a turbulent flow. In this case, the loss ratio of load can be determined by the Blasius relation

$$\Lambda = \frac{0.316}{R_e^{1/4}} = \left(\frac{0.01}{R_e}\right)^{1/4}$$

In Fig. 9 we represent the variation of the pressure loss versus mass flow rate. We notice that more the mass flow rate increases more the pressure loss increases too (Equations (14)). This is due to the several accidents met by the liquid coolant inside the exchanger. For the experimental masse flow rate (0.2 $kg \cdot s^{-1}$) the pressure loss is about 9952 Pa.

TABLE.III Calculation of the Reynolds number.

Mass flow rate(kg/s)	*Re*	Λ	ΔP (pa)
0.1	4970	0.037	2968
0.15	7455	0.034	6138
0.2	9940	0.031	9952
0.25	12425	0.029	14550
0.3	14910	0.028	20232

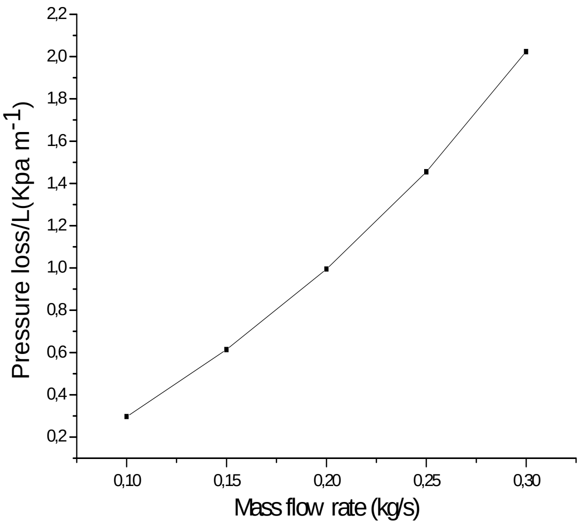

Fig.9. Pressure loss versus mass flow rate.

V. CONCLUSION

In the present study conic basket, geothermal heat exchanger (CBGHE) was buried at 3m and tested in the Research and Technology Center of Energy from Tunisia. The following conclusions can be drawn from this study:

- Thermal potential in Tunisia offers a good exploitation of horizontal conic basket geothermal heat exchanger (CBGHE). Indeed the experimental ground temperature shows that, at sufficient depth, it is always lower than that of the outside air in summer. The ground temperature is nearly constant below a depth of 3 m.
- The energy efficiency for the CBGHE system considered are found to range from 17% to 62%.
- The heat exchange rate, when the temperature in the outlet side of the exchanger is stabilized (steady state), is about 32W/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 (0.2 $kg \cdot s^{-1}$) the pressure loss is about 9952 Pa.

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Nomenclature

A	Surface area (m^2).
C_p	Specific heat of water at constant pressure (J/kgK)).
$\dot{m}$	Mass flow rate (kg/s).
Δp	pressure loss, Pa
Q	Heat rate(W.
r	Radius (m).
T	Temperature (°C).
u	Velocity (m/s).
U	Overall heat transfer coefficient (W/m^2°C).
z	Depth of soil (m).
ΔT	Difference between the maximum temperature and surface temperature (°C).
ΔTLM	Log mean temperature difference (°C).

Greek letters

λ	thermal conductivity (W/mK)
ρ	density (kg/.m^3)
a	thermal diffusivity (m^2/s)
Λ	linear loss ratio of load
ξ	singular loss ratio of load

Subscript

a	Ambient
s	Soil
g	Ground
in	Inlet
out	Outlet
m	average temperature over the year(°C)

Abbreviations

GHE	Ground heat exchanger
CBGHE	Conic basket geothermal heat exchanger

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