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Thermal performance of a conic basket heat exchanger coupled to a geothermal heat pump for greenhouse cooling under Tunisian climate

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ABSTRACT

This paper presents an experimental analysis to examine the performance of a new conic basket geothermal heat exchanger (CBGHE) for greenhouse cooling. This system has never been used or exploited in Tunisia for any research or industrial purposes. Therefore, an experimental system was designed, installed and tested in the Research and Technology Center of Energy (CRTEn) of Borj Cedria.

The configuration typically consists of a series of parallel coil implanted in 3 meter depth. The experiments are conducted between 7th and 8th June 2014. The results obtained show that the CBGHE system can be used in the Mediterranean regions such as Tunisia for greenhouses cooling. During the experimental period the maximum quantity of heat transferred to the ground by the CBGHE is about 8 kW. The maximum average temperature difference between the inlet and outlet CBGHE system is approximately 30 °C, with measured mass flow rate of 0.08 kg/s. The air temperature inside the greenhouse decreased of about 12 °C.

After the stabilization of the CBGHE system, the performances coefficients of the geothermal heat pump (COP_{hp}) and the overall system (COP_{sys}) are 3.9 and 2.82, respectively.

1. Introduction

Tunisia has a Mediterranean climate, its hot dry summer lasts from May until October. Indeed Tunis receives an average solar energy of 4 kW h m^{-2} day^{-1} with a total insulation period of 3500 h year^{-1} and 350 sunny days per year [1]. Therefore, the crop thermal comfort under greenhouses requires usually a cooling system during summer in order to establish an optimum vegetation growth condition [2]. Whereas, cooling greenhouses requires a high level of energy, so to reduce energy costs, available renewable energy should be utilized as much as possible. The form of renewable energy that seems to be very adapted in cooling greenhouses is the geothermal energy. Geothermal energy is stored as heat under the earth's surface and is available everywhere. It is one of numerous renewable energy that could be very useful in farming and agriculture production thanks to its low cost. The exploitation of the geothermal surface energy usually requires the use of a geothermal heat pump (GHP). In literature, there are a great number of studies which deal with the ground source heat pump systems in both experimental and numerical devices.

An energy analysis of geothermal heat pump is presented by Michopoulos and Kyriakis [3] in which they stated that 0.03% of the energy exchanged in the ground heat exchanger and 1.13% of the electricity consumption are consistent and independent of the chosen operation time.

Ghosal and Tiwari [4] used successfully an air-earth heat exchanger (EAHE) for greenhouse cooling and heating and studied the stored thermal energy into the ground in India.

Seung-Hwan and Joong Yong [5] used Surplus Air Thermal Energy (SATE) for greenhouse cooling and heating. The experimental measurement, conducted between January and March, proves that the COP of the heat pump system is between 2.91 and 3.16. Berdal et al. [6] studied experimentally and numerically the system combining a reversible geothermal heat pump with thermal solar collectors for building heating and cooling and for domestic hot water production. The proposed system was installed in a residence of 180 m^2. Louis et al. [7] developed an analytical solution which gives very similar results compared with numerical values reported in the literature. Urchueguía et al. [8] performed an experimental comparison between a geothermal heat pump system and a conventional air/water heat pump system in order to compare their performance in an area of 250 m^2 heating. Comparing the two systems, the authors found that for full season, the geothermal system will save 43% of the energy consumed by the conventional system

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Nomenclature

A	surface area (m^2)
cop	coefficient of performance
C_p	specific heat of water at constant pressure (J/kg K)
f	frequency (s^{-1})
G	horizontal global solar radiation ($W\,m^{-12}$)
H	enthalpy (J/kg)
h	heat transfer coefficient ($W\,m^{-12}$ K)
I	solar radiation on horizontal surface ($W\,m^{-12}$ h)
$\dot{m}$	mass flow rate (kg/s)
q	heat flux of density ($W\,m^{-12}$)
Q	heat rate (W)
r	radius (m)
t	time (s)
T	temperature (°C)
u	velocity (m/s)
U	overall heat transfer coefficient ($W\,m^{-12}$ °C)
w	power consumption (W)
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 ($W\,m^{-1}$ K)
ρ	density (kg/m^3)
ε	emissivity
σ	Stefan–Boltzmann constant ($5.67010^{-8}\,W\,m^{-12}\,K^4$)
a	thermal diffusivity (m^2/s)
ρ_{albdo}	coefficient albedo of the soil surface
w	pulsation (rad/s)
τ	phase shift

Subscript

a	ambient
s	soil
g	ground
in	inlet
out	outlet
sky	sky
m	average temperature over the year (°C)
hp	heat pump
sys	system
GR	greenhouse
$comp$	compressor
cp	circulation pump

Abbreviations

GHE	ground heat exchanger
CBGHE	conic basket geothermal heat exchanger
GSHP	ground source heat pump

in heating season and 37% in cooling season. Naili et al. [1,9,10] studied the performance of ground source heat pump system in building cooling. They evaluated the influence of different parameters on the ground heat exchanger performance. Their obtained results show that, for cooling mode, the COP_{hp} and COP_{sys} are about 4.25 and 2.88, respectively.

Kozai [11] used the ground water at 14 °C as a source of waste energy for a system of water pump of 87 kW cooling capacity, used to heat a commercial greenhouse area of 333 m^2. A minimum air temperature of 12 °C during the night was maintained in the greenhouse used for the carnation production. The COP is between 1.76 and 2.16. Fuel consumption was reduced by 50%. Adaro et al. [12] used a low-temperature geothermal source, which provides ground water at 28 °C, in order to heat 1000 m^2 of greenhouse surface. They stated that the average air temperature under greenhouse is about 19 °C for an average ambient temperature of 16 °C. Predrag et al. [13] showed that geothermal energy can be used for heating and that there are two systems for its utilization: the direct and indirect system. Benli et al. [14] developed and constructed a system of geothermal heat pump with a latent heat storage. They found that the heat pump coefficients of performance vary between 2.3 and 3.8. Concerning the COP_{sys} it is between 2 and 3.5. For greenhouse cooling, Ahmet et al. [15] have established an experimental system composed by a solar photovoltaic panel and a soil-air heat exchanger. They found that the difference between the inlet and outlet temperature of the heat exchanger is about 8 °C.

In another study, Ahmet et al. [16] evaluated the exergetic performance of an air-earth heat exchanger (EAHE) coupled with a photovoltaic cell solar photovoltaic cell (PV) for reducing electric power consumption. They found that the average exergetic efficiency of the heat exchanger is about 56.3% while the exergetic efficiency of the solar photovoltaic cell is about 4.94%. Omid et al. [17] developed a numerical study which simulates the heat exchange between a geothermal pile and its surrounding ground. A sensitivity study is performed to identify key parameters that can significantly affect the difference between the initial soil temperature and the temperature of fluid flow.

In the open literature, there are many studies which deal with ground source heat pump (GSHP) system with different configurations. Unfortunately, in Tunisia the test of the GSHP system is limited to horizontal one.

This paper makes a first attempt to evaluate the experimental thermal performance of conic basket heat exchanger for cooling greenhouse purpose in Tunisia.

The experimental set-up consists, of parallel coil, implanted in 3 meter of depth, coupled with geothermal heat pump. The results obtained during experience prove that the CBGHE system is a promising solution to reduce the energy consumption in greenhouses cooling.

2. Experimental set-up

2.1. Description of materials

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 essentially consists of three components: (i) geothermal Heat pump HP, (ii) conic basket geothermal heat exchanger and (iii) two greenhouses oriented East West (Fig. 1).

(i) The geothermal heat pump HP unit utilized is a reversible water-to-water Ageo CIAT type, which is considered as an individual heater and cooling system (Fig. 2). The characteristics of the heat pump (HP) are regrouped in Table 1.
(ii) Two Conic Basket Geothermal Heat Exchanger (CBGHE) represented in Fig. 3, installed vertically at 3 m depth in the ground. The heat exchangers are designed and realized in the Thermal Processes Laboratory, their characteristics are given in Table 2. The CBGHE are made up of 23 coils. The distance between the two conic basket heat exchangers is 4 m (Fig. 4).
(iii) A chapel greenhouses with the dimensions 1.5 m wide, 2.5 m long and 2 m high m in the center, as show in (Fig. 5). To evaluate the performance of the installed geothermal system for greenhouse cooling, one greenhouse is equipped with a