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A performance of a heat pump system connected a new conic helicoidal geothermal heat exchanger for a greenhouse heating in the north of Tunisia

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ABSTRACT

The aim of this experimental study is made to examine the performance of a new conic helicoidal geothermal heat exchanger (CHGHE) for greenhouse heating. The main advantage of this geometry of heat exchangers type is to reduce the used area and the operating cost compared to horizontal and vertical, respectively. An experimental study is composed of CHGHE implanted in 3 m depth connected to a geothermal heat pump which is connected to a ceiling panel installed into a greenhouse. This ceiling unit is constituted of an exchangers suspended in internal air and others placed on the ground. This conditioning system allowed a recover the energy in excess into the greenhouse during the day by the exchangers placed on the ground, or, this energy stored is brought back to heat the air in the greenhouse by the suspended exchangers during the night. The experimental results showed that the recovered heat rate from the ground by the CHGHE is about 4.7 kW. However, they are between 12 kW and 10 kW in into greenhouse. The coefficient of the performance of the heat pump (COPhp) and the overall system (COPsys) were found to be 3.93 and 2.64 respectively. The geothermal system insure a quantity of heat equal to 692.208 kW witch correspond to a temperature increasing of 3 °C under greenhouse for an optimal water flow rate of 0.6 kg/s.

1. Introduction

In Tunisia, greenhouse areas increased from 4600 to 8683 ha (Bouadila et al., 2014). They face exaggerated cooling problems during the winter at night. Therefore, a consumption of fossil fuels used for greenhouse heating has risen (Yang and Rhee, 2013). The use of renewable energy is an important idea. Several research works are made to resolve this problem. Indeed, Ozgener and Hepbasli (2005) and Ozgener (2010), conducted several studies which aim to condition the greenhouse. They determined experimentally the average rate of heat extraction from the soil by a geothermal heat pump coupled to a solar collector for greenhouses heating. They found that the heat extraction rate is equal to 57.78 W/m. In another study, Ozgener and Ozgener (2010) used a buried galvanized pipe for tunnel greenhouse heating. They showed that the average extracted heat from the ground is 3.77 kW and the minimum diurnal air temperature under the greenhouse is about 13 °C. Benli (2011) and Benli and Durmuş (2009) proposes a special technique for air greenhouse heating. In this study, they used a ground-source heat pump heating system with a latent heat thermal storage tank. They found that the heat pump allows an increase of temperature from 5 °C to 10 °C. The average of the coefficient of performances of the heat pump and the global system were 4.2 and 4 respectively. In another study, Benli (2013) studied experimentally the comparison between horizontal and vertical ground-source heat pump exchangers for greenhouse heating. The results indicate that the vertical system (HGHE) is more efficient than the horizontal system (VGHE). Indeed, they found that the COP of the HGHE and the VGHE system vary between 3.1–3.6 and 3.2–3.8, respectively. In a study conducted by Hussain et al. (2016) concentrated photovoltaic thermal (CPVT) systems for greenhouse heating. In their study, a comparison between experimental and numerical results was done. The average efficiencies of the CPVT system were found to be 76%, and the heat loss value was 1.74. Noorollahi et al. (2016) investigated the thermal performance of a GSHP system for supplying the energy needs of a greenhouse heating and cooling. Based on an economic analysis with these two operations and initial costs. In their study carried out the GSHP system are reported to be more efficient and competitive compared with conventional greenhouse energy suppliers. To minimize the fuel heating consumption, Kondili and Kaldellis (2006) did an optimal design of geothermal greenhouses. Aranzaba et al. (2016) investigated 3D numerical simulations a determine the thermal characteristics of surrounding geological layers of a geothermal heat exchanger. Hein et al. (2016) conducted a numerical study on the sustainability and efficiency of borehole heat exchanger coupled ground source heat pump systems.

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Nomenclature

COP	coefficient of performance
C_p	specific heat of water at constant pressure, $J\,kg^{-1}K^{-1}$
$\dot{m}$	mass flow rate, $kg{\cdot}s^{-1}$
Q	heat exchange rate, W
T	Temperature, °C

Subscript

a	ambient
s	soil
g	ground
in	inlet
out	outlet
hp	heat pump
sys	system
GR	greenhouse
comp	compressor
cp	circulation pump

Abbreviations

GHE	ground heat exchanger
CHGHE	conic helicoidal geothermal heat exchanger
GSHP	ground source heat pump

In Laboratory of Thermal Process (LPT) of the Research and Technology Center of Energy CRTEn, Researchers conducted many works concerning greenhouse conditioning. Indeed, without heating system the nocturnal interior air temperature and relative humidity under greenhouse during the cold period (from December to March) are uncomfortable to the growth of the plant (Lazaar et al., 2004). For a plant of tomato, it is necessary to maintain the temperature 12 °C at night. Lazaar et al. (2004, 2008) used a polypropylene capillary heat exchanger for heating autonomously of tunnel greenhouse. Bouadila et al. (2013, 2014) and Lazaar et al. (2015), studied experimentally the performance of solar air collector with latent energy storage for chapel greenhouse heating. They show that this system recovered 31% of the required amount of heat at night. Attar and Farhat (2015) and Attar et al. (2013, 2014) used a flat plat collector and storage tank capillary heat exchangers. This system is used to control the greenhouse climate in Tunisia. They found that the excess of energy in the soil inside of the greenhouse has increased the air temperature by 6 °C during typical nights of December to February. Boughanmi et al. (2015, 2017) conducted a study that aims to study the performance of conic geothermal heat exchanger coupled to a geothermal heat pump for greenhouse heating and cooling.

For this purpose, several researches are carried out in geothermal systems for heating applications using, simple technology and low operating expenses. Generally, in order to exploit their energy (GHE), it can be distinguished two main types of heat exchangers which are buried in the ground horizontal design (Naili et al., 2016) and the vertical one (Gonzalez et al., 2012). On the other hand, new geometry of GHE is recently studied as called the helicoidal GHE. However, few numerical research are found (Fujii et al., 2013; Chong et al., 2013; Zhang et al., 2015) which studied a different configuration of GHE including slinky tube, linear single tube and helical tube. They found that the ground heat exchanger depends on the soil and climate conditions. The authors concluded that the heat transfer has a better efficiency than the other types of exchanges. Several researchers begin to focus their investigations on spiral-coil. Lee et al. (2015), Xiong et al. (2015) and Congedo et al. (2012) and evaluate the impact of several factors of the horizontal GHEs such as slinky type, linear single pipe and spiral-coil type. This study allowed that the spiral coil of the GHES is the most efficient one as well as some shallow and cheap solutions as geothermal conics can help to reduce investment costs. In this case Tinti et al. (2017) presents a combination of different technologies Ground Source Heat Pump (GSHP) coupled to geothermal conics with an Air Source Heat Pump (ASHP). He found that the system (operation of GSHP and ASHP) allows energy savings compared to the stand-alone ASHP on the effective energy needs and the ambient conditions with different impact per day.

This study is a contribution to resolve the problem of exaggerated cooling of the greenhouse at night. It aims to evaluate the performance of a novel conic helicoidal heat exchanger coupled with a geothermal heat pump for greenhouse heating under Tunisian climate. The experimental set-up is described in Section 2. A thermal analysis of the GSHP system is carried out in Section 3. We will present in Section 4, the experimental results and summary and comparison of the results. Finally, the main remarks of this study will be reported in the conclusion.

2. Experimental set-up

In this study, we describe the characteristics of the various components of the heating of greenhouses chapel type using the geothermal system. The main components of the experimental device are composed of two chapel greenhouses, a geothermal heat pump, a heat exchangers and a data acquisition system. They have been installed at the Research and Technology Centre of Energy (CRTEn) of Borj Cedria (North Africa, Tunisia: Latitude 36°43′N and Longitude 10°25′E).

2.1. Description of the experimental greenhouses

A chapel greenhouse occupies a floor area equal to 14.8 m^2 (4 m long, 3.7 m wide) and 3 m high at the center (Fig. 1). The thermal and physical characteristics of the greenhouse are listed in Table 1. The greenhouse structure (wall, roof and thickness) are given in Table 2, greenhouses are oriented to East–West.

2.2. Ground source heat pumps

Reversible Geothermal Heat Pump (GHP) water-to-water Ageo type

Fig. 1. Experimental greenhouses.