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Increasing the storage capacity of a solar pond by using solar thermal collectors: Heat extraction and heat supply processes using in-pond heat exchangers

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ABSTRACT

In this study, an experimental investigation of the performance of a salinity gradient solar pond (SGSP) integrating solar collectors is presented. The SGSP is located in Barcelona (Spain) and has a cylindrical tank 3 m in height and 8 m in diameter with a total area of 50 m^2. For this purpose, four solar thermal collectors (10 m^2) are integrated, as an external source of heat, with the solar pond pilot plant in order to increase the storage capacity and its overall efficiency. The aim of this study is to evaluate heat extraction and heat supply processes from and to the SGSP under different seasonal conditions. Two in-pond heat exchangers are used, a conventional one situated on the bottom of the pond and a second one covering the lateral wall area of the pond. Heat extraction and supply experiments are performed using both heat exchangers individually or both at the same time. The experiments are conducted under two different seasonal temperature conditions: winter (February and March) and summer (July). The variations of the temperature inside the pond during the heat extraction/supply tests are monitored and analyzed. The results have indicated that the use of solar collectors as an extra source of heat for the solar pond led to a 50% increase in the daily efficiency during the cold season tests, while heat extraction only appeared as the best option during the warm season tests. Higher daily efficiency and heat supply results can only be obtained if large amounts of heat are extracted, otherwise, the daily efficiency of the solar pond could decrease. Finally, the solar collectors can be considered a good alternative for avoiding a significant decrease in solar pond temperatures (especially during the cold season), which would not only result in a significant energy storage efficiency improvement but also increase the capacity of the solar pond to supply heat to an external application.

1. Introduction

Heat storage technologies, systems, and applications are currently of great interest in the field of solar energy (Dincer, 2012) due to environmental awareness of climate change and the need to minimize the dependence on non-renewable fuels (Bozkurt and Karakilcik, 2012). Solar ponds and collectors are very important solar energy systems that generate heat energy from solar energy. A salinity gradient solar pond (SGSP) is a body of water that typically has three main regions (from top to bottom) (Tabor and Weinberger, 1981; Zangrando, 1980): the upper convective zone (UCZ), the non-convective zone (NCZ), and the lower convective zone (LCZ). The UCZ is a homogeneous area formed by low salinity water. Below it, there is an intermediate zone consisting in a thermally insulating layer that contains several layers of different density such that the layers near the bottom area are more saline than those near the surface zone. This salinity gradient prevents the occurrence of convection currents and, as a result of solar energy absorption, a gradient of temperature is also established. This NCZ is the key feature of the solar pond technology. The LCZ is a homogeneous area with the highest salinity: near to saturation. In this zone, solar energy is absorbed and stored.

Solar ponds have been investigated during the last five decades and research efforts have been directed to improve their efficiency (Akbarzadeh et al., 2009; Andrews and Akbarzadeh, 2005; Bozkurt and Karakilcik, 2012; Ganguly et al., 2017; Kumar and Rosen, 2011; Leblanc et al., 2011; Yaakob et al., 2011). Recently, it has been

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Nomenclature

Acronyms

SGSP	Salinity Gradient Solar Pond
UCZ	Upper Convective Zone
NCZ	Non-Convective Zone
LCZ	Low Convective Zone
LHS	Lateral Heat Supply
BHS	Bottom Heat Supply
LHE	Lateral Heat Extraction
BHE	bottom Heat Extraction

General signs

T	temperature
Q	heat
A	area
H	radiation
ΔE	energy change
$\dot{m}$	mass flow rate

Subscripts

SC	solar collectors
SP	solar pond
stored	stored in the system
ext	extracted from the system
sup	supplied to the system
balance	variables measured by the sensors
bottom	variable referred to the bottom heat exchanger
lateral	variable referred to the lateral heat exchanger
in	input water flow to the heat exchanger
out	output water flow from the heat exchanger

Greek characters

Δ	increment
η	efficiency
τ	time period
τ	daily

proposed to extract the absorbed solar energy by simultaneously extracting heat from the LCZ and NCZ to increase the efficiency of the solar pond (Alcaraz et al., 2016; Andrews and Akbarzadeh, 2005; Date et al., 2013; Leblanc et al., 2011; Yaakob et al., 2011). It has been demonstrated that heat extraction from the NCZ improves the overall efficiency of the solar pond compared to conventional heat extraction from the LCZ. The main advantage of solar ponds is their long-term thermal energy storage capability, which can supply sufficient heat along the entire year. The idea of using solar ponds as a thermal energy storage system has been proposed in recent years (Singh et al., 2012, 2013, 2014). However, few studies have been devoted to increasing the solar pond performance by coupling solar pond technology with any external source of heat. Also limited studies have reported the integration of a solar pond with solar collectors, i.e., Bozkurt and Karakilcik (2012) evaluated the integration of a cylindrical solar pond with a radius of 0.8 m and a depth of 2 m and solar collectors. The system energy balance analysis concluded that energy efficiency was slightly higher when the solar collectors are used, moreover allowed storing more thermal energy in the LCZ and the performance of the integrated solar pond depended upon the total radiation reaching its zones and collector's surface.

Ganguly et al. (2017, 2018) also studied the addition of heat from an external source by using Evacuated Tube Solar Collector (ETSC). The addition of external heat proved to enhance both the heat extraction and thermal efficiency of a solar pond but with certain constraints, e.g., it is necessary to prevent the heat loss from the LCZ by extracting more heat from the LCZ. In our previous studies, the solar pond pilot plant construction, the establishment of the salinity gradient and a numerical model based on the energy balance of the solar pond have been reported (Bernad et al., 2013; Valderrama et al., 2011). The evaluation of an alternative system of heat extraction to enhance the thermal efficiency of the system has recently been proposed, with this purpose, an in-pond heat exchanger covering the pond wall (NCZ & LCZ) has been used and compared with the traditional heat-extraction method using an in-pond heat exchanger placed at the bottom of the pond (Alcaraz et al., 2016). In view of state of the art and taking into account our preliminary knowledge, it is proposed to experimentally evaluate the solar pond pilot plant storage capacity by integrating an external source of heat and to analyze its impact on the energy efficiency of the system.

The aim of this study is to increase the solar pond performance of a 50-m^2 pilot plant by using an external source of heat (10-m^2 of solar collectors) in order to benefit from the storage capacity of the solar

Fig. 1. Solar pond pilot plant in Martorell: (a) the solar thermal collectors used in the heat supply experiments and (b) cooler system used in the heat extraction test.