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Exergy analysis of a solar pond integrated with solar collector

Ismail Bozkurt [a,*], Mehmet Karakilcik [b]

[a] Department of Mechanical Engineering, Faculty of Engineering, University of Adiyaman, Adiyaman 02040, Turkey
[b] Department of Physics, Faculty of Sciences and Letters, University of Cukurova, Adana 01330, Turkey

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Abstract

In this paper we present the energetic and exergetic performance of a solar pond integrated with four flat plate solar collectors. The integrated solar pond system was built and tested at Cukurova University in Adana, Turkey. The solar pond consists of salty water zones to prevent convection heat losses from the heat storage zone (HSZ) of the solar pond. The temperature distributions of the solar pond and the inlet–outlet of the heat exchanger were measured by using thermocouples and a data acquisition device. An energy and exergy models were developed to study the energetic and exergetic performance of the integrated solar pond. The energy and exergy performances were compared for the each zone of the solar pond. The reference environment temperature in the exergy analysis was specified as the average representative temperature of each month of the year. The energetic and exergetic performances of the integrated solar pond for the heat storage zone were found to be maximum 32.55% and 28.69% in August, and to be minimum 9.48% and 5.51% in January, respectively.

Keywords: Solar energy; Integrated solar pond; Energetic and exergetic analyses

1. Introduction

Solar energy is considered a key source for the future, not only for Turkey, but also for all over the world. Therefore, the development and usage of solar energy systems are increasingly becoming vital for sustainable economic development (Cetin and Egrican, 2011). One of the useful solar energy systems is solar pond. Its main advantage is to prevent convection heat losses by dissolving salt into the bottom layer of this pond, making it too heavy to rise to the surface, even when hot (Dincer and Rosen, 2011).

Due to the high solar energy potential in Turkey, solar thermal applications are interesting options for the future energy demand. Therefore, solar thermal systems may be an important option for the supply of the energy demand. Experimental and theoretical temperature distributions, performance analysis of the inner zones and exergy analysis were investigated for different dimensions solar ponds by Karakilcik et al. (2006a,b); Karakilcik and Dincer (2008); Karakilcik et al. (2013a). Recently published studies provide detailed analysis and assessments of energy performance of solar pond (Kurt et al., 2006a; Kurt and Özkaymak, 2006b; Dah et al., 2010; Karim et al., 2010; Saleh et al., 2011; Karim et al., 2011; Sakhrieh and Al-Salaymeh, 2013; Bozkurt et al., 2014). Some experimental and theoretical studies were investigated about integrated solar pond with different applications (El-Sebaii, 2005; Velmurugan and Srithar, 2007; El-Sebaii et al., 2008; Akbarzadeh et al., 2009; Velmurugan et al., 2009; Singh et al., 2011). Integrating solar pond with collector system

* Corresponding author.
E-mail addresses: ismail_bozkurt44@yahoo.com (I. Bozkurt), kkilcik@cu.edu.tr (M. Karakilcik).

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Nomenclature

A	surface area (m^2)
C	specific heat (J/kg K)
E	the amount of solar energy reaching to the pond (MJ/m^2)
F	absorbed energy fraction at a region of δ-thickness
h	solar radiation ratio
HSZ	heat storage zone
k	thermal conductivity (W/m °C)
m	mass (kg)
NCZ	non-convective zone
Q	heat (J)
s	salinity (g/kg)
T	temperature (K)
UCZ	upper convective zone
Greek Letters	
η	energy efficiency
Ξ	exergy (J)
δ	thickness where long wave solar energy is absorbed (m)
α	emissivity of the absorber surface of the flat plate collector
β	incident beam entering rate into water
θ	angle (rad)
ρ	density (kg/m^3)
T	transmission coefficient of the collector surface
ψ	exergy efficiency
Subscripts	
dest	destruction
dw	down wall
fpc	flat plate collector
i	incident
in	energy input
m	mean
out	energy output
r	refraction
solar	solar energy
st	heat stored inner zones of the pond
sw	side wall
up	just above zone

was studied to increase solar pond performance by Bozkurt and Karakilcik (2012). There are very little experimental and theoretical investigations on exergetic performance analysis of the solar ponds through exergy efficiency. The investigation of exergetic performance analysis of the solar pond and comparison with the corresponding energy efficiencies during the months of the year becomes the first work in this area (Karakilcik and Dincer, 2008). Furthermore, the dynamic exergetic performance assessment, through exergy efficiency of the integrated solar pond was studied according to the number of collectors by Karakilcik et al. (2013b).

The objective of the paper is to point out the energetic and exergetic performance assessment on the integrated solar pond during the year. For the experimental study, an integrated solar pond was constructed at Cukurova University in Adana, Turkey (i.e., 35°18′ E longitude, 37°05′ N latitude). The energetic and exergetic performance of the solar pond was increased by using four flat plate solar collectors. The heat energy which was obtained from four flat plate solar collectors was transferred to the heat storage zone of the solar pond by using a heat exchanger system. The energetic and exergetic performance of the integrated solar pond were determined and compared.

2. Integrated solar pond system

There are some differences between an ordinary pond or lake and a salt gradient solar pond. When solar energy is absorbed by an ordinary pond, water in the lower parts of the pond becomes warmer and rises to the surface of the pond, where it loses the absorbed heat to the ambient. In solar ponds, this phenomenon is inhibited by dissolving salt into lower parts of pond, making them heavier and keeps them from rising to the surface, even when the bottom water layer is hot (Dehghan et al., 2013). The integrated solar pond consists of a solar pond and four flat plate solar collectors. There are three zones in the solar pond. The bottom of the solar pond is filled with saturated salty water. This zone is called as Heat Storage Zone (HSZ). Afterward, the salty water layers whose brine density gradually decreases towards Upper Convective Zone (UCZ) are formed. This zone is called as Non-Convective Zone (NCZ). NCZ consists of four different density layers. NCZ is a transparent insulation zone to allow an extensive amount of solar radiation to penetrate into the storage zone while inhibiting the propagation of long-wave solar radiation from escaping because water is opaque to infrared radiation. Then the last zone UCZ is created with fresh water at the top of the pond. This zone provides the cleanliness of the pond and filling the lost water due to evaporation.

For the experimental study, an integrated solar pond consisting of the cylindrical solar pond, heat exchanger and four solar collectors were constructed as seen in Fig. 1. The solar pond has a radius of 0.80 m and a depth of 2 m. The conventional flat plate solar collector has dimensions of 1.90 m × 0.90 m. The thicknesses of the zones are 0.2, 0.8, 1 m for UCZ, NCZ and HSZ, respectively. The range of density is 1000–1030 kg/m^3 in UCZ,