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Exergetic performance analysis of a salinity gradient solar pond

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ABSTRACT

Solar pond technology is an effective and most economical way for converting and storing the solar heat energy. In this paper, numerical and experimental studies have been conducted for investigating the energy/exergy distributions and also efficiencies in the inner zones of a circular solar pond. For this purpose, a small scale solar pond with a circular cross-section was built and tested in Urmia University in Urmia-Iran. The height and area of the solar pond were equal to 1.1 m and 4 m^2, respectively. In the small solar ponds, the shading walls affects the accumulation of solar energy and thermal energy storage. Therefore, for achieving a complete understanding of the energy performance in the small solar ponds, a shading model is also developed for circular solar ponds. Therefore, by using the proper relations and considering the shading effect, energy and exergy efficiencies were analyzed in the inner zones of the pond. For lower convective zone, the highest energy and exergy efficiencies were obtained in the month of June and were equal to 9.37% and 0.76%, respectively. The results confirmed that most of the thermal energy is stored in the lower convective zone and it can be used in various applications.

1. Introduction

Limited sources and increasing prices of fossil energy, environmental pollutant emissions and energy supply security clarify the essence of paying more attention to the renewable energies. For achieving diverse energy resources, reducing the dependence on an energy carrier and also according to the environmental considerations, many developed and developing countries concentrate their attention to the renewable energy sources (solar, wind, geothermal, biomass, etc.) in recent years (Sukhatme and Sukhatme, 1996). Using the renewable energies and environmentally friendly methods for producing electricity are the priorities of the developed countries. Nowadays, solar energy has the greatest potential to meet the world's needs as a source of renewable energy in the future (Mekhilef et al., 2011).

So far, a variety of technologies have been offered for the conversion of the solar thermal energy into the usable energy. Absorbing and storing the solar energy is the most important matter in this field. Different collectors can be used for absorbing the solar energy for different purposes such as power generation, desalination, water heating, space heating and etc. A solar pond is a low cost solar collector for collecting and storing the thermal energy for a long period of time (Swift et al., 1987).

Solar ponds are divided into two general types, convective shallow ponds and non-convective ponds (El-Sebaii et al., 2011). The most important type of non-convecting deep ponds is the salt gradient ponds.

The salt gradient solar pond (SGSP) is a stable artificial pond of salt water, in which the salt concentration gradient increases through the depth of the pond (Munoz and Almanza, 1992). The solar radiation is absorbed as heat energy and stored for a long time. The salt gradient solar pond is comprised of three layers; upper convective zone (UCZ), non-convective middle zone (NCZ) and lower convective zone (LCZ). In the UCZ layer, the salt concentration is homogeneous and convective heat transfer is occurred, the temperature is approximately equal to the ambient temperature and the salinity is about the sea water salinity (3.3 wt%). NCZ layer is a gradient type layer with conductive heat transfer. The saline density and temperature increase quasi-linearly to achieve the maximum level, hence the convection is not possible and the heat transfer is done through conduction. LCZ layer is the storage layer with the densest and uniform salinity close to saline saturation. The thickness of the LCZ layer is variable and can be up to 2 m. The LCZ temperature is dependent on various factors such as the thickness of the LCZ, radiation intensity, NCZ thickness, ambient temperature and stability of salt gradient.

In recent decades, several studies have been conducted experimentally and numerically to analyze the performance of solar ponds and understand their functional mechanisms. The experimental studies have been mainly focused on constructing, utilizing and measuring the temperature and density of solar ponds (Nakoa et al., 2015; WU et al., 2013; Nie et al., 2011; Sakhrieh and Al-Salaymeh, 2013; Wang et al., 2014; Farahbod et al., 2013), while the heat analyze of solar ponds subjected to different conditions using proper mathematical models is investigated in the numerical studies (Chiasson et al., 2000; Shah et al.,

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Nomenclature

UCZ	upper convective zone
NCZ	non-convective zone
LCZ	lower convective zone
Q_{solar}	the radiation energy reaching and absorbing in each zone (W/m^2)
Q_{cond}	conductive heat transfer (W/m^2)
A	total surface area of the layer (m^2)
A_e	the sunny or effective radiation area
A_{sh}	the shaded area
C_p	heat capacity of water (kJ/kg°K)
k	thermal conductivity of water (W/m°K)
m	mass of the pond water (kg)
I	solar radiation reaching the pond surface (W/m^2)
I_0	solar radiation entering to the pond surface (W/m^2)
$h(x)$	fraction of solar radiation that reaches a depth x (W/m^2)
R	reflection coefficient
E	energy (W)
X	exergy (W)
r	radius of the circular pond (m)
X_{ucz}	thickness of the UCZ layer (m)
X_{ncz}	thickness of the NCZ layer (m)
X_{lcz}	thickness of the LCZ layer (m)
x	depth in solar ponds (m)
T	temperature (°K)
T_0	atmospheric temperature (°K)
T_{sun}	sun's surface temperature (°K)
t	time (s)
n	index of refraction

Greek symbols

η	energy efficiency
ψ	exergy efficiency
θ_i	angle of incidence
θ_r	angle of refraction
ρ	density (kg/m^3)
$\Delta\tau$	time intervals
Ψ	Petela expression
ξ	the fraction of beam radiation

1981; Ali, 1989, 1986; Sayer et al., 2016; Ding et al., 2016; Monjezi and Campbell, 2016; Bernad et al., 2013; Mansour et al. 2006; Boudhiaf and Baccar, 2014). According to the many simplifications in the offered analytical solutions, the obtained results are not in good agreement with experimental results and thus can not to be used (Kurt et al., 2000). In contrast, the numerical methods have the potential to predict the thermal behavior of the ponds accurately with the appropriate initial and boundary conditions.

Several numerical models have been introduced for simulating the heat transfer mechanism and energy storage in the solar ponds using finite difference method. Hull (1980), Hawlader and Brinkworth (1980), and Rubin et al. (1984) proposed some primary models of finite difference for modelling the solar ponds. In recent years, Karakilcik et al. (2006) and Kurt et al. (2006) developed the finite difference model to predict the temperature distribution in solar ponds layer by layer. Suárez et al. (2010) used the finite volume discretisation to evaluate the solar ponds performance.

In fact, several issues associated with long-term working, maintenance, and measuring the required data for analyzing the thermal performance of the ponds have been offered by researchers. From the thermodynamic perspective, the conversion efficiency of solar energy to heat, the temperature distribution, the heat transfer between the different layers and heat losses from the pond have remained the main research areas. Thus, for better understanding of the heat transfer mechanism in the solar pond, a number of studies have focused on the ponds thermodynamics (El-Sebaii et al., 2013; Leblanc et al., 2011). The offered thermodynamical models were based on the principles of energy conservation, i.e., the First Law of Thermodynamics, to predict and improve the performance of the solar ponds.

The calculation of the energy transfer and losses are known as energy analysis. On the other hand, along with energy analysis, exergy analysis based on the Second Law of Thermodynamics is proposed as a useful tool for designing an efficient energy system with reduced irreversibility in the system and processes. In addition, energy and exergy analysis are the complementary tools of thermodynamics.

Many studies have focused on the exergy analysis of the thermal power plants and other engineering heating systems (Saidur et al., 2012), however applying exergy analysis for solar energy applications, particularly solar ponds, is still in the early stages of research. To the best of our knowledge, only a few cases have been provided in the field of exergetic efficiency of solar ponds. However, unfortunately some improper relations have been used in those papers (Khalilian, 2016a,b).

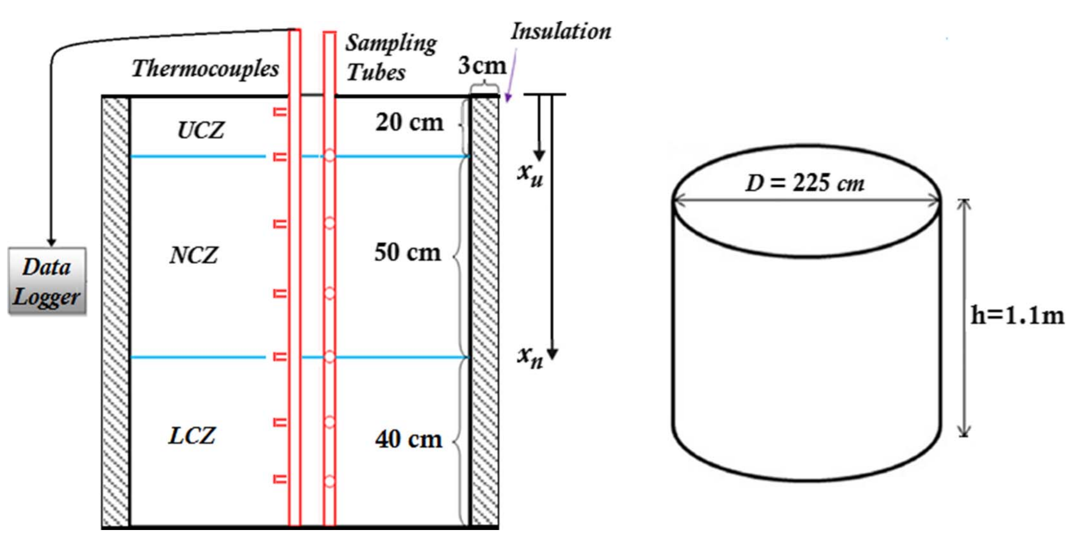

Fig. 1. Schematic deign and dimension of solar pond.