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Performance assessment of a magnesium chloride saturated solar pond

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ABSTRACT

This paper deals with the experimental investigation of a magnesium chloride saturated solar pond and its performance evaluation through energy and exergy efficiencies. The solar pond system is filled with magnesium chloride containing water to form layers with varying densities. A solar pond generally consists of three zones, and the densities of these zones increase from the top convective zone to the bottom storage zone. The incoming solar radiation is absorbed by salty water (with magnesium chloride) which eventually increases the temperature of the storage zone. The high-temperature salty water at the bottom of the solar pond remains much denser than the salty water in the upper layers. Thus, the convective heat losses are prevented by gradient layers. The experimental temperature changes of the solar pond are measured by using thermocouples from August to November. The densities of the layers are also measured and analysed by taking samples from at the same point of the temperature sensors. The energy and exergy content distributions are determined for the heat storage zone and the non-convective zone. The maximum exergy destructions and losses appear to be 79.05 MJ for the heat storage zone and 175.01 MJ for the non-convective zone in August. The energy and exergy efficiencies of the solar pond are defined as a function of solar radiation and temperatures. As a result, the maximum energy and exergy efficiencies are found to be 27.41% and 26.04% for the heat storage zone, 19.71% and 17.45% for the non-convective zone in August, respectively.

1. Introduction

Renewable energy resources and technologies have a key role to play in meeting current and future energy needs. They cause less environmental impact than the conventional energy sources [1]. Turkey, situated on the sunny belt between 36° N and 42° N latitude, is located in a relatively more advantageous geographical location for harvesting solar energy. Especially, Mediterranean and Aegean Sea coastal zones have very high potential for utilization of solar energy [2]. During the past decades, solar energy sources have gained greater importance to meet the energy demands for various sectors. Solar energy systems have used for several applications like heating water, warming greenhouses, drying, water desalination, power generation and so on. One of these systems is solar pond where the main goal is to heat a large mass of water [3]. In this regard, various studies on solar ponds have been undertaken and their heat transfer and thermodynamic aspects have been investigated by various researchers [4–14]. Singh et al. [15] designed and tested a combined system of thermosyphon and thermoelectric modules for the generation of electricity from low-grade thermal sources like solar pond. Bozkurt and Karakilcik [16] investigated an integrated solar pond where heat collected from the flat-plate solar collector is transferred to the storage zone through a heat exchanger system. The system performance was determined both experimentally and theoretically according to the number of flat-plate collectors. Karakilcik et al. [17] studied a solar pond performance with and without shading effect and comparison of the energy efficiencies of the experimental solar pond. Thus, the shading effect and its ratios were determined to study the efficiency of the solar pond. Most of these studies aimed to investigate the performance of the solar ponds and study the effects of varying

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operating conditions and thermophysical properties on the pond performance. Sodium chloride has been the most commonly used salt in most of these studies. In a few studies, however, magnesium chloride salt has been used. Subhakar and Murthy [18–20] studied saturated solar pond by using magnesium chloride and potassium nitrate salts for the experimental testing and performance assessment. A comparison was also made with an unsaturated solar pond. The temperature and concentration gradients were developed by heating the pond from the bottom and adding finely powdered salt from the top.

Most of the experimental studies presented in the literature focuses on energetic performance evaluation of the ponds. In this study, an experimental magnesium chloride saturated solar pond is constructed, built and employed for experimental investigations, and its performance is investigated and evaluated through energy and exergy efficiencies. Although the energetic performance of the magnesium chloride solar pond was studied previously, the exergetic based analysis and assessment of a magnesium chloride saturated solar pond is the original contribution of this study. Since exergy analysis and assessment provide a true and meaningful picture of the system, we aim to compare the results with the energetic results where the first-law of thermodynamics (based on conservation law) is used. This is in fact the key motivation behind the present work.

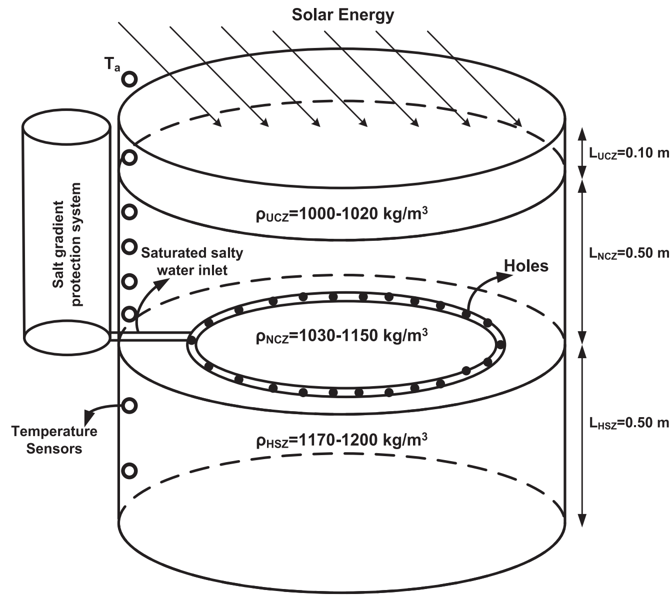

Fig. 1. A schematic representation of the magnesium chloride saturated solar pond.

2. Experimental system and procedure

A solar pond is of various regions as types and sizes. It generally consists of two main regions as outer and inner regions. First, the outer region is called insulation region to prevent the heat losses by conduction from inner region to surrounding of the pond. Second, the inner region is a large body of salty water with a salinity gradient to prevent heat loss by convection. The body of the region generally consists of three zones (e.g., surface zone, middle zone and bottom zone). The surface zone is called as upper convective zone (UCZ). UCZ is the fresh water layer at the top of the pond. The middle zone is called as non-convective zone (NCZ). NCZ is composed of different salty water layers whose density gradually increases toward bottom of the pond. This zone plays a key role in the solar pond because this zone constitutes a transparent insulating layer to prevent convective heat losses from bottom zone to UCZ. In this regard, the size of NCZ is very important to increase the performance of a solar pond so that Husain et al. [21] developed a rational analytical insight for judicious selection of NCZ size considering optimum thermal performance as well as stability aspects. Finally, bottom zone of the pond is composed of salty water with highest density. Thanks to this feature, it is absorbed the solar radiation that reaches the bottom of the pond and converted as heat, and stored as heat storage zone (HSZ).

In this study, an experimental solar pond with the area of 0.72 m^2 and a depth of 1.10 m was built in Cukurova University in Adana, Turkey (i.e., 35°18′ E longitude, 37°05′ N latitude). The pond's bottom and side-wall was insulated by using 0.10 m thickness glass wool. The pond temperature was measured at 7 points, starting from the bottom, at 0.25, 0.40, 0.55, 0.65, 0.75, 0.85 and 1.05 m heights by using thermocouples with an accuracy of about ±1 °C. The pond was filled with the different densities magnesium chloride water to set up the density gradient of the pond in August 2012 and worked.

Fig. 1 shows a schematic representation of the experimental solar pond system that built in salt production system. In the inner region of the pond, the ranges of magnesium chloride water density in UCZ, NCZ and HSZ are 1000–1020 kg/m^3, 1030–1150 kg/m^3 and 1170–1200 kg/m^3, and the thicknesses of the zones are 0.10, 0.50, 0.50 m, respectively. The density distributions are also measured and analysed by taking samples from at the same point of the temperature sensors.

As seen in Fig. 1 the salt gradient protection system is used to protect the density gradient against erosion of the magnesium chloride water in the inner zones of the pond. The protection system was a system based on the natural circulation of water caused by density difference, as it was first proposed by Akbarzadeh and Mac Donalds [22].

3. Energy and exergy analyses

The energy and exergy values of the solar pond are calculated using conservation of mass and energy principles as well as second law analysis. Therefore, in this section, energy and exergy analyses of the solar pond, through the balance equations, are presented. The energy balance equations are useful to know the thermal behaviour of solar ponds. In this study, we focus on both energy and exergy fluxes in HSZ and NCZ, because the useful thermal energy is not stored in UCZ.

3.1. Energy analysis of heat storage zone

The energy balance equation of HSZ is written as follows:

$$Q_{stored} = Q_{solar,HSZ} - Q_{loss,HSZ} = \beta E A_{HSZ}[(1-F)h(x-\delta)] - \left\{ \frac{k_s A}{\Delta x_{HSZ-NCZ}}(T_{HSZ}-T_{NCZ}) + \frac{k_{sw} 2\pi r L_{HSZ}}{\Delta x_{side}}(T_{HSZ}-T_a) + \frac{k_{sw} A}{\Delta x_{down}}(T_{down}-T_a) \right\} \quad (1)$$

where E is the solar energy reaching the surface, A_{HSZ} is the area of the HSZ, F is the fraction of energy absorbed at a region of δ-thickness, h is the solar radiation ratio, A is the surface area, T_a is the air temperature, k_{sw} is the thermal conductivity of the walls, k_s is the thermal conductivity of the salty water, L_{HSZ} is the thickness of the HSZ, r is inner radius of the cylindrical solar pond, Δx_{down} is the thickness of the down wall, Δx_{side} is the thickness of the side wall, $\Delta x_{HSZ\text{-}NCZ}$ is the thickness of the HSZ's middle point and the NCZ's