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Experiment and optimization of mixed medium effect on small-scale salt gradient solar pond

Mohammad Reza Assari [a,*], Hassan Basirat Tabrizi [b], Mohsen Parvar [a], Ali Kavoosi Nejad [a], Alireza Jafar Gholi Beik [a]

[a] Department of Mech. Eng., Jundi Shapur University of Technology, Dezful, Iran
[b] Department of Mech. Eng., Amirkabir University of Technology, Tehran, Iran

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ABSTRACT

Salt gradient solar pond is one of the methods for absorbing and storing solar energy. This study investigates experimentally the performance of mixed medium at the lower convection zone of laboratory scale solar pond. The experiment was carried out in Dezful, Iran. This specific geographical location mainly has a high-level of solar radiation and intense dusty climate. The climatic condition criterion and mixed medium distinguishes the novelty of this research. Data was obtained in 90 days period for the temperature distribution and salinity gradient. For comparison, two similar solar ponds of circular cross section with surface area of 0.51 m^2 and height of 63 cm were designed and built. Two layers of pebble and ball bearing as porous medium were used for one of the solar ponds in the lower convection zone (LCZ). At the end of test period, the temperatures of mixed medium and conventional in the lower convection were obtained at 75 °C and 71 °C, respectively. Therefore, the mixed medium solar pond indicated an increase of 5.6% in temperature. In addition, variation of maximum temperature of the mixed medium pond was less than the conventional LCZ solar pond. Using the mixed medium in the LCZ resulted in more thermal stability and lower temperature drop. However, mixed medium indicated higher thermal resistance and more storage capacity for the pond. Non-dimensional numbers have been introduced for the optimization of this mixed medium condition. A criterion parameter has been obtained for the optimization of the mixed medium in the solar pond.

1. Introduction

Environmental concerns have led to use of solar energy, which is more abundant and applicable. It has the potential to use and store simultaneously during the daytime. Solar ponds are one of the well-known heat storage systems, which accumulate the thermal energy using solar radiation. Salt gradient solar ponds are one of the different types of solar ponds, which can be formed by applying different types of salt, one of the most common ones being sodium chloride.

In fact, salt gradient solar ponds consist of three layers or zones. The first zone is the surface layer with the least salt and thickness, which refers to upper convective zone (UCZ). Then the second zone, which is the middle layer, and refers to the non-convective zone (NCZ). In this layer, saturation increases by the depth and thickness being wider than UCZ. Finally, the lowest layer refers to the lower convective zone (LCZ), which is usually near saturated water. In this layer, the heat is stored. NCZ acts as a thermal insulation for the bottom layer and helps to prevent heat loss. Despite the penetration of solar radiation into the depth, it cannot escape from the zone. Common method for energy removal from a solar pond is heat extraction from lower convective zone (LCZ) through an internal heat exchanger, which can be installed in LCZ.

Andrews and Akbarzadeh (2005) overviewed the solar ponds as one of the methods for collecting absorbing and storing solar energy and evaluated the rise of thermal efficiency of a solar pond by heat extraction from the gradient layer. Ould Dah et al. (2010) undertook an experimental study and numerical research on the heat extraction, efficiency, and performance of a small solar pond. Their study was for heat extraction from NCZ layer. The results indicated considerable improvement; however, it caused reduction in the stability. To indicate some important research over the solar ponds, e.g. Zangrando (1980) proposed a simple method to establish a salt gradient solar pond. This research, investigated the redistribution method for salinity gradient on solar pond. Moreover, El-Sebaii et al. (2011) discussed the history and an overview on the solar ponds. Some authors studied on natural solar ponds, for

* Corresponding author.
E-mail address: mr_assari@yahoo.com (M.R. Assari).

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Nomenclature

C_p	heat capacity (kJ/kg °C)
E	storage heat of energy (kJ)
e	energy per volume (kJ/m^3)
m	mass (kg)
V	volume (m^3)
x	pebbles layer volume fraction
y	ball bearings layer volume fraction

Greek symbol

δ_{total}	total uncertainty
δ_{sensor}	sensor accuracy
$\delta_{instrument}$	instrument accuracy
ΔT	temperature difference (°C)
ρ	density (kg/m^3)
β_{eik}	criterion parameter for indicating which porous material is suitable for energy saving or economically feasible to use

Subscripts

br	brine
pb	pebble
bb	ball bearings
DPSP	dual porous salinity gradient solar pond
MMSP	mixed medium salinity gradient solar pond
LCZ	Lower Convective Zone
NCZ	None Convective Zone
UCZ	Upper Convective Zone

example, Nie et al. (2011) carried out an experimental study of a natural solar pond in Tibet. In their study, maximum temperature of LCZ reached 39.1 °C. Jaefarzadeh (2004) studied the thermal behavior of a salt-saturated small solar pond via the wall shadow. He carried out modeling thermal behavior of small salinity salt gradient solar pond. The analysis shows that wall shading is very important for reducing of LCZ temperature. Many researchers studied the performance of solar ponds. Karakilcik et al. (2013) evaluated the performance of a solar pond with and without the effect of shadow. The results showed that removing of shading area could increase the solar pond storage efficiency. Bozkurt and Karakilcik (2015) studied the effect of sunny area ratios on the thermal performance of solar ponds. They found that increasing the sunny area ratio, caused an increase of solar pond performance, but with an increase of area surface of solar pond performance rate increase was reduced little by little. In addition, some authors studied on clarity and maintaining of solar pond. Valderrama et al. (2011) investigated the energy storage by placing the solar pond on the ground and controlling the salt gradients. In their study, they controlled the clarity with added HCl at different height of pond. Malik et al. (2011) used experimental evaluations to maintain the clarity of a salt gradient solar pond. Therefore, they looked at three solar ponds in Australia. Their research showed that combination methods consisting of chemical and biological treatment methods maintained clarity and improved thermal efficiency of solar pond. Gasulla et al. (2011) worked on maintaining the clarity of salt gradient solar pond. They carried out about two chemical methods against algae consisting of chlorine and a novel chemical product copper ethylamine complex. In a study, Singh et al. (2011) produced electricity by combining two systems of thermosiphon and thermomodule. Further, Singh et al. (2012) produced electricity using the low degree heat of the salt gradient solar pond. Agha et al. (2004) undertook an experiment on mixing the gradient zone of a solar pond and the method was used to explain two types of surface water flushing under the different design conditions. Wang et al. (2011) focused on the linear dynamic behavior of non-convective zone of a salt gradient solar pond in order to obtain better thermal performance and stability. Husain et al. (2012) proposed an innovative design for non-convective zone of a solar pond for maintaining of salinity profile and increasing of temperature a layer between UCZ and NCZ. Sakhrieh and Al-Salaymeh (2013) carried out a numerical study on the solar pond in Jordan. They used Matlab software code for prediction of temperature and compared with their experimental data. Atiz et al. (2014) studied turbidity effect on exergetic performance of solar pond; found that turbidity effect had great effect on performance, and decreases maximum exergy efficiency. Boudhiaf and Baccar (2014) studied on transient hydrodynamic, heat and mass transfer in a salinity gradient solar pond. The problem of double-diffusive natural convection results indicated that internal Rayleigh number and aspect ratio are affected on the solar pond. Sayer et al. (2016) studied theoretical modeling of heat transfer in solar pond and preformed energy balance for each layer using Matlab software. Their model showed that great temperature for solar ponds in summer and winter is in the Middle East region. In addition, heat loss was calculated. It was found that the perimeter of the pond has a great effect on heat loss from small solar pond. Some researchers studied the effect of porous media on solar pond performance and stability. Choubani et al. (2010) investigated the stability of salt gradient saturation in solar ponds in an experiment. They designed a solar pond in laboratory scale and mid-scale in outdoors, carried out quantitative data and dynamic process on solar pond, and found that porous medium could increase the stability of NCZ layer. Shi et al. (2011) studied the effect of porous medium in salt and thermal emission of solar ponds. They performed two different experiments; laboratory and field-test and observed that the porous media in the bottom of solar pond could enhance thermal insulation, with salt diffusion being slow. In the field test, they observed that adding porous media could increase the temperature of LCZ. Wang et al. (2014) investigated temperature distribution of solar pond with added coal cinder to bottom of LCZ layer experimentally and theoretically. Their results indicated an increase in the LCZ temperature. Another experimental studied by Wang et al. (2015) showed the effect of porous medium on salt diffusion of solar pond. Assari et al. (2015) investigated experimentally the effect of solar ponds with and without phase change material. Their results indicated that phase change material decreases thermal efficiency and thermal difference. In addition, it increases the thermal stability on solar pond. Further, Assari et al. (2015) investigated experimentally the effect of geometry, greenhouse condition, and covering effect on the thermal performance of solar ponds. Thus comparing different shapes of solar ponds, their study compares two similar solar ponds with and without porous medium at the same condition. However, most researchers have not investigated the climatic effect with mixed medium solar pond.

In recent years, the climate pattern of the Middle East especially south and southwest of Iran has changed drastically due to global warming. Even though there is significant solar radiation in this region, however, the average sunny hours per day and access to sunlight have been reduced due to dust flow. Therefore, the sunlight is accessible discontinuously. Many days are hazy and the region affected with dust storms in such a way that the direct sunny hours may decrease to one hour or even less. In 2012, the number of dusty days reported was nearly 75 days for the city of