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The effect of sunny area ratios on the thermal performance of solar ponds

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ABSTRACT

In this study, we investigated the effect of the sunny area ratios on thermal efficiency of model solar pond for different cases in Adiyaman, Turkey. For this purpose, we modeled the solar ponds to compute theoretical sunny area ratios of the zones and temperature distributions in order to find the performance of the model solar ponds. Incorporating the finite difference approach, one and two dimensional heat balances were written for inner zones and insulation side walls. Through, careful determination of the dimensions, insulation parameter and incoming solar radiation reaching the storage zone increased the efficiency of the solar pond. The efficiencies of the model solar pond were determined for case1a–2a–3a–4a to be maximum 14.93%, 20.42%, 23.51% and 27.84%, and for case1b–2b–3b–4b to be maximum 12.65%, 16.76%, 21.37% and 23.30% in August, respectively. With the increase of the sunny area ratio, the performance of the solar pond significantly increased. However, with the increasing rate of the surface area, performance increase rate decreased gradually. The results provide a strong perspective to determine the dimensions of the solar pond before starting the project of a solar pond.

1. Introduction

Solar energy is the most important renewable energy source; it has not yet become widely commercial, even in nations with high solar potential such as Turkey [1]. The yearly average solar radiation is 3.6 kW h/m^2 day, and the total yearly radiation period is 2610 h in Turkey [2]. One main factor that limits the application of solar energy is that it is a cyclic, time-dependent energy resource. Therefore, solar energy systems require energy storage to provide energy during the night and overcast periods [3]. One of the thermal energy storage systems is solar pond. Solar pond was discovered as natural phenomena around the turn of the last century in the Medve Lake in Transylvania in Hungary. In this lake, temperatures up to 70 °C were recorded at a depth of 1.32 m at the end of the summer season. Nowadays, mini model solar ponds are also being constructed for various thermal applications [4]. Solar ponds are simple in principle and operation. They are long-lived and require little maintenance. Heat collection and storage are accomplished in the same unit, as in passive solar structures. The ponds need cleaning, like a swimming pool, to keep the water transparent to light. A major advantage of solar ponds is the independence of the system. No backup is needed because the pond's high heat capacity and enormous thermal mass can usually buffer a drop in solar supply that would force a single-dwelling unit to resort to backup heat [5].

Compared with conventional energy, solar energy has many attractive advantages, such as inexhaustibility, cleanness and cheapness. More and more governors, scientists and decision makers have become interested in solar energy utilization systems [6]. Recently, many studies have been conducted on the efficiency of different solar energy applications. The performance of a thermal collector was reported by using synthesized Cu nanoparticles/ethylene glycol as the nanofluid. Comparing with previous works in similar subjects, new method for producing one-step metal nanofluid was used [7]. To obtain more accurate prediction of the annual performance of solar chimney power plants, a comprehensive theoretical model is developed by taking into account the hourly variation of solar radiation [8]. The combined heat transfer in heat exchangers filled with a fluid saturated cellular porous medium was investigated. The flow was modeled by the Darcy–Brinkman equation. The steady state model of this combined heat transfer is solved semi-analytically based on the homotopy perturbation method and numerically based on the finite difference method [9]. A mathematical model that describes the thermal performance of the pond has been developed and solved. The upper layer of the pond is made of mineral oil and the lower layer is made

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Nomenclature

A	area (m^2)
C	heat capacity (J/kg °C)
E	total solar energy reaching to the pond (J)
F	absorbed energy percentage at a region of δ-thickness
h	solar radiation ratio
HSZ	heat storage zone
k	thermal conductivity (J/m °C h)
L	length (m)
LCZ	lower convective zone
m	mass (kg)
n	number of day
NCZ	non-convective zone
s	salinity (g/kg)
t	time
T	temperature (°C)
Q	heat energy (MJ)
UCZ	upper convective zone
y	depth (m)

Greek letters

η	thermal energy efficiency
δ	thickness where the long wave solar radiation is absorbed (m)
β	incident beam entering rate into the water
φ	latitude angle (rad)
χ	ratio
θ	angle (rad)
ρ	density (kg/m^3)
Δx	thickness of horizontal layers (m)
Δy	thickness of vertical layers (m)

Subscripts

a	air
d	declination
dw	down wall
h	hour
i	incident
r	refracted
sa	sunny area
sw	side wall
st	heat stored
s	salty water
sur	surface
sh	shading
up	just above zone
w	wall
wd	width

of nanofluid [10]. Furthermore, we have paid lots of attention to reach solar pond systems. The solar pond energetic or exergetic performance was studied experimentally and theoretically by many researchers [11–21]. Furthermore, an integrated solar pond system has been suggested and developed by Bozkurt and Karakilcik [22]. In the literature, some studies have been undertaken on shading effect in solar ponds by various researchers [23–26]. Some of those determined the thermal performances of the solar pond which are affected due to the shading areas of the side walls. Therefore, many studies are focus on the performance investigation in order to better understand the problems behind low energy efficiencies of the solar pond and various significant aspects, such as side wall shading, incident solar radiations, insulations and the dimensions of the zones are also investigated. Bozkurt et al. [27] used a mathematical model based on finite differences to determine the heat storage performance of the solar pond with a surface area of 2.096 m^2 and a depth of 2.0 m. The heat storage performance of the solar pond was determined theoretically and experimentally. To the authors' best knowledge, no studies have investigated the sunny area ratios of each zone of the solar ponds in different cases, separately.

The effect of the sunny area ratios on thermal efficiency of model solar pond was investigated for different cases in Adiyaman, Turkey. Thermal energy loss were determined for each of the zones of the solar ponds. Present work deals with the investigation of the sunny area ratios through the shading area and its ratios to compare the energy efficiencies for upper convective zone, non-convective zone and heat storage zone as well as determination of the temperature distributions each zones of the model solar ponds.

2. System description

Model solar pond has three zones. The first zone is Upper Convective Zone (UCZ) which filled with fresh water. However, this zone's density gradually increases due to upward salt transport by diffusion, surface evaporation, heating, cooling and wave-action. The second zone is Non-Convective Zone (NCZ) acts as an insulating layer of the pond. The density in NCZ increases with increasing depth of the gradient layers. The third zone is Lower Convective Zone (LCZ) known as Heat Storage Zone (HSZ) at the bottom of the solar pond. This zone is formed by high density salty water which absorbs the solar radiation and converts to useful heat. The heat is usually extracted from this zone by using the heat exchanger. On the other hand, the heat extraction from the Non-Convective Zone was investigated by Date et al. [28]. In that study, the comparison of the transient thermal performance of solar pond with heat extraction from LCZ alone and that with combined heat extraction from LCZ and NCZ were presented. The thicknesses of the zones has key role on the thermal performance of the solar ponds. The performance depends on the temperature and the amount of the thermal energy to be stored [29]. The amount of the solar radiation to reach on the surface area of the zones affects the thermal performance. The vertical walls surrounding of inner zones of the pond cause a shading area. The shading area is defined as the area where solar radiation does not reach. Thus, the incident solar energy on surface of the pond decreases the pond's efficiencies by shading from vertical side walls. Therefore, it is important to understand the shading effect on performance of the solar pond.

The dimensions of the model solar pond was changed from case1a to case4a with the values of the surface area of 1, 4, 9 and 16 m^2, and with the thickness of inner zones 0.90 m, 0.5 m and 0.1 m. It has the same surface areas for case1b to case4b with thickness 1.40 m, 0.5 m and 0.1 m for HSZ, NCZ and UCZ, respectively.

3. Sunny area ratios of inner zones

In this section, we determined the sunny area ratio for different surface and height. The angle of refraction, which is the angle that the refracted ray makes with the normal line, is defined by the Snell law as [30]:

$$\theta_r = \sin^{-1}[1.33\sin(\theta_i)] \tag{1}$$

where θ_i is called incidence angle and is defined as [30]: