Solar Energy 135 (2016) 297–307

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

A comprehensive transient model for the prediction of the temperature distribution in a solar pond under mediterranean conditions

Alireza Abbassi Monjezi *, A.N. Campbell

Department of Chemical and Process Engineering, Faculty of Engineering and Physical Sciences, University of Surrey, Guildford GU2 7XH, UK

ARTICLE INFO

Article history:
Received 13 November 2015
Received in revised form 24 February 2016
Accepted 5 June 2016

Keywords:
Solar pond model
Salinity gradient
Transient heat transfer
Heat storage

ABSTRACT

Salinity gradient solar ponds can be used to store heat by trapping solar radiation. The heat can then be employed to drive various industrial applications that require low-grade heat. In this study, a comprehensive finite difference transient model has been developed incorporating many processes that affect the performance of a solar pond to predict the hourly temperature distribution. The model includes novel approaches to simulation of both the Heat Storage Zone (HSZ) and the Upper Convective Zone (UCZ) where in addition to convective, evaporative and radiative heat losses, the cooling effect of adding freshwater to the surface of the pond is taken into account. The HSZ is treated as one layer, with uniform temperature, in the finite difference method. A solar pond of 100 m^2 surface area is simulated for southern Turkey. The results indicate that, if the operation starts on the first day of June, the HSZ would take 65 days to reach the boiling point while this would be 82 days if the operation commences on the first day of December. The simulations highlight that 41–47 l of freshwater will need to be supplied to the UCZ daily and the associated cooling effect of such addition is approximately 10 times larger than the convective heat loss in the first 65 days of operation. In addition, as 22.4% of the incoming radiation in the form of long wavelength radiation, is absorbed within the top 1 cm of the pond, there is a sharp increase in the temperature of the UCZ creating a hot-zone which slowly moves downwards to the Non-Convective Zone (NCZ) and eventually the HSZ. Hence, the HSZ does not initially prevail as the hottest zone in the pond. However, as the temperature rises and the pond approaches pseudo-steady state, the hot-zone slowly moves downwards and finally reaches the HSZ. This phenomenon is consistent with experimental studies and proves the imprecision of pseudo-steady state models. Furthermore, the HSZ becomes more resistant to losing the accumulated heat to the layers above as its temperature increases due to the better establishment of the NCZ as the insulator for the HSZ.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

The growing demands for energy and fuel, along with fossil fuels becoming more challenging and costly to exploit, are leading to scientific initiatives taking place across the globe in order to explore novel ways of generating energy. Amongst those, solar energy has been subject to much development and debate.

Energy consumption is expected to increase by 37% by 2040 according to the recent World Energy Outlook (2014). In addition, greenhouse gas levels are endangering the global climate (Earth System NOAA Earth System Research Laboratory/Global Monitoring Division, 2013). Hence, the employment of fossil fuels to drive low-grade heat industrial processes is becoming increasingly irrational. Solar ponds offer a low-cost easily maintained option in comparison with other solar energy technologies. While concentrated solar power sites, vacuum tube solar heat collectors or photovoltaic solar cells are costly and require much maintenance, solar ponds demand low capital costs and can operate with minimal maintenance. Heat obtained from solar ponds has been used in electricity generation, desalination, industrial processes driven by low-grade heat and greenhouse heating (Akbarzadeh et al., 2005; Tabor and Doron, 1986; Rabl and Nielsen, 1975).

Three zones exist in a salinity gradient solar pond, namely the Upper Convective Zone (UCZ), the Non-Convective Zone (NCZ) and the Heat Storage Zone (HSZ). With the purpose of maintaining the aforementioned zones, freshwater is added to the top layer from time to time. The UCZ is a relatively thin layer with a very low salinity. Salinity increases through the NCZ which acts as an insulation for the HSZ. The solar radiation penetrates into this zone and the temperature rises with the depth. The HSZ has a very high salinity. In fact in most cases the HSZ contains saturated brine in

* Corresponding author.
E-mail address: a.abbassimonjezi@surrey.ac.uk (A. Abbassi Monjezi).

http://dx.doi.org/10.1016/j.solener.2016.06.011
0038-092X/© 2016 Elsevier Ltd. All rights reserved.

Nomenclature

A	surface area
C	specific heat
E	total solar energy reaching pond
F	absorbed energy fraction at δ-thickness
G	quantity of water evaporated
h	solar radiation fraction
HSZ	Heat Storage Zone
IBW	Insulated Bottom Wall
J	column number of the cells
K	1, 2, 3, ..., 24 (index for time interval Δt)
k	thermal conductivity
NCZ	Non-Convective Zone
P	pressure
Q	heat
R	thermal resistance
S	salinity
T	temperature
UCZ	Upper Convective Zone
V	velocity
x	humidity ratio

Greek symbols

β	fraction of incident beam entering into water
γ	thickness absorbing long-wave solar energy
Δx	thickness of horizontal layers
Δy	thickness of vertical layers
Δt	time difference
δ	declination angle
θ	angle
ε	emissivity
ρ	density
σ	Stefan–Boltzman coefficient
φ	the latitude of the location

Subscripts

a	air
amb	ambient
atm	atmospheric
b	bottom
c	convection
down	just below zone
dy	day
e	evaporation
fw	freshwater
H	humidity
I	layer
i	incidence
in	incoming
ins	insulation
k	conduction
L	length
n	number of day (1–365) in year
r	refraction
s	surface
solar	solar irradiation
t	total
W	width
w	water
wa	from water to air
ws	water in moist air

order to store solar thermal energy more efficiently. Hot brine is subsequently transferred to be used in various applications. A schematic view of a salinity gradient solar pond with its three zones is shown in Fig. 1.

In order to minimise the convective motion of the NCZ it is important to ensure that there is a high concentration gradient in this section of the pond. Hence, solar energy will predominantly be stored in the HSZ making heat storage more convenient and easier to transfer the hot brine and for employment in various applications (Velmurugana and Srithar, 2008).

A number of studies focused on the thermodynamics of solar ponds to provide a better understanding of the heat transfer process (Kooi, 1979; Sodha et al., 1981; Bansal and Kaushik, 1981; Own and Ambel, 1982; Beniwal et al., 1985; Jaefarzadeh and Akbarzadeh, 2002; Karakilcik et al., 2006a, 2006b; Mazidi et al., 2011; Sakhrieh and Al-Salaymeh, 2013; Bernad et al., 2013). These models consider the rate of incident solar radiation and its consequent absorption to estimate the temperature of brine in different locations of the solar pond.

Several models have been introduced in order to simulate the mechanism of heat transfer and storage in solar ponds using a finite difference (FD) method. Hull (1980), Hawlader and Brinkworth (1981) and Rubin et al. (1984) introduced the initial FD models for solar ponds while in recent years Karakilcik et al., 2006a, 2006b and Kurt et al. (2006) developed FD models to predict temperature distributions within a solar pond in a layer-by-layer manor. Suárez et al. (2010) employed finite-volume discretisation to examine the performance a solar pond. However, there seem to be a number of anomalies in the aforementioned models which have been addressed in this study. For example, there is little attention paid to the varying density, heat capacity and thermal conductivity of brine as a function of concentration and temperature to provide fully transient models which can predict the temperature distribution on an hourly basis. There is also a novel method proposed by this study to determine the required addition of freshwater to the UCZ and evaluate its associated effect on the performance of solar ponds.

This paper aims to present a comprehensive numerical model to predict transient temperature variations within a solar pond. Therefore, a one-dimensional forward-stepping semi-implicit finite difference model has been developed to simulate the transient behaviour of a solar pond by introducing novel approaches to treating UCZ and HSZ as well as a varying profile for density and heat capacity of brine corresponding to the increasing concentration and temperature throughout the pond. The impact of freshwater supply to the LCZ is also accounted for in this study. A transient model for the simulation of a solar pond from the very start of operation which can predict the temperature of brine in any layer on an hourly basis is therefore provided. The model comprises various previously developed formulations.

The rest of this paper is organised as follows; in Section 2 a mathematical model is presented to forecast solar radiation factors, enabling the prediction of solar thermal energy available to store. Then, a comprehensive finite-difference model where various factors are combined and improvements made with respect to the previous works is introduced. Results from the model are presented and discussed in Section 3 and finally, in Section 4, conclusions are drawn.

2. Formulation and modelling

In this section a comprehensive model is outlined, whereby the performance of a solar pond can be predicted. The model begins

Download English Version:

https://daneshyari.com/en/article/7936734

Download Persian Version:

https://daneshyari.com/article/7936734

Daneshyari.com