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ScienceDirect

Solar Energy 122 (2015) 204–214

SOLAR ENERGY

www.elsevier.com/locate/solener

Experimental studies on the effect of using phase change material in salinity-gradient solar pond

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Received 10 January 2015; received in revised form 12 July 2015; accepted 25 July 2015
Available online 18 September 2015

Communicated by: Associate Editor Aliakbar Akbarzadeh

Abstract

Performance of adding phase change material (PCM) to small salinity-gradient solar pond was studied experimentally. Two ponds with an area of 3.4 m^2 and depth of 1 m were chosen. Horizontal cylindrical capsules containing Paraffin Wax as PCM were used in one of the pond's lower convective zone. The capsules were made of black iron whose thermal conductivity was about 80 W/m °C and its height and diameter were 0.5 m and 75 mm respectively. The study was covered within period of summer for 6 weeks. An internal heat exchanger was used in the lower convective zone of pond. The hourly as well as daily variation of temperatures of the storage zone, surface zone, ambient, inlet and outlet of the internal heat exchanger have been measured and analyzed for ponds. It was shown the assisted PCM pond decreases the temperature difference between night and day. In addition, the pond had more thermal stability over environmental condition and more thermal and salinity stability on heat extraction. Hence the maximum temperature of the pond, outlet water temperature of heat exchanger, and, accordingly, the thermal efficiency decreased by using PCM. However, the heat exchanger outlet water temperature and, accordingly, the thermal efficiency, can be constant by increasing the length of the heat exchanger pipe. Therefore, based on this study, in such applications which one needs lower temperature difference and more uniform temperature, or where applications need a specific temperature range or controlled maximum temperature, PCM with a suitable melting point might be beneficial.

Keywords: Phase change material; Salinity-gradient solar pond; Heat extraction

1. Introduction

High cost of solar system is due to low thermodynamic efficiency and cost of separated solar storage systems. Therefore, it is essential to design the solar thermal devices, which can collect and store solar energy simultaneously. Solar pond can be a typical example of such solar thermal devices among various solar energy systems (Ranjan and Kaushik, 2014).

Kalecsinsky was a pioneer in the research on the solar pond (see Tundee et al., 2010). In the study, the solar-heated natural salt-water lake was considered. The lake showed temperatures as high as 70 °C at a depth of 1.32 m in the summer season. The minimal temperature was 26 °C during early spring. Following this study, the idea of solar energy collection was further developed using artificially created salinity-gradient solar ponds (SGSP) (Tundee et al., 2010), which were large bodies of water

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http://dx.doi.org/10.1016/j.solener.2015.07.053
0038-092X/

Nomenclature

A	heat transfer surface area of the heat exchanger (m^2)
A_i	internal surface area of the heat exchanger (m^2)
A_o	external surface area of the heat exchanger (m^2)
A_{sp}	area of the solar pond (m^2)
C	heat capacity rate per unit area of pond for heat transfer of fluid in the gradient-layer (W/m^2 °C)
C_p	Specific heat capacity of fluid (J/kg °C)
d_i	external diameter of the pipe (m)
d_o	internal diameter of the pipe (m)
G	solar radiation at the surface of the pond (W/m^2)
h_o	external convective heat transfer coefficient (W/m^2 °C)
h_i	internal convective heat transfer coefficient (W/m^2 °C)
H	average global solar radiation incident on the surface of the pond (W/m^2)
k_t	thermal conductivity of the wall tube (W/m °C)
L	total lengths of the heat exchanger pipe (m)
L_o	total outside lengths of the heat exchanger pipe (m)
L_i	total inside lengths of the heat exchanger pipe (m)
L^{*l}	new total lengths of the heat exchanger pipe of hypothetical designed solar pond with PCM which has an equal efficiency to the similar pond without PCM (m)
$\dot{m}$	mass flow rate (kg/s m^2)
NaCl	sodium chloride
$\dot{Q}$	rate of heat extraction from the LCZ per unit area of the solar pond (W/m^2)
U	overall heat transfer coefficient based on external surface area (W/m^2 °C)
PE	Polyethylene
R_{FI}	resistance due to fouling on the heat transfer fluid (HTF) side (°C/W)
R_{fi}	fouling factors at inner surfaces (m^2 °C/W)
R_{FO}	resistance due to fouling on the solar pond side (°C/W)
R_{fo}	fouling factors at outer surfaces (m^2 °C/W)
R_p	heat transfer resistance from the brine in the solar pond to the wall tube (°C/W)
R_{tube}	thermal resistance of the wall tube (°C/W)
R_{water}	heat transfer resistance from the wall tube to the HTF (°C/W)
r_i	external radius of the pipe (m)
r_o	internal radius of the pipe (m)
R^*_{overal}	the independent of length overall resistance (°C/W)
R_{overal}	overall resistance (°C/W)
T_a	ambient temperature (°C)
T_o	outlet temperature of the internal heat exchanger (°C)
T_i	inlet temperature of the internal heat exchanger (°C)

Greek symbols

Θ	non-dimensional temperature
η	thermal efficiency of the pond
η^{*l}	thermal efficiency of the hypothetical designed solar pond with PCM
δ_{total}	total uncertainty
$\delta_{instrument}$	measuring instrument accuracy
δ_{sensor}	sensor accuracy

Abbreviation

HTF	heat transfer fluid
IHE	internal heat exchanger
JSUT	Jundi Shapour University of Technology
LCZ	lower convective zone
LHTES	latent heat thermal energy storage
LMTD	logarithmic mean temperature difference
NCZ	none-convective zone
PCM	phase change material
P_{LMLT}	pond with less maximum LCZ temperature
P_{HMLT}	pond with higher maximum LCZ temperature
SHTES	sensible heat thermal energy storage
SGSP	salt gradient solar ponds
TES	thermal energy storage
UCZ	upper convective zone

Subscripts

PLMLT	pond with less maximum LCZ temperature
PHMLT	pond with higher maximum LCZ temperature
pwp	pond with PCM
pop	pond without PCM
$*l$	new hypothetical parameter
$*$	new predicted parameter

acting as solar collectors and heat storage (Dehghan et al., 2013). Researches on solar ponds have been conducted in a number of countries. In the last 50 years, solar ponds have been successfully built and operated in Europe, USA, Australia and developing countries, mostly on experimental basis (Ranjan and Kaushik, 2014). A typical solar pond consists of three regions: the upper convective zone (UCZ), the non-convective zone (NCZ) and the lower convective zone (LCZ) as shown in Fig. 1. The UCZ is a relatively thin layer that consists almost of fresh water. The NCZ is below the