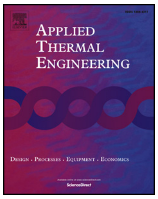
Applied Thermal Engineering 143 (2018) 1–10

Contents lists available at ScienceDirect

Applied Thermal Engineering

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



Research Paper

Improving performance of an inverted absorber multi-effect solar still by applying exergy analysis

Ebrahim Shanazari, Rasool Kalbasi*

Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran

HIGHLIGHTS

- Performing energetic and exergetic analysis on a multi-effect solar still.
- The highest irreversibility occurred through the absorber plate.
- In a certain basin, irreversibility decreased with increasing number of effects.
- With increase in effect from one to ten, overall second efficiency increased by 471%.
- Total yield and irreversibility increased by 407% and 11%, respectively.

ARTICLE INFO

Keywords:
Multi-effect solar still
Exergy
Efficiency
Irreversibility
Daily yield

ABSTRACT

In this paper, the energetic and exergetic analyses of an inverted absorber multi-effect solar still has been studied. A new criterion was defined to determine the efficiency of the first law of thermodynamics for multi-effect solar stills. Energy and exergy balance equations have been developed for water basins, condensing surfaces and absorber plate to evaluate the irreversibility through the various components. Heat and modified mass transfer coefficients along with accurate properties of humid air were used to solve the governing system of differential equations. Results affirmed that the exergy loss through the absorber plate, water basins and condensing covers in a certain basin decrease as the number of effects increase. However, the increase in basins number from one to ten leads to increase in total irreversibility through the water basins by 337%. Calculations on energy balance equations showed that with increase in effect from one to ten, heat transfer to ambient decreased by 74.8%, which in turn increased the first law efficiency by 174.6%. It is found that with increase in effect from one to ten, the total yield, irreversibility and overall second efficiency increased by 407.3%, 10.4% and 471%, respectively, but global second efficiency decreased by 20.6%.

1. Introduction

Water is considered as the vital resources of the earth. Almost 75% of the earth surface is covered with water. However, only 2.5% of the water resources are suitable for drinking. [1,2]. Freshwater resources have fixed volume of supply while the world population is predicted to reach 9.1 billion in 2050 [3]. Therefore, the non-potable water should be converted to drinking water through effective, inexpensive methods. The brackish water is converted to drinkable water by the reverse osmosis, electro dialysis, vapor compression and multi stage flash methods. In these methods, a great amount of energy is used to produce fresh water. For remote area, water distillation based on the solar energy, is an efficient low cost technique. A solar power water distillation system accumulates the solar radiation to produce drinkable water by the evaporation and condensation process [4]. But, the yield and efficiency of a conventional solar still are around about 3–5 $\frac{\text{kg}}{\text{m}^2\ \text{day}}$ and 30–45%, respectively [5]. Numerous techniques have been made by various researchers to increase the solar still daily yield such as: addition of spreader materials such as jute and cotton cloth [6,7],wicks material [8], sensible heat storage material [9], phase change material [10,11], external and internal condenser [12,13], external reflector [14], flat plate collector [15], multi-effect (using heat of vaporization) [16,17], nanoparticle [18–20], pin fins absorber [21] and sponge cubes [22].

The inverted absorber solar still (IASS) has a curved reflector in which the solar radiation heats the water from below [23–26]. The experimental comparison between an inverted absorber solar still and conventional single slope solar at various water depths have been

---

* Corresponding author.
E-mail address: r.kalbasi@pmc.iaun.ac.ir (R. Kalbasi).

https://doi.org/10.1016/j.applthermaleng.2018.07.021
Received 22 January 2018; Received in revised form 23 April 2018; Accepted 5 July 2018

Nomenclature

Symbols

A	area (m^2)
c_P	specific heat of humid air $\left(\frac{J}{kg\ \ K}\right)$
c	specific heat of water $\left(\frac{J}{kg\ \ K}\right)$
EX	exergy (J)
h	enthalpy $\left(\frac{kJ}{kg}\right)$
h_{c_m}	convective heat transfer coefficient from condensing cover of basin ‘m’ to water mass in basin ‘m + 1’, $\left(\frac{W}{m^2\ \ K}\right)$, where $1 \le m \le n{-}1$
h_{c_n}	convective heat transfer coefficient from the glass cover (condensing surface of last basin) to ambient, $\left(\frac{W}{m^2\ \ K}\right)$
h_{cw}	convective heat transfer coefficient from water surface to condensing surface $\left(\frac{W}{m^2\ \ K}\right)$
h_{cpw1}	convective heat transfer coefficient from absorber plate to water mass in basin 1, $\left(\frac{W}{m^2\ \ K}\right)$
h_w	total heat loss coefficient from water surface to condensing surface $\left(\frac{W}{m^2\ \ K}\right)$
h_{w_m}	total heat transfer coefficient from water mass in basin ‘m’ to condensing surface of basin ‘m’, $\left(\frac{W}{m^2\ \ K}\right)$, where $1 \le m \le n$
h_{ew}	evaporative heat transfer coefficient from water surface to condensing surface $\left(\frac{W}{m^2\ \ K}\right)$
h_{ew_m}	evaporative heat transfer coefficient from water mass in basin ‘m’ to condensing surface of basin ‘m’, $\left(\frac{W}{m^2\ \ K}\right)$, where $1 \le m \le n$
h_{rw}	radiation heat transfer coefficient from water surface to condensing surface $\left(\frac{W}{m^2\ \ K}\right)$
h_{pg2}	convective heat transfer coefficient from absorber plate to glass 2 $\left(\frac{W}{m^2\ \ K}\right)$
h_{fg}	latent heat of vaporization $\left(\frac{J}{kg}\right)$
$I(t)$	solar radiation $\left(\frac{W}{m^2}\right)$
k	thermal conductivity $\left(\frac{W}{m\ \ K}\right)$
g	gravity acceleration $\left(\frac{m}{s^2}\right)$
$L_c \equiv \frac{A}{p}$	characteristic length (m)
Le	Lewis Number, $Le = \frac{\alpha_{mix}}{D_{mix}}$
m	mass (kg)
$m_{pro,m}$	water produced in basin ‘m’ $\left(\frac{kg}{m^2\ \ day}\right)$
$m_{pro,t}$	total produced water from a multi-effect solar still $\left(\frac{kg}{m^2\ \ day}\right)$
M	molecular weight $\left(\frac{kg}{kmol}\right)$
N	number of effect in a multi-effect solar still
N	average number of reflections
Nu	Nusselt Number
P	pressure (kPa)
p	perimeter (m)
P_{lm}	logarithmic mean pressure, $P_{lm} = \frac{P_{v,c} - P_{v,w}}{log\frac{P_0 - P_{v,w}}{P_0 - P_{v,c}}}$ (Pa)
$P_{v,c}$	pressure vapor at condensing temperature (kPa)
$P_{v,w}$	pressure vapor at water temperature (kPa)
P_0	total pressure (kPa)
Pr	Prandtl number
Q	Heat Transfer (W)
r	reflectivity
R_u	universal gas constant $\left(8314\ \frac{J}{mol\ \ K}\right)$
Ra	Rayleigh Number, $Ra = \frac{\rho g\beta L_c^3}{\mu\alpha}$
s	entropy $\left[\frac{kJ}{kg\ \ K}\right]$
T	temperature (K)
T_{c_m}	temperature of condensing surface of basin ‘m’, where $1 \le m \le n$-1, (K)
T_{c_n}	temperature of glass cover (condensing surface of last basin), (K)
T_{gi}	temperature of inner surface of condensing glass cover, (K)
T_{go}	temperature of outer surface of condensing glass cover, (K)
T_{w_1}	temperature of water mass in basin 1, (K)
T_{w_m}	temperature of water mass in basin ‘m’ where $2 \le m \le n{-}1$, (K)
T_{w_n}	temperature of water mass in last basin, (K)
U_r	back loss coefficient, $\left(\frac{W}{m^2\ \ K}\right)$
$U_{p,a}$	overall total loss coefficient from absorber to ambient, $\left(\frac{W}{m^2\ \ K}\right)$, $U_{p,a} = \left(\frac{1}{h_{pg2}} + \frac{1}{U_r}\right)^{-1}$
$U_{n,a}$	overall total loss coefficient from water mass in the last basin of a multi-effect solar still to ambient, $\left(\frac{W}{m^2\ \ K}\right)$, $U_{n,a} = \left(\frac{1}{h_{c_n}} + \frac{1}{h_{w_n}}\right)^{-1}$
$U_{w,a}$	overall total loss coefficient from water mass in the basin 1 to ambient, $\left(\frac{W}{m^2\ \ K}\right)$, $U_{w,a} = \left(\frac{1}{h_{pg2}} + \frac{1}{U_r} + \frac{1}{h_{cpw1}}\right)^{-1}$
$U_{m,m+1}$	overall heat transfer coefficient from water mass in basin ‘m’ to water mass in basin ‘m + 1’ ($1 \le m \le n{-}1$), $\left(\frac{W}{m^2\ \ K}\right)$, $U_{m,m+1} = \left(\frac{1}{h_{c_m}} + \frac{1}{h_{w_m}}\right)^{-1}$
$U_{m-1,m}$	overall heat transfer coefficient from water mass in basin ‘m-1’ to water mass in basin ‘m’ ($2 \le m \le n{-}1$), $\left(\frac{W}{m^2\ \ K}\right)$, $U_{m-1,m} = \left(\frac{1}{h_{c_{m-1}}} + \frac{1}{h_{w_{m-1}}}\right)^{-1}$

Greek letters

α	absorptivity
β	volumetric expansion coefficient $\left(\frac{1}{K}\right)$
ε_{eff}	effective emissivity coefficient
ρ_c	density of water vapor at the condensation surface $\left(\frac{kg}{m^3}\right)$
ρ_w	density of water vapor at the water surface $\left(\frac{kg}{m^3}\right)$
μ	dynamic viscosity $\left(\frac{kg}{m.s}\right)$
σ	Stefan's constant
τ	transmissivity

Subscripts

a	ambient
v	vapor
c	condensing surface
g1	glass cover 1
g2	glass cover 2
fc	first criterion
gl	global
mix	humid air
m	m^{th} effect of a multi-effect solar still
n	last effect of a multi-effect solar still
Ov	overall
p	absorber plate
sat	saturation
Sc	second criterion
tot	total
w	water