Theoretical Investigation of Solar Still Coupled with Solar Air Heater

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Abstract

In this paper an attempt is made to theoretical investigate the performance of conventional solar still when it is coupled with solar air heater which provides heat at the basin of conventional solar still capable of providing higher temperature at the basin of stepped solar still resulting higher yield. Various energy balance equations are solved with the help of MATLAB software in order to find the various temperatures and fresh water productivity. Some data are taken from previous researches. It is predicted that the water productivity increased about 24 % in comparison to the solar still without solar air heater.

Keywords — *solar still, solar air heater, solar desalination and solar energy.*

I. INTRODUCTION

Fresh water is one of basic necessity for the good health as it prevent from many deceases. This requirement of fresh water increases day by day because of the industrialization, and a rise of the world population. Only about 3% of the available world water is potable and the amount of this water is not evenly distributed on the earth. Solar desalination is the process where the energy coming from sun is utilized for water purification. Solar still is a solar desalination device used for distillation of fresh water. However, the amount of productivity obtained from this device is quite low. Many research works has been carried out for increment in the fresh water productivity. There are many factors which affect the productivity of the solar still [1] such as solar input, ambient temperature, water depth, and wind velocity The concept of integrating the stepped solar still along with inclined flat plate collector was introduced by Alaudin et al. [2]. An experimental performance based on stepped solar still coupled with solar air heater was investigated by Abdulla et al. [3]. The effect of water flow over the glass cover and the use of aluminium filling as a thermal storage device were also studied. He found an increment of about 112 % fresh water productivity over the conventional still. The impact of depth of tray on the performance of stepped solar still was investigated by Kabeel et al. [4]. According to their investigation at a depth of 5 mm and tray width 120 mm maximum productivity obtained in comparison with conventional still. Velmurugan et al. [5] designed and analyzed the stepped solar still performance. Also an experimental performance of the stepped solar still and effluent settling tank for desalinating the textile effluent was investigated by Velmurugan et al. [6]. He found that an increase in the productivity of 98% over conventional still when fin, sponge and pebbles are used in the basin of the stepped solar still. In addition Velmurugan et al. [7] performed experiments by the use of mini solar pond with different combinations of solar stills the productivity obtained for these combinations in comparison with conventional still was higher. Omara et al. [8] made an experimental study based on the comparison between a stepped solar still with and without internal reflectors and compared it with a conventional solar still. According to their results, the daily productivity of the modified stepped solar still by the use of internal reflectors is approximately 75% more than that for conventional still. A Modeling for the study of performance of a regenerative solar desalination unit in comparison with the convention solar still was made by Zurigat et al. [9]. The result obtained from this study shows that the regenerative still is 20% more efficient than conventional still. Shukla et al. [10] designed a multi wick single slope solar still to predict the performance of the solar stills. Experimental results were validated with the computer model by the use of modified heat transfer coefficients. Reviews of researches and developments on solar still carried out by kabeel et al. [11]. Srither et al. [12] compared analytical and experimental results of an open type flat plate collector for tannery effluent treatment. The analytical performance based on flat plate collector with and without porous media was studied by Yousaf et al. [13]. The optimized modeling of flat plate collector design was simulated by the Ajlan et al. [14].

II. MATHEMATICAL MODEL

The schematic diagram for conventional solar still coupled with solar air heater is shown in figure 1.

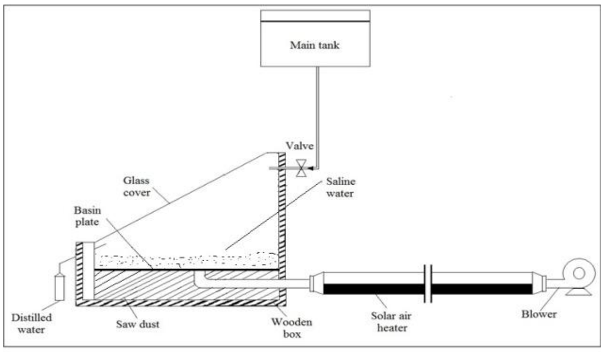

Fig. 1 Schematic Diagram

The analytical results for saline water, absorber plate and glass cover are obtained by solving various energy balance equations for saline water, absorber plate, glass cover, air coming from solar air heater and bottom surface at the bottom of still.

The energy balance equation for glass cover is,

$$m_g c_{pg}(dt_g/dt) = I(t)\alpha_g A_g + Q_{c,w-g} + Q_{r,w-g} + Q_{e,w-g} - Q_{r,g-sky} - Q_{c,g-sky}$$

(1)

The energy balance equation for saline or brackish water is,

$$m_w c_{pw}(dt_w/dt) = I(t)\alpha_w A_w + Q_{c,b-w} - Q_{c,w-g} - Q_{r,w-g} - Q_{e,w-g}$$

(2) The energy balance equation for basin plate is,

$$m_b c_{pb}(dt_b/dt) = I(t)\alpha_b A_b + Q_{c,f-b} - Q_{c,b-w} - Q_{r,b-s}$$

(3)

The energy balance equation for bottom surface is,

$$m_s c_{ps}(dt_s/dt) = Q_{c,f-s} + Q_{r,b-s} - Q_{loss}$$

(4)

The energy balance equation for air coming from solar air heater is,

$$T_{f2} = T_{f1} - (L^2 W/2m_f C_{pf})(Q_{c,f-b} + Q_{c,f-s})$$

(5)

Temperature of glass, water, plate and bottom surface are taken as an ambient temperature at the first iteration, and an increase in basin temperature (dt_b), water temperature (dt_w) and glass cover temperature (dt_g) is computed for every time interval (dt) of 5 sec by solving equation 1-5 respectively. For the calculation of these temperatures the values of intensity of solar radiation, ambient temperature and wind velocity has been taken from various research papers used in the simulation. This iteration is performed for total duration of 10 hours from 9 am to 6 pm. The parameters for the next time step can be written as,

$$t_g = t_g + dt_g$$

(6)

$$t_w = t_w + dt_w$$

(7)

$$t_b = t_b + dt_b$$

(8)

The overall condensation rate can be written as,

$$dm_c/dt = h_{e,w-g}(t_w - t_g)/h_{fg}$$

(9)

The convective heat transfer for basin and water is written as,

$$Q_{c,b-w} = h_{c,b-w} A_b (t_b - t_w)$$

(10)

The convective heat transfer co-efficient between basin and water, $h_{c,b-w}$ is taken as 135 W/m^{2}K. The heat loss from basin to ambient is neglected due to introduction of the air coming from solar air heater at the bottom of basin.

The convective heat transfer for water and glass is written as,

$$Q_{c,w-g} = h_{c,w-g} A_w (t_w - t_g)$$

(11)

The convective heat transfer co-efficient for water and glass is written as,

$$h_{c,w-g} = 0.884\{(t_w - t_g) + [p_w - p_g][t_w + 273.15]/[268.9\times10^3 - p_w]\}^{1/3}$$

(12)

The radiative heat transfer for water and glass is written as,

$$Q_{r,w-g} = h_{r,w-g} A_w (t_w - t_g)$$

(13)

The radiative heat transfer co-efficient for water and glass is written as,

$$h_{r,w-g} = \varepsilon_{eq}\sigma[(t_w + 273)^2 + (t_w + 273)^2] \times (t_w + t_g + 546)$$

(14)

where,

$$\varepsilon_{eq} = (1/\varepsilon_w + 1/\varepsilon_g - 1)^{-1}$$

(15)

The evaporative heat transfer for water and glass is written as,

$$Q_{e,w-g} = h_{e,w-g} A_w (t_w - t_g)$$

(16)

The evaporative heat transfer co- efficient for water and glass is given by,

$$h_{e,w-g} = (16.273\times10^{-3})h_{c,w-g}(P_w - P_g)/(t_w - t_g)$$

(17)

The radiative heat transfer for glass and sky is written as,

$$Q_{r,g-sky} = h_{r,g-sky}A_g(t_g - t_{sky})$$

(18)

The radiative heat transfer co- efficient for glass and sky is written as,

$$h_{r,g-sky} = \varepsilon\sigma[(t_g + 273)^4 - (t_w + 273)^4]/(t_g - t_{sky})$$

(19)

The effective sky temperature is given by,

$$t_{sky} = t_a - 6$$

(20)

The convective heat transfer for glass and sky is written as,

$$Q_{c,g-sky} = h_{c,g-sky}A_g(t_g - t_{sky})$$

(21)

The convective heat transfer co- efficient for glass and sky is written as,

$$h_{c,g-sky} = 2.8 + 3.0V$$

(22)

The convective heat transfer for fluid and basin is written as,

$$Q_{c,f-b} = h_{c,f-b}A_b(t_f - t_b)$$

(23)

The convective heat transfer co- efficient for fluid and basin is written as,

$$h_{c,f-b} = Nuk_f/D_h$$

(24)

where,

$$Nu = 0.0158(Re)^{0.8}$$

(25)

$$Re = m_f D_h/A_f\mu$$

(26)

The convective heat transfer for fluid and bottom surface is written as,

$$Q_{c,f-s} = h_{c,f-s}A_s(t_f - t_s)$$

(27)

The convective heat transfer co- efficient for fluid and bottom surface is written as,

$$h_{c,f-s} = h_{c,f-b}$$

(28)

The radiative heat transfer for basin and bottom surface is written as,

$$Q_{r,b-s} = h_{r,b-s}A_b(t_b - t_s)$$

(29)

The radiative heat transfer co- efficient for basin and bottom surface is written as,

$$h_{r,b-s} = \varepsilon_{eff}\,\sigma(t_b^2 - t_s^2)(t_b + t_s)$$

(30)

where,

$$\varepsilon_{eff} = (1/\varepsilon_b + 1/\varepsilon_s - 1)^{-1}$$

(31)

The surface loss is determined by

$$Q_{loss} = U_s A_s(t_s - t_a)$$

(32)

The daily efficiency η_d is calculated by,

$$\eta_d = \Sigma m h_{fg}/\sum AI(t)$$

(33)

III.RESULTS AND DISCUSSION

Some data is taken from precious researches done by the researchers in which wind velocity is taken as 3 m/s and ambient temperature is taken as 20 ^{o}C and intensity of solar radiation is varied from 220 to 730 W/m^2.

A. Variation of Temperature Corresponding to Time with the Effect of Solar Radiation

Firstly by solving various energy balance equations for conventional solar still the various temperatures that are basin, water and glass are obtained as shown in the table 1. The variation of these temperatures with respect to time as shown in figure 2

Table 1 Conventional Solar Still

Time (hr)	Solar Intensity (w/m²)	Basin Temp. (°c)	Water Temp. (°c)	Glass Temp. (°c)	Hourly Output (ml/m².h)
9	280	32.811	32.169	20.851	0.311
10	430	40.513	39.614	23.775	0.347
11	630	50.601	49.341	27.779	0.384
12	780	58.038	56.494	30.853	0.404
13	730	55.571	54.123	29.822	0.399
14	670	52.595	51.261	28.593	0.389
15	600	49.101	47.896	27.171	0.378
16	460	42.039	41.088	24.368	0.353
17	300	33.845	33.171	21.237	0.317
18	220	29.696	29.154	19.703	0.295

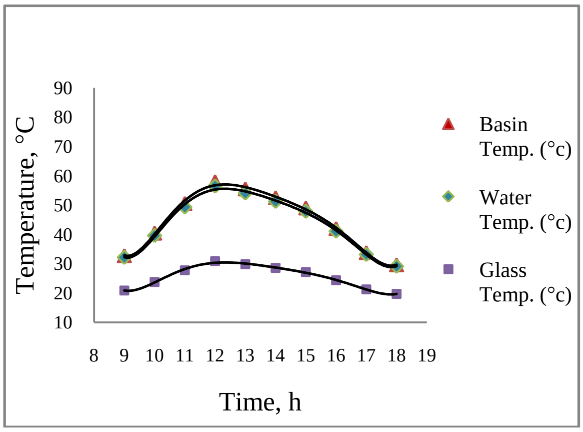

Fig. 2 Temperature Variation Conventional Solar Still

The various energy balance equations are obtained by coupling conventional solar still with solar air heater and the various temperatures that are basin, water and glass are obtained by using Matlab software as shown in the table 2. The variation of these temperatures with respect to time as shown in figure 3

Table 2 Conventional Solar Still Coupled with Solar Air Heater

Time (hr)	Solar Intensity (w/m²)	Basin Temp. (°c)	Water Temp. (°c)	Glass Temp. (°c)	Hourly Output (ml/m².h)
9	280	54.87	53.246	28.621	721.8
10	430	64.265	62.249	32.521	765.1
11	630	76.451	73.889	37.812	815.4
12	780	85.346	82.361	41.833	847.8
13	730	82.406	79.561	40.488	837.1
14	670	78.843	76.171	38.881	824.4
15	600	74.647	72.169	37.012	808.2
16	460	66.118	64.021	33.309	775.8
17	300	56.136	54.461	29.136	727.2
18	220	51.048	49.576	27.079	700.2

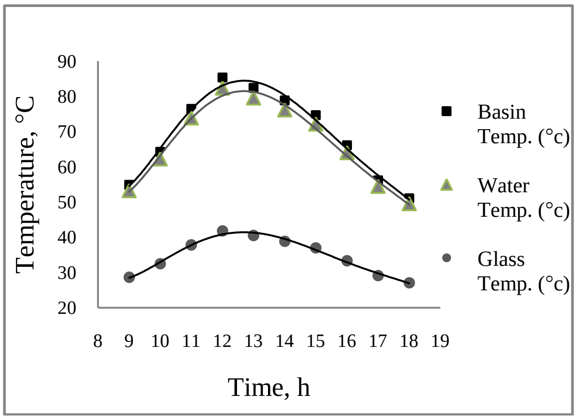

Fig. 3 Temperature Variation of Coupled Solar Still

From the figure it is found that with the increase of the intensity of solar radiation, temperature increase with time up to maximum value (noon) and vice versa.

Also from fig. 2 and fig. 3 it is observed that the rise of basin temperature, water temperature and glass temperature in case of coupled solar still with solar air heater is more than that of conventional still.

B. Fresh Water Productivity

The fresh water productivity variation with respect to time for conventional solar still and conventional solar still coupled solar air heater is illustrated in fig. 4. It is cleared from the figure that the maximum fresh water productivity is at noon due to higher temperature. This is due to the low temperature of water in the still in the early morning after that it goes on increase till noon and then after it starts decreasing during evening. Thus maximum fresh productivity occurs at maximum saline water temperature.

It is also observed from fig. 4 that the fresh water productivity for coupled solar is greater than that of conventional solar still.

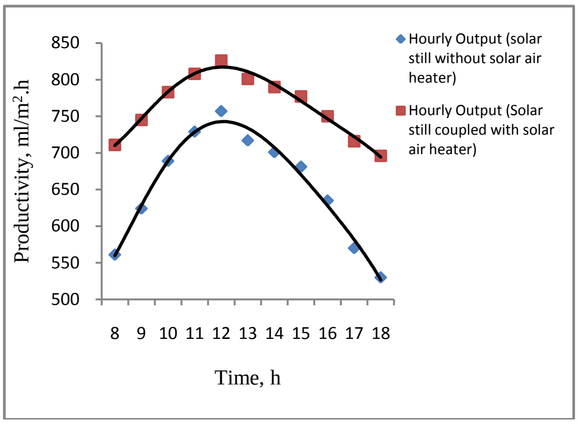

Fig. 4 Fresh Water Productivity

C. Daily Productivity

From the above results we found that the daily efficiency for the conventional solar still with solar air heater is approximately 24% more than that of conventional still. So the solar still coupled with solar air heater is more efficient.

IV. CONCLUSIONS

From the present theoretical results of solar still with solar air heater and solar still without solar air heater the following conclusion can be drawn:

- The temperature of basin, saline or brackish water and glass of coupled solar still is more than that of the conventional still.
- The productivity of fresh water for coupled solar still is higher than that of conventional still.
- There is an increase in 24% of the daily productivity in case of solar still coupled with solar air heater than that of conventional still.

Nomenclature

A area of cross-section, m^2
C specific heat, J/Kg K
D_h hydraulic diameter, m
h heat transfer coefficient, W/m^2 K
h_{fg} enthalpy of evaporation at T_w, J/kg
I(t) solar intensity, W/m^2
L collector length, m
m mass, kg
Nu Nusselt number
p partial pressure, N/m^2
Re Renold number
t temperature, ^oC
U heat loss coefficient at bottom, W/m^2 K
V wind velocity, m/s
W collector width, m

Greek symbols

ε emissivity
α absorptivity
ρ density, kg/m^3
μ dynamitic viscosity, Pa.s
σ Stefan-Boltzman constant
η_d daily efficiency

Subscripts used

a ambient
b basin
c convective
e evaporative
f fluid
g glass
r radiative
s bottom surface
w water

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