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Developing Thermal Model for Single Basin Double Slope Solar Desalination System

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Abstract

Pure water scarcity is a major problem now days. To overcome this problem, the purification of saline/ brackish water is needed. Solar desalination is one of the economical ways to purify the water. The output of solar still is termed as yield (purified water). Yield depends upon various environmental, design and operational parameters like wind speed, intensity of solar radiation, orientation of solar still, depth of water present in the basin of solar still etc. To improve the productivity of system optimum values of different parameters are required. To check the effect of all the parameters on the yield, number of solar stills is required running under various operational conditions. This will take lots of time and very uneconomical too. Varying different parameters in a well formulated thermal model, different theoretical yields can be obtained. Using different heat transfer relations across various part of the still, thermal model has been developed. With the help of MATLAB PROGAMME, these equations are solved. This programme provides information of temperature of water and yield at every hour. Theoretical values are in close agreement with the experimental values.

Keywords: Solar desalination, Backish water, Thermal model, Yield

INTRODUCTION

Like air; water is also one of the important components required for survival of human being. People can survive without food up to a month but cannot live without water even for a week. The water we drink provides for biological functions, metabolic reactions and the activities of cell. Water is a renewable resource, made continuously available through solar energy, which enables it to evaporate from oceans and land, redistributing it around the world. This water runs off in rivers and refills our aquifers. With two thirds of the earth's surface covered by water and the human body consisting of 75 percent of it, it is clear that water is one of the prime elements responsible for life on earth. If look at distribution of water on earth surface we find that ocean covers about 96.5 % of water, 1.7% groundwater, 1.7% glaciers and ice caps and rest is in the form of vapors and clouds. The exponential rise in population shows that by 2025 there will be approx. 8-10 billion people. This huge increase in population will decrease the amount of available fresh water per person per year by 40% i.e. from 8000 to 5000m^3. So in order to manage thisthe only way is to purify the required amount of saline or impure water. The main factor behind water pollution is we human beings. Our needs and greed are increasing in such a way that we must exploit the available water to fulfill it. Water pollution are mostly caused by city sewage and industrial waste disposal to water bodies. In our agriculture field we are using a lot of fertilizers, chemicals, pesticides to increase our production. These chemicals, fertilizers and pesticides seep into ground water by a process known as leaching. This led to increase in nitrate content of ground water**.**

Solar distillation uses the heat of the sun to heat salt water and also human labor to periodically change the feed water. It heats the salt water in a basin with a transparent cover of glass and water vapor condenses on the underside of the cover. The condensate then drips into a pure water collection trough. Although numerous enhancements of solar stills have been proposed and tested, most sources suggest a basic single basin design as the most economical and proven. In hot climates, single basin stills generally produce 2-3 l/day for each m^2 of area. The simple and independent operation of solar stills is suitable for small-scale and remote applications. Solar still works on the principles of evaporation and condensation. In solar still saline water is supplied and are collected in basin. Solar radiation falls on glass cover it partially absorb some part of radiation, reflect back some part transmit most of the radiations to water surface. The same phenomenon occurs on the surface of saline water. It also absorbs some radiations, reflect some radiations and transmit rest to basin liner. From basin liner some part of radiation is lost to ground by conduction called as bottom loss. While it also absorbs some radiation and transmit most of radiation toward saline water by conduction and convection causing the water to heat up which result its evaporation. When the water inside solar still evaporates, it leaves all the impurities like salts bacteria in the basin. This evaporated water moves upward and losses its heat in the form of convective, evaporative and radiative heat transfer. After losing its heat, vapor condenses and collected in collector. The impurities are removed from the basin and additional water is feed to the still. The productivity of a solar still is highly influenced by the environmental conditions, such as solar radiation intensity, atmospheric temperature, wind velocity and cloud and dust cover, relative humidity etc. which are out of control of human beings [1].

The first modern solar still of blackened wood with sloping glass cover was built in by Charles Wilson (1872) in Las Salinas, Chile to supply 20,000 liters per day water to persons and animals working in mining operations. Continuous attempts have been made by various researchers to enhance the productivity of solar stills. The various designs of passive solar stills have been proposed and research work carried out. Yadav and Sudhakar [2] reviewed many designs of solar stills. Tripathi and Tiwari [3] studied the effect of different water depths in the basin of active solar distillation on the heat and mass transfer coefficients. Tripathi and Tiwari [4] also made an attempt to find out the effect of water depth. It was concluded that the heat transfer coefficients depend significantly on water depth. Khalifa and Hamood [5] investigated cover tilt angle as most crucial parameter which affects the performance of still. Abdallah Salah et al. [6] used different types of absorbing materials to examine their effect on the yields of solar stills. Dev et al. [7] formulated characteristic equations of single slope passive solar still. It was observed that passive solar still with inclination of 45^0 gives better performance both in winter and summer. Abu-Hijleh & Rababa'h [8] examined that, when sponge cups of a conventional solar still basin were used to maximize the evaporation area, the productivity increased by 273%. Sandeep et al. [9] proposed a new design having secondary condensing surface which enhanced the productivity of singe slope solar still. Sandeep et al. [10] also evaluated heat transfer coefficients for the modified solar still.

METHODOLOGY

Using different heat transfer relations across various part of the still, a thermal model has been developed. With the help of MATLAB PROGAMME, these equations are solved. Dwivedi and Tiwari [11] conducted the experiments on a double slope solar still installed at IIT Delhi (India). The proposed model has been validated using experimental observations given by Dwivedi and Tiwari [11].

Energy balances on West cover

The energy balances in terms of W/m^2 for inner and outer surfaces of west condensing covers are as follow

(a)Inner condensing cover

$$\alpha'_g I_W + h_{tW}(T_w - T_{ciW}) + U_{EW}(T_{ciE} - T_{ciW}) = \frac{K_g}{L_g}(T_{ciW} - T_{coW})$$

and,

(b)Outer condensing cover

$$\frac{K_g}{L_g}(T_{ciW} - T_{coW}) = h_{aW}(T_{coW} - T_a)$$

where, $h_{tW} = h_{cwW} + h_{ewW} + h_{rwW}$

Energy balance for water mass

$$(MC)_w \frac{dT_w}{dt} = (I_E + I_W)\alpha'_w + 2U_{bw}(T_b - T_w) - h_{tE}(T_w - T_{ciE}) - h_{tW}(T_w - T_{ciw})$$

Energy balance for basin liner

$$\alpha'_b(I_E + I_W) = 2U_{bw}(T_b - T_w) + 2U_{ba}(T_b - T_a)$$

With the help of above Equations, one can get the following one order differential equation as,

$$\frac{dT_w}{dt} + aT_w = f(t)$$

where,

$$a = \frac{1}{MC_w}\left[\frac{2U_{bw}U_{ba}}{U_{bw}+U_{ba}} + \frac{(p-A_2)h_{tE}}{p} + \frac{(p-B_2)h_{tW}}{p}\right]$$ and

$$f(t) = \frac{1}{MC_w}\left[\left(\alpha'_w + \frac{\alpha'_b U_{bw}}{U_{bw}+U_{ba}}\right)(I_E + I_W) + \frac{h_{tE}A_1 + h_{tw}B_1}{p} + \frac{2U_{bw}U_{ba}T_a}{U_{bW}+U_{ba}}\right]$$

The solution of this equation with initial condition, $T_w = T_{w0}$ at t=0, becomes

$$Tw = \frac{\overline{f(t)}}{a}\left[1-\exp(-a\Delta t)\right] + T_{w0}\exp(-a\Delta t)$$

After knowing water temperature from above equation, the inner and outer glass cover temperatures can be obtained as

$$T_{ciE} = \frac{A_1 + A_2 T_w}{p}$$

$$T_{ciW} = \frac{B_1 + B_2 T_w}{p}.$$

$$T_{coE} = \frac{\frac{K_g}{L_g} T_{ciE} + h_{aE} T_a}{\frac{K_g}{L_g} + h_{aE}}$$

$$T_{coW} = \frac{\frac{K_g}{L_g} T_{ciW} + h_{aW} T_a}{\frac{K_g}{L_g} + h_{aW}}$$

The obtained values of water and inner condensing cover temperature become initial temperature for next set of calculations. Similarly this procedure has been adopted for other set of time interval.

The evaporative heat transfer rate from east and west side of a double slope solar still is given by

$$\dot{q}_{ewE} = h_{ewE}(T_w - T_{ciE})$$

$$\dot{q}_{ewW} = h_{ewW}(T_w - T_{ciW})$$

Then, hourly yield can be calculated with the help of following equations

$$\dot{m}_E = \frac{\dot{q}_{ewE} \times 3600}{L}, \text{ and}$$

$$\dot{m}_W = \frac{\dot{q}_{ewW} \times 3600}{L},$$

The energy balance equations are written for different components of solar still such as for east and west side of condensing cover, water mass and basin liner. By solving differential equation, water temperatures can be obtained. Further, inner and outer glass cover temperatures are determined with the help of different equations written in previous chapter. With the help of evaporative heat transfer coefficients, water and inner glass cover temperatures, distillate output from east and west sides are determined. A program was developed in MATLAB to find out water temperature, inner and outer glass cover temperature and distillate yield for east and west side of solar still. The design parameters used in the thermal modelling are given in Table 1. The closeness between theoretical and experimental data can be mentioned in terms of coefficient of correlation and root mean square of percent deviation. The expression for coefficient of correlation and root mean square percent deviation given by Chapra and Canale (1989) are as follows

$$r = \frac{N\sum X_i Y_i - \sum(X_i)\sum(Y_i)}{\sqrt{N\sum X_i^2 - (\sum X_i)^2}\sqrt{N\sum Y_i^2 - \left(\sum Y_i\right)^2}}$$

(4.1)

and

$$e = \sqrt{\frac{\sum(e_i)^2}{N}}$$ where,

$$e_i = \frac{X_i - Y_i}{X_i}$$

Table 1: Design parameters

Design parameters	**Values**
α_b	0.8
α_g	0.05
α_w	0.6
ε_w	0.95
ε_g	0.95
$\alpha\tau$	0.8
L_b	0.005 m
L_g	0.004 m
K_b	0.035 W/Mk
K_g	0.78 0 W/Mk
C_W	4188 J/kgK
M	20 kg
σ	5.67×10^{-8} W/m^{2}K^4
V	0.8 m/s

RESULTS AND DISCUSSION

Table 2 and figure 1 compare experimental and theoretical values of hourly variation in the temperature of water in the still. Water temperature rises till the mid noon and then falls constantly.

Table 2: Temperature of water

Time	Temperature of water (°C)	
	Theoretical	Experimental
7	20.108	21.7
8	28.541	24.6
9	43.6823	29.3
10	53.9363	42.2
11	60.1529	52.2
12	64.8273	63.5
13	66.9508	67.3
14	62.7848	69.2
15	60.2985	71.6
16	52.3198	67.4
17	47.3348	60.7
18	35.1377	52.1
19	29.5274	44.7
20	26.7148	37.1
21	25.763	32.7
22	24.7801	28.7
23	23.7843	28.3

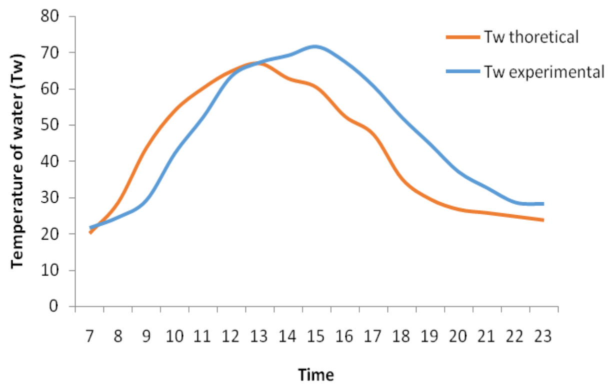

Figure 1: Comparison of temperature of water

Table 3 and figure 2 compare the experimental and theoretical values of yield received through west facing cover. Theoretical results show better yield in the morning hours. This prediction does not match with the experimental results. Thermal inertia is the reason behind this discrepancy.

Table 3: Yield in west direction

Time	Hourly yield west (Kg)	
	Theoretical	Experimental
7	0	0
8	0.0122	0.01
9	0.1056	0.02
10	0.3026	0.01
11	0.4633	0.07
12	0.5684	0.18
13	0.566	0.24
14	0.2634	0.34
15	0.2673	0.29
16	0.0015	0.28
17	0.0288	0.23
18	0.0901	0.18
19	0.0197	0.14
20	0.0026	0.06
21	0.0015	0.04
22	0.0013	0.03
23	0.0011	0.02

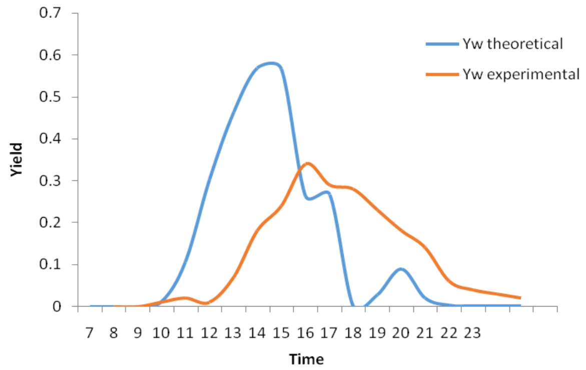

Figure 2: Comparison of yield in west direction

Figure 3 depicts the comparison between the experimental and theoretical values of yield received through east facing cover. Similar trend follows as that with west facing cover. The values of co-efficient of correlation and root mean square percent deviation are 0.8456 and 0.220 respectively.

Table 4: Yield in east direction

Time	Hourly yield east (Kg)	
	Theoretical	Experimental
7	0	0
8	0.0159	0.01
9	0.1196	0.01
10	0.3211	0.07
11	0.4926	0.16
12	0.6112	0.28
13	0.6165	0.34
14	0.2911	0.35
15	0.3098	0.27
16	0.0032	0.23
17	0.0708	0.16
18	0.0838	0.09
19	0.0058	0.07
20	0.0019	0.04
21	0.0013	0.03
22	0.0012	0.03
23	0.0012	0.02

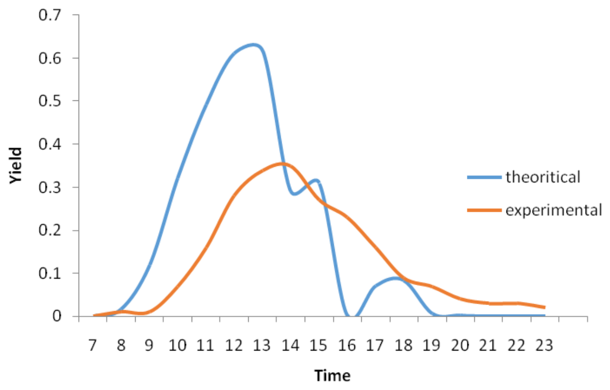

Figure 3: Comparison of yield in east direction

CONCLUSION

The proposed thermal model predicts the values of water temperature, and yields through west and east facing condensing covers with reasonable accuracy.
With the help of the proposed model, one can predict the productivity of the solar still with different design, climatic and operating conditions.

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