Effect of Varying Glass cover thickness on Performance of Solar still: in a Winter Climate Conditions

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Abstract- In this research paper, an attempt has been made to unearth the effect of different thicknesses glass cover on passive single-slope single basin solar still in winter climatic conditions of Mehsana (23°12' N, 72°30') from September, 2010 to Feb. 2011. Experiment used three identical size solar stills having three different thicknesses of glass cover of 4 mm, 8 mm and 12 mm. Here, Dunkle model is used for comparison of various heat transfer coefficients of solar stills. The objective of the present paper is to evaluate the behavioral variation in various parameters on solar still. Six month study shows that, lower glass cover thickness increases the distillate water output, water temperature, evaporative heat transfer coefficient, convective heat transfer coefficient as well as efficiency of solar still. Hence, 4 mm glass cover thickness is most prominent thickness of present experiment.

Keywords-Heat and mass transfer, Distillate output, Glass cover thickness.

1. Introduction

Solar desalination is gaining more importance for obtaining potable water. The main advantage of this process is that, it does not utilize costly conventional fossil fuels, which creates problem. The solar energy is naturally and freely available. Though the solar desalination plants require skilled labor, its maintenance cost is low. In many areas of world, the desalination of sea water is a common method for producing drinking water, which is currently increasing in importance. [34] Many desalination techniques have been developed during the past decades. [4, 11, 17, 35, 38] Thermally driven distillation plants such as multi stage flash evaporation (MSF), multiple effect distillation (MFD), are the majority of high capacity desalination installations. The operating temperatures of these thermally driven and conventionally powered processes are in the range of about 70º to 120º [27, 28, 29]. Single slope solar stills can be used for water desalination. Probably, they are considered one of the cheapest solutions for fresh water production. However, the amount of distilled water produced per unit area is somewhat low which makes the single-basin solar still unacceptable in some instances. To capture and condense evaporated fresh water, a cold surface (glass cover) is needed. Due to the slope in the glass for solar still, the condensate vapor will flow through the distillation channel then collected in the distillation vessel. [17, 18, 23, 24, 25, 26] An excellent review on the use of renewable energy in various types of desalination systems and a survey of the various types of solar thermal collectors and applications were presented by Kalogirou [21, 22, 32, 33]. Many experimental and theoretical works have been conducted on single basin solar stills for testing the performance of different enhancement parameters. Different absorbing materials were used by Akash et al. [2], and Nijmeh et al. [29] to study their effect in a solar still, and thus enhance the productivity of water, using a single-basin solar still with double slopes. Akash et al. [3] examined the effect of using a solar still with various cover tilt angles of 15, 25, 35, 45 and 55 º and the optimum tilt angle for water production was found to be 35º. Also the authors studied the effect of the salinity of water on solar distillation, and concluded that the distilled water production decreased with salinity. Nafey et al. [27] investigated the main parameters affecting solar still performance using four different still design parameters operated under the same weather conditions. A general equation is developed to predict the daily productivity of a single sloped solar still. Whereas, Nafey et al. [28] studied experimentally the use of black rubber or black gravel materials within a single sloped solar still as a storage medium to improve the still productivity. Khalifa et al. [28] conducted an experimental study on new designs of basin type solar stills, and examined the effect of certain modifications on the productivity and efficiency. These modifications included preheating of feed water by means of a solar heater and utilizing external and internal condensers for vapor condensation as well as for feed water preheating. Boukar and Harmim [9, 10] studied the effect of desert climatic conditions on the performance of a simple basin solar still and a similar one coupled to a flat plate solar collector. The performance of the simple still is compared with the coupled one. They found that the coupled still is more productive than the simple one. A comparative experimental study was conducted by Al-Karaghouli and Al-Naser [7, 8] between single basin and double decker having the same basin area. The authors concluded the following: (1) adding 2.5 cm of styrobore insulation material to the solar stills' sides causes noticeable increase in water production; and (2) the daily average still production for the double basin still is around 40% higher than the production of the single-basin still. Aboul-Enein et al. [1] presented a simple transient mathematical model for a single basin still through an analytical solution of the energy-balance equations for different parts of the still. The authors also investigated the thermal performance of the still both experimentally and theoretically, and the influence of cover slope on the daily productivity of the still. This transient mathematical model was used by El-Sebaii [12] for a vertical solar still to conduct parametric investigation. He found that the daily productivity of the still increases with increase of the still length, width, and wind speed up to typical values. Furthermore, El-Sebaii [13, 14] examined the effect of wind speed on the daily productivity of different designs of single slope solar stills with single, double and triple basins using computer simulation. He found that daily production increases with the increase of wind speed up to a typical velocity beyond which the increase in production becomes insignificant. Most recent work by El-Sebaii [15] is the investigation of the thermal performance using a transient mathematical model of triple basins solar still. Hamdan et al. [19] preformed an experimental and theoretical work to find the performance of single, double and triple basins solar still. Whereas, Jubran et al. [20] developed a mathematical model to predict the productivity and the thermal characteristics of a multistage solar still with an expansion nozzle and heat recovery in each stage of the still. Al-Hinai et al. [5] reported the use of a mathematical model to predict the productivity of a simple solar still under different climatic, design and operational parameters in Oman. Furthermore, Al-Hinai et al. [6] developed two mathematical models to compare the productivity of single-effect and double-effect solar stills under different climatic, design and operational parameters. Mathioulakis et al. [25] suggested a simplified theoretical method for the evaluation of the performance of a typical solar still and the prediction of long-term water production. Moreover, Voropoulos et al. [41] preformed an evaluation for this simple method in three steps, the first being experimental determination of the coefficients and successive prediction of output, the second being calculation of coefficient values through analytical relations and the third being the use of the model in a continuous way. Thermal modeling and characterization of solar still were presented by Tiwari [34], Tiwari and Noor [35], Tiwari and Prasad [36], and Tiwari et al. [37]. A transient analysis of a double basin solar still was studied by Suneja and Tiwari [32]. They investigated the effect of water depth in the lower basin on the performance of the system. The authors observed that the daily yield of an inverted absorber double basin solar still increases with the increase of water depth in the lower basin for a given water mass in the upper basin. Tiwari et al. [39] derived expressions for water and glass temperatures, hourly yield and instantaneous efficiency for both passive and active solar distillation systems. Recently, Tripathi and Tiwari [40] analyzed the distribution of solar radiation, using the concept of solar fraction inside a conventional single slope solar still by using simulation model for a given solar azimuth, altitude and latitude angles, and longitude of the place. Srivastava et al. [31] in their numerical computations showed that there is a significant effect in the plant, water temperatures and distilled output due to change in the fraction of the solar radiation incident on the north wall, depth of water, absorptivity of basin and the inclination of the roof whereas the heat capacity of the plant has a marginal effect on these temperatures and distilled output. Fath et al. [16] presented analytical, thermal and economic comparisons between pyramid and single slope solar stills. They found that the single slope gave higher daily yield (30%) in winter and 3% higher in summer; they attributed this due to the larger radiation losses from the cover surface of the pyramid. Goosen et al. [18] found that the theoretical analysis (i.e., modeling) of different solar desalination systems is an effective tool for predicting system performance. They found that the efficiency of single-basin solar stills is very low compared to the multi-effect solar desalination systems which reuse the latent heat of condensation. They concluded that the increase in efficiency, though, must be balanced against the increase in capital and operating costs compared to the single-basin still.This paper describes an attempt to carry out suitable thickness of glass cover like 4 mm, 8 mm and 12 mm thickness for maximum yield from solar still in climate conditions of Mehsana during winter. Various heat transfer coefficient have been determined experimentally as well as theoretically and they show good agreement.

2. Experimental Setup

Fig.1. shows three solar stills taken for experiment in climate conditions of Mehsana. Three solar still consist of area of 1 meter square. Solar stills consist of condensing cover or glass cover inclination of 30 degree, fabricated to accommodate water depth of 20 cm constant. The bottom surface of still was painted black paint to receive maximum solar radiation as well as increase absorptivity. It is shown from literature of [2 3 4], output of solar still become maximum for least water depth in basin. To avoid spilling of basin water outside of solar still, height of lower vertical side of still was kept 30 cm. Bottom part of solar still must be insulated to prevent heat transfer losses, hence It is made of Fiber reinforced Plastic (FRP) of 5 mm thickness. To prevent leakage between top cover and solar still, rubber gasket is provided. The output from the still is collected through a channel, fixed at the end of small vertical side of basin and a plastic pipe is provided to drain distillate water to an external measuring jar.

Fig.1. Experimental Set up of Solar Still

2.1. Procedure of Experiments

All experiments started from 10 am morning to 5 pm evening. The following parameters were measured for every hour.

- Outer glass cover temperature
- Inner glass cover temperature
- Vapor temperature
- Water temperature
- Ambient temperature
- Distillate output
- Solar insolation

Water, glass and vapor temperatures were recorded with help of calibrated copper constantan thermocouples and digital temperature indicator.

Table 1. Accuracies and error for various measuring instruments

Quantity.	Symbol	Expression
Specific Heat	C_p	$999.2 + 0.1434 \times T_v + 1.101\times T_v^{-2} - 6.75 \times 10^{-8}\times T_v^{3}$
Density	ρ	$\frac{353.44}{(T_v + 273.15)}$
Thermal Conductivity	λ	$0.0244 + 0.7673 \times 10^{-4}\times T_v$
Viscosity	μ	$1.718 \times 10^{-5} + 4.620 \times 10^{-8}\times T_v$
Latent Heat of vaporization of water	L	$3.1615 \times 10^{6} \times [1- (7.616\times 10^{-4}\times T_v]$ When T_v>70°C and $2.49 \times 10^{6} \times [1- (9.4\times 10^{-4}\times T_v+1.312 \times 10^{-7}\times T_v^{2} - 4.19 \times 10^{-9}\times T_v^{3}]$ When T_v<70°C
Partial saturated vapor pressure at condensing cover temperature	P_{ci}	$\frac{\exp[25.317 - 5144]}{T_{ci} + 273}$
Partial saturated vapor pressure at water temperature	P_w	$\frac{\exp[25.317 - 5144]}{T_w + 273}$
Expansion Factor	**β**	$\frac{1}{T_v + 273.15}$

The ambient temperature was measured by calibrated mercury in glass thermometer. The distillate output was recorded with help of calibrated Solarimeter. Wind speed measured by Anemometer. Table 1 shows accuracies and errors for various measuring instruments used in experiments. Table 2 shows Temperature dependent physical properties of vapor. In this table Tv, Tci and Tw are frequently used. Tv is called temperature of vapor, it is obtained after evaporation of water inside the solar still. Tci called inner glass cover temperature, which shows the condensation of water from vaporization of water. It is also called condensation zone. Tw is called Temperature of water inside solar still. It shows evaporation temperature of water inside the solar still. Tv, Tci and Tw are measured by using thermocouples.

Daily measured parameters of all three solar stills containing different glass cover thickness varying from 4 m, 6 mm and 12 mm are shown in Table 3, Table 4 and Table 5. Each Table shows Time in Hour, Solar insolation in Watt per meter square, Outer glass cover temperature, inner glass cover temperature, Water vapor Temperature and Temperature of Water inside solar still and mass of water in Kg. Here Dunkle model used for comparing present model of solar still and comparison of various heat transfer coefficients like convective heat transfer coefficient, evaporative heat transfer coefficient and radiative heat transfer coefficient made in Table 6, Table 7 and Table 8. They shows comparison between present model as well as Dunkle model by using different glass cover thickness like 4 mm, 7 mm and 12 mm.

Table 2. Temperature dependent physical properties of vapor

12	Instrument	Accuracy	Range	% error
1	Thermometer	±1°C	0-100°C	0.25%
2	Copper Constantan Thermocouple	±0.1°C	0-100°C	0.5%
3	Solarimeter	±1W/m^2	0-2500 W/m^2	2.5%
4	Anemoter	±0.1 m/s	0-15 m/s	10%
5	Measuring Jar	±10 ml	0-1000 ml	10%

Table 3.measured parameters for 4 mm thickness of glass cover in typical day of January 10, 2011

2.2. *Thermal Model*

Vapor consists of moisture and dry air. They freely convected above water surface to the condensing cover by the action of buoyancy force caused by density variation. This is due to density difference. This process within the unit always happens in natural mode and in case of heat transfer context. It is known as natural convection. But external heat transfer from condensing cover to atmosphere takes place due to either natural convection or forced convection.

2.2.1. *Governing Equations of Solar Still*

Action of buoyancy force due to density difference of humid air due to temperature difference is the major reason behind the convective heat transfer coefficient in solar still. The convective heat transfer coefficient of water surface to condensing glass cover is given by:

$$q_{cw} = h_{cw}(T_w - T_g) \qquad (1)$$

Here, h_{cw} is convective heat transfer coefficient of solar still.

The following relation of non dimensionalNusselt number carries the convective heat transfer coefficient inside solar still.

$$N_u = \frac{h_{ce}}{\lambda} L_v = C(G_r \times P_r)^n \quad (2)$$

Equation (2) must be rewritten as,

$$h_{cw} = \frac{\lambda}{L_v} \times C(G_r \bullet P_r) \quad (3)$$

In equation (1),(2) and (3) non dimensional numbers like Gr and Pr are called Grashof number and Prandlt numbers, respectively. This can be solved by given expression. Variables on right hand side of expressions are the temperature dependent physical properties and given in Table 2.

$$Gr = \frac{\beta g L_v^{\ 3} \rho^2 \Delta T}{\mu^2} \quad (4)$$

$$\Pr = \frac{\mu C_p}{\lambda} \quad (5)$$

In equation (2), there are two unknown parameters C and n. They are determined by regression analysis made from experimental data by Kumar and Tiwari [8] model. Regression analysis is simple and here Dunkle's [9] correlation was used. The Dunkle relation is:

$$h_{cw} = \frac{0.884[(T_w - T_g) + (P_w - P_g)(T_w + 273)}{(268.9 \times 10^3 - P_w)^{\frac{1}{3}}} \quad (6)$$

Major aim of the solar still is to produce distilled water; hence distillate output can be derived by following equation:

$$m_{ew} = \frac{q_{ew} \times A_w \times t}{\Delta h_v} \quad (7)$$

Where,

$$q_{ew} = h_{ew}(T_w - T_g) \quad (8)$$

And

$$h_{ew} = 16.27 \times 10^{-3} \times h_{cw} \times \frac{(P_w - P_g)}{(T_w - T_g)} \quad (9)$$

By putting value of h_{cw} from equation (2) into equation (9), hence

$$h_{cw} = 0.01623 \times C(G_r \bullet P_r)^n \times \left(\frac{P_w - \varphi \bullet P_{ci}}{T_w - T_{ci}} \right) (10)$$

Now, put hcw into equation (8) and hence qew into equation (7), we can get

$$m_{ew} = \frac{0.01623}{\Delta h_v} \times \frac{\lambda}{L_v} \times A_w \bullet t \bullet (P_w - \varphi P_{ci}) \bullet C(G_r \bullet P_r)^n \quad (11)$$

Equation (11) can be rewritten as,

$$m_{ew} = R \bullet C(G_r \bullet P_r)^n \quad (12)$$

Equation (12) can also be written as,

$$\frac{m_{ew}}{R} = C(G_r \bullet P_r)^n \quad (13)$$

$$\text{Here,}R = \frac{0.01623}{\Delta h_v} \bullet \frac{\lambda}{L_v} \bullet A_w \bullet t \bullet (P_w - \varphi \bullet P_{ci}) \quad (14)$$

Taking Logarithm both side of Equation (13) and comparing it with equation of straight line,

Y = mx + c ……………………………………(15)

Hence, we get,

Y = ln , C0 = ln C, x = ln (Gr × Pr) and m = n; (16)

From regression analysis, m and C_0 can be obtained by following equation:

$$m = \frac{N\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{(N)\left(\sum x^2\right) - \left(\sum x\right)^2} \quad (17)$$

$$C_0 = \frac{\left(\sum y\right)\left(\sum x^2\right) - \left(\sum x\right)\left(\sum xy\right)}{N\left(\sum x^2\right) - \left(\sum x\right)^2} \quad (18)$$

The constants, m and C_0 can be calculated from equation (17) and (18) from data obtained from experiments, as one of glass cover thickness obtained in Table 3,4 and 5. Value of m and C_0 is used to evaluate constants C and n by following equations:

$$C = \exp(C_0) \quad (19)$$

$$n = m \quad (20)$$

2.2.2. Internal Heat Transfer Coefficients of Solarstill

In internal heat transfer coefficient, Heat transfer from water to glass cover inside the solar still is done by three possible ways called evaporation, convection and radiation, Hence total internal heat transfer coefficient of solar still is sum of all three possible ways heat transfer coefficients,

$$h_1 = h_{cw} + h_{ew} + h_{rw} \qquad (21)$$

From equation (21), h1 is total heat transfer coefficient and h_{cw}, h_{ew} and h_{rw} are called convective, evaporative and radiative heat transfer coefficients.

Radiative heat transfer coefficient is given by following equation:

$$h_{rw} = \varepsilon_{effect}\sigma[(T_w + 273)^2 + (T_g + 273)^2] \qquad (22)$$

Where, $\sigma = 5.669 \times 10^{-8} W/m^2K^4$,

$$\varepsilon_{effect} = \left(\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_w} - 1\right)^{-1}$$

$$\varepsilon_g = \varepsilon_w = 0.9$$

Where, ε_w and ε_g are emissivity of water and glass cover.

Efficiency of Solar still:

Efficiency of solar still is simply defined as the ratio between thermal energy utilized to get distillate water in a period and energy supplied to solar still during the same period.

$$\eta = \frac{\sum m_{ew} \bullet \Delta h_v}{\sum I(t) \bullet A_b + m_w \bullet C_w \bullet (T_{ini} - T_{amb})} \text{ x } 100 \qquad (23)$$

In equation (23), the denominator term (T_{ini} – T_{amb}) is used for positive values only, otherwise it is treated as Zero".

3. Result & Discussion

Distillate output is principal factor in solar still. Every researcher works to improve the distillate output .Fig 2 represents relation between Time (Hr) and Distillate output by using thickness of glass as a variable. It shows that, 4 mm glass cover thickness increases distillate output compared with 8 mm as well as 12 mm glass cover thickness inside the solar still.

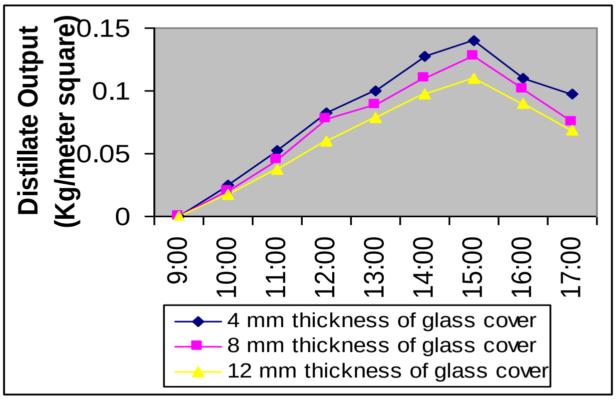

Fig.2. Effect of varying glass cover thickness on distillate output from solar still, January 10, 2011

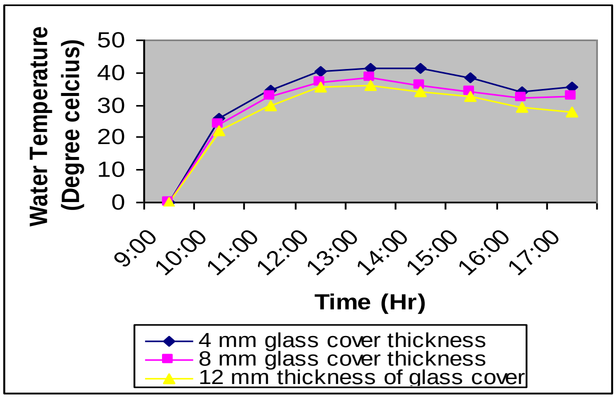

Fig.3. Effect of varying glass covers thickness on Water Temperature of solar still, January 10, 2011

Evaporation of water is also a key factor in solar still. It occurs due to the thermal energy of solar still. It also depends on glass cover thickness. Fig. 3 shows relation between Time (Hr) and Water Temperature of glass cover. It shows that, 4 mm glass cover thickness increases water temperature compared with 8 mm as well as 12 mm glass cover thickness inside solar still.

Thermal conductivity of glass cover is low and heat dissipation from the glass cover to the atmosphere is due to by natural convection as well as radiation. Hence, overall heat transfer coefficient is very low reducing the heat transfer between glass cover as well as atmosphere. Hence part of latent heat of condensation is accumulated in air vapor mixture, this phenomena in thermal science is called thermal inertia. Temperature of glass cover also increases due to its lower thermal conductivity and low heat capacity, hence during afternoon hours, temperature difference between water and glass cover decreases instead of increases, hence during afternoon hours, rate of condensation decreases. Fig. 4 shows relation between Time (Hr) and Water Temperature of glass cover. It shows that, 12 mm glass cover thickness increases inner glass cover temperature compared with 8 mm as well as 4 mm glass cover thickness. It shows that, condensation temperature is lower for 4 mm glass cover thickness compared with 8 mm as well as12 mm thickness.

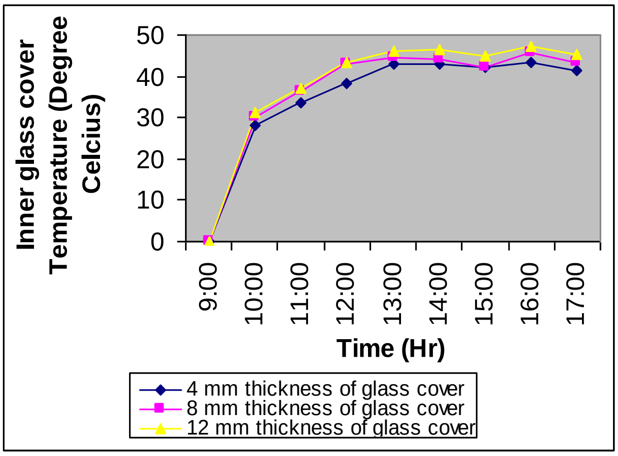

Fig.4. Effect of varying glass covers thickness on inner glass cover temperature of solar still, January 10, 2011

Fig.5, 6, 7 represent the relation between Time (Hr) and Convective heat transfer coefficient for different glass cover thickness using data available in table .6. Fig. shows that, values obtained from the present model are very close to the Dunkle model for convective heat transfer coefficient for water temperature range of 50° C.

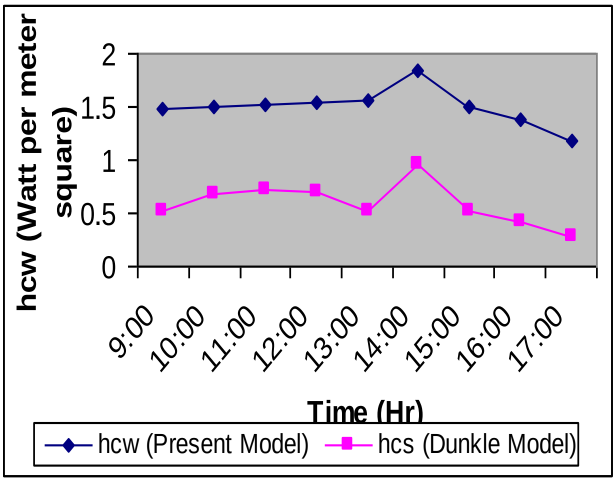

Fig.5. Variation of convective heat transfer coefficient (h_{cw}) for 4 mm glass cover thickness, January 10, 2011

There is a significant difference of 70 % for convective heat transfer coefficient. In morning 9 am, temperature found very low, but increased up to 14: 00 pm then decreased gradually. The corresponding values of C and n are shown in Table No.8 for both convective as well as evaporative heat transfer coefficient Fig.8, 9, 10 represent the relation between Time (Hr) and Evaporative heat transfer coefficient for different glass cover thickness using data available in table .6. Values obtained from present model are very close to the Dunkle model. There is a significant difference of 72 % for evaporative heat transfer coefficient.

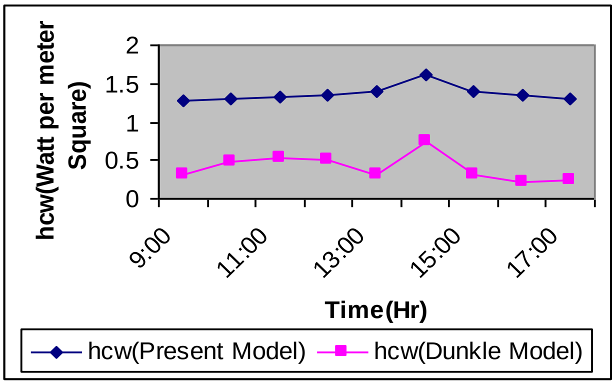

Fig.6. Variation of convective heat transfer coefficient (h_{cw}) for 8 mm glass cover thickness, January 10, 2011

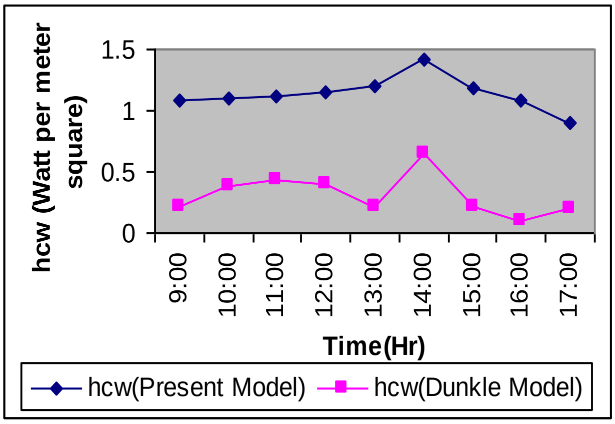

Fig.7. Variation of convective heat transfer coefficient (h_{cw}) for 12 mm glass cover thickness, January 10, 2011

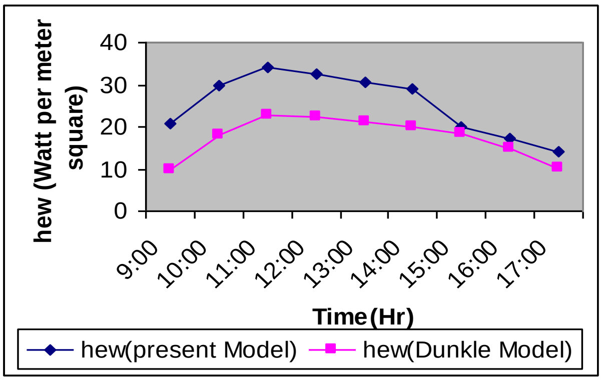

Fig.8. Variation of evaporative heat transfer coefficient (h_{ew}) for 4 mm glass cover thickness, January 10, 2011

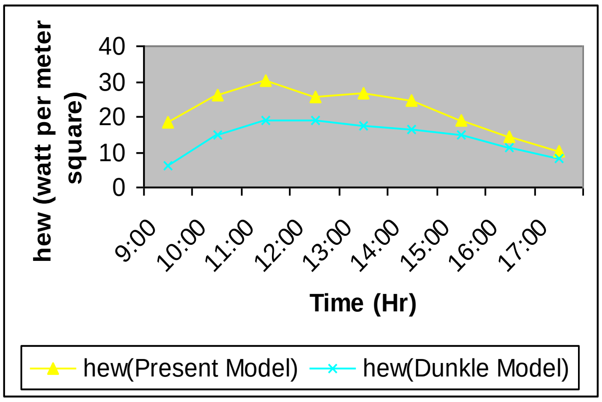

Fig.9. Variation of evaporative heat transfer coefficient (h_{ew}) for 8 mm glass cover thickness, January 10, 2011

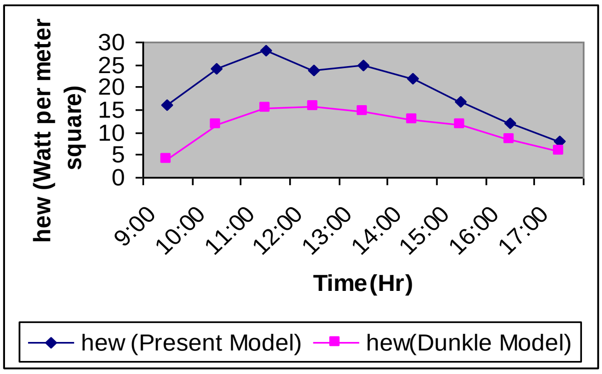

Fig.10. Variation of evaporative heat transfer coefficient (h_{ew}) for 12 mm glass cover thickness, January 10, 2011

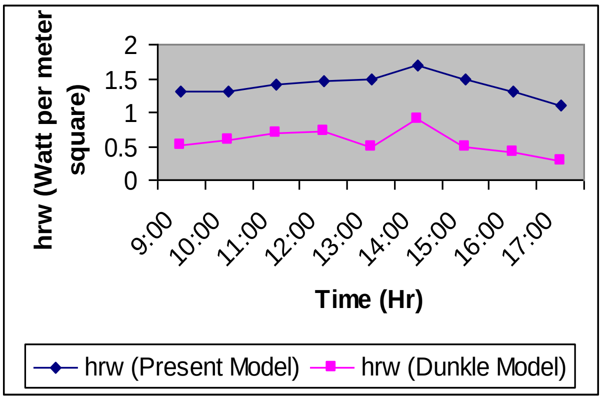

Fig.11.Variation of radiative heat transfer coefficient (h_{rw}) for 4 mm glass cover thickness, January 10, 2011

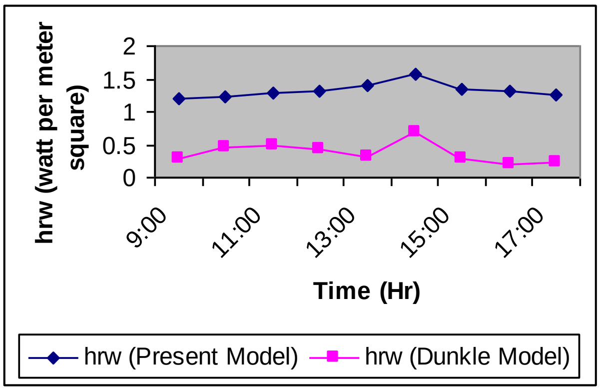

Fig.12. Variation of radiative heat transfer coefficient (h_{rw}) for 8 mm glass cover thickness, January 10, 2011

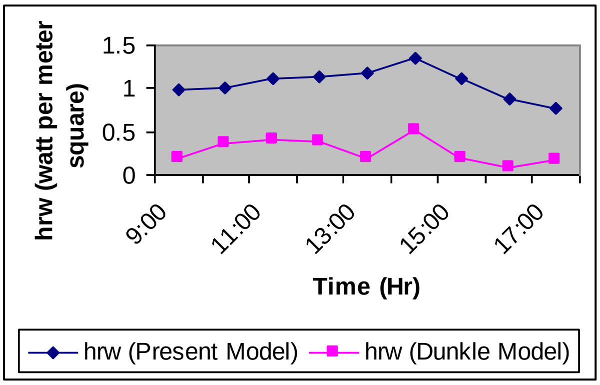

Fig.13. Variation of radiative heat transfer coefficient (h_{rw}) for 12 mm glass cover thickness, January 10, 2011

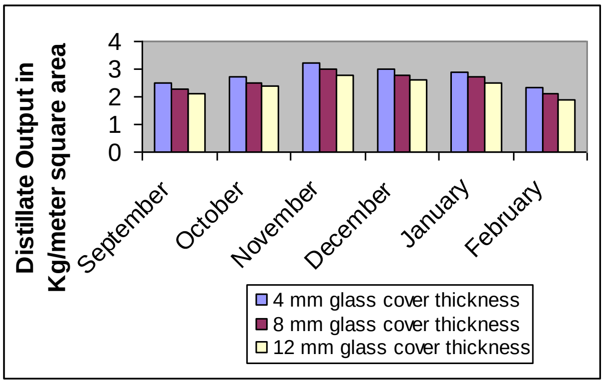

Fig.14. Distillate output achieved during September 2010 to February 2011.

Fig. 11, 12 and 13 show variation of radiative heat transfer coefficient by variation of glass cover thickness like 4 mm, 8 mm and 12 mm. They show that there are good agreements between them. There is a significant difference of 65 % for radiative heat transfer coefficient. Here, compared with evaporative as well as convective heat transfer, radiative heat transfer is not much important but its study is important while designing a "solar still. Fig. 14 shows distillate output obtained from solar still in a various months. It is clear that, during month of November highest distillate output is obtained compared with other months. One thing is clear from Fig. 15 that, each month produces highest output from 4 mm glass cover thickness compared with 8 mm as well as 12 mm thickness. In solar still, how much efficiency is obtained, that is a very simple question, which must be known by researcher, hence fig. 15 shows efficiencies obtained by various glass cover thickness. It is very clear that, 4 mm glass cover thickness produces higher temperature difference between water as well as inner glass cover temperature and temperature difference is directly proportional to efficiency, it is shown in equation (23). 4 mm glass cover thickness produces highest efficiency compared with 8 mm as well as 12 mm glass cover thickness.

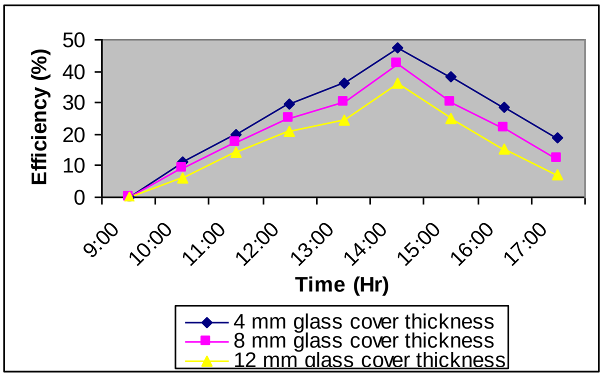

Fig. 15. Variation of efficiencies of various glass cover thicknesses, January 10, 2011

4. Conclusion

In present research several conclusions can be obtained.

- Lower glass cover thickness increases distillate output from solar still, i.e. 4 mm glass cover thickness produces more distillate output compared with 8 mm as well as 12 mm.
- There is good agreement between present model as well as Dunkle Model.
- Lower glass cover thickness increases water temperature inside solar still, i.e. 4 mm glass cover thickness increases water temperature compared with 8 mm as well as 12 mm thickness of glass cover.
- Lower glass cover thickness decreases inner glass cover temperature inside solar still, i.e. 12 mm glass cover thickness produces highest inner glass cover temperature compared with 4 mm as well as 8 mm thickness of glass cover..
- Lower Glass cover thickness increases temperature difference between water as well as inner glass cover temperature, i.e. 4 mm glass cover thickness creates higher temperature difference compared with 8 mm as well as 12 mm thickness of glass cover.
- Highest Distillate output is obtained in the month of November, 2010 among other 5 months. But in this month, highest distillate output is obtained due to 4 mm glass cover thickness.

5. References

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Appendix

Table 3. Measured parameters for 4 mm thickness of glass cover in typical day of January 10, 2011

Sr. No.	Time (Hr)	Solar InsolationW/m^2	T_{co} °C	T_{ci} °C	T_V °C	T_W °C	Mass of Mass of Water in Kg
1	9:00 am	370	25.00	26.12	30.17	21.87	0.010
2	10:00 am	470	30.00	31.12	36.42	26.12	0.025
3	11:00 am	530	36.12	37.25	42.41	34.51	0.052
4	12:00 pm	650	43.30	43.42	46.24	40.47	0.082
5	13:00 pm	680	45.25	46.19	49.78	41.27	0.10
6	14:00 pm	680	44.12	46.29	50.12	41.25	0.128
7	15:00 pm	340	42.05	44.87	51.28	38.47	0.140
8	16:00 pm	150	38.65	47.14	53.14	34.12	0.110
9	17:00 pm	70	39.12	45.17	50.78	35.76	0.089

Table 4. Measured parameters for 8 mm thickness of glass cover in typical day of January 10, 2011

Sr. No.	Time (Hr)	Solar InsolationW/m^2	T_{co}°C	T_{ci}°C	T_V°C	T_W°C	Mass of Mass of Water in Kg
1	9:00 am	370	22.15	25.71	28.17	18.24	0.009
2	10:00 am	470	28.00	30.12	34.21	24.17	0.020
3	11:00 am	530	34.12	36.17	40.19	32.47	0.048
4	12:00 pm	650	41.23	42.87	44.17	37.17	0.077
5	13:00 pm	680	43.48	44.57	47.28	38.47	0.094
6	14:00 pm	680	42.18	44.18	48.74	36.17	0.110
7	15:00 pm	340	40.17	42.27	47.98	34.17	0.127
8	16:00 pm	150	36.27	45.71	51.73	32.17	0.101
9	17:00 pm	70	35.15	43.17	47.87	32.78	0.075

Table 5. Measured parameters for 12 mm thickness of glass cover in typical day of January 10, 2011

Sr. No.	Time (Hr)	Solar InsolationW/m^2	T_{co}°C	T_{ci}°C	T_V°C	T_W°C	Mass of Mass of Water in Kg
1	9:00 am	370	22.00	21.78	27.98	17.17	0.010
2	10:00 am	470	26.00	28.00	34.21	22.18	0.018
3	11:00 am	530	31.18	33.78	40.19	30.00	0.038
4	12:00 pm	650	37.16	38.17	44.17	35.78	0.060
5	13:00 pm	680	39.48	42.89	47.28	36.17	0.079
6	14:00 pm	680	39.89	42.98	48.74	34.28	0.098
7	15:00 pm	340	37.87	42.00	47.98	32.75	0.110
8	16:00 pm	150	33.98	43.18	51.73	29.18	0.090
9	17:00 pm	70	32.45	41.28	47.87	38.87	0.079

Table 6.Variation in present model and Dunkle Model for different glass cover thickness.

Sr. No.	Time (Hr)	h_{cw} (Present Model) 4 mm thickness of glass	h_{cw} (Dunkle Model) 4 mm thickness of glass	h_{cw} (Present Model) 8 mm thickness of glass	h_{cw} (Dunkle Model) 8 mm thickness of glass	h_{cw} (Present Model) 12 mm thickness of glass	h_{cw} (Dunkle Model) 12 mm thickness of glass
1	9:00 am	1.483	0.521	1.283	0.321	1.083	0.221
2	10:00 am	1.495	0.677	1.295	0.477	1.095	0.376
3	11:00 am	1.513	0.729	1.315	0.529	1.115	0.428
4	12:00 pm	1.532	0.704	1.352	0.504	1.152	0.4
5	13:00 pm	1.562	0.523	1.395	0.323	1.195	0.223
6	14:00 pm	1.847	0.955	1.621	0.755	1.421	0.655
7	15:00 pm	1.51	0.513	1.39	0.313	1.19	0.213
8	16:00 pm	1.39	0.418	1.35	0.218	1.09	0.108
9	17:00 pm	1.19	0.29	1.29	0.25	0.9	0.2

Table 7.Variation in present model and Dunkle Model for different glass cover thickness evaporative heat transfer coefficient (h_{ew}), January 10, 2011

Sr. No.	Time (Hr)	h_{ew} (Present Model) 4 mm thickness of glass	h_{ew} (Dunkle Model) 4 mm thickness of glass	h_{ew} (Present Model) 8 mm thickness of glass	h_{ew} (Dunkle Model) 8 mm thickness of glass	h_{ew} (Present Model) 12 mm thickness of glass	h_{ew} (Dunkle Model) 12 mm thickness of glass
1	9:00 am	20.82	9.816	18.28	6.15	16.27	4.17
2	10:00 am	29.9	17.94	26.15	14.87	24.17	11.87
3	11:00 am	34.24	22.64	30.48	18.75	28.17	15.47
4	12:00 pm	32.71	22.412	25.47	18.98	23.87	15.78
5	13:00 pm	30.498	21.145	26.71	17.47	24.82	14.75
6	14:00 pm	28.9	20.178	24.67	16.47	21.98	12.71
7	15:00 pm	20.14	18.54	18.98	14.78	16.78	11.84
8	16:00 pm	17.45	14.87	14.12	11.47	12.01	8.45
9	17:00 pm	14.21	10.24	10.17	8.18	8.17	5.98

Table 8.Variation in present model and Dunkle Model for different glass cover thickness radiative heat transfer coefficient (h_{rw}), January 10, 2011

Sr. No.	Time (Hr)	h_{rw} (Present Model) 4 mm thickness of glass	h_{rw} (Dunkle Model) 4 mm thickness of glass	h_{rw} (Present Model) 8 mm thickness of glass	h_{rw} (Dunkle Model) 8 mm thickness of glass	h_{rw} (Present Model) 12 mm thickness of glass	h_{rw} (Dunkle Model) 12 mm thickness of glass
1	09:00 am	1.32	0.6	1.217	0.45	1	0.357
2	10:00 am	1.4	0.701	1.3	0.5	1.105	0.4
3	11:00 pm	1.45	0.718	1.324	0.42	1.138	0.378
4	12:00 pm	1.5	0.5	1.39	0.312	1.175	0.2
5	13:00 pm	1.68	0.9	1.578	0.7	1.341	0.512
6	14:00 pm	1.48	0.498	1.35	0.298	1.12	0.2
7	15:00 pm	1.3	0.4	1.32	0.2	0.87	0.087
8	16:00 pm	1.1	0.28	1.25	0.238	0.78	0.18
9	17:00 pm	0.97	0.20	1.18	0.200	0.67	0.10

Table 9.The values obtained for different glass cover thickness for observations.

Sr. No.	Values Obtained	4 mm depth of water	8 mm depth of water	12 mm depth of water
1	Value of C	22.25	10.24	8.25
2	Value of n	0.0184	-0.0414	-0.03212
3	Average Value of h_{cw}, watt per meter square	1.62	0.81	0.57
4	Average Value of h_{ew}, watt per meter square	10.14	7.21	4.32

Symbols

A_w	Evaporative surface area of solar still, m^2
C	Unknown Constant
C_w	Specific Heat of water, J/Kg K
Gr	Grashof Number
h_1	Total Heat Transfer Coefficient, W/m^2
h_{cw}	Convective Heat Transfer Coefficient, W/ m^2
h_{ew}	Evaporative Heat Transfer Coefficient, W/ m^2
h_{rw}	Radiative Heat Transfer Coefficient, W/m^2
Δh_v	Enthalpy of evaporation of water, J/Kg
I(t)	Incident Total Radiation, J/m^2 h
L_v	Dimension of Condensing Cover, m
m_{ew}	Distillate Output, Kg
n	Unknown in Nusselt Number Expression
Nu	Nusselt Number
P_{ci}	Partial Saturated Vapor pressure at condensing Cover temperature, N/m^2
Pr	Prandtl Number
P_w	Partial Saturated vapor pressure, N/m^2
Q	Rate of Heat Transfer by convection, W
q_{ew}	Rate of evaporative heat transfer, W/m^2
T_{ci}	Temperature of inner glass cover, °C
T_s	Evaporated surface Temperature, °C
T_w	Temperature of Water, °C
T_{ini}	Initial Temperature of water at starting of Experiment
T_{amb}	Ambient Temperature, °C

Greek

ε_{eff}	Effective Emissivity
ε_w	Emissivity of water
ε_g	Emissivity of glass
λ	Thermal Conductivity of humid air, W/m°C
φ	Relative Humidity

Authors Brief

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